CAPSULE PIPELINE RESEARCH CENTER (CPRC)

University of Missouri-Columbia

NSF State/Industry University Cooperative Research Center

7TH ANNUAL REPORT

Period Covered: 9/1/97-8/31/98

May 1998

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Capsule Pipeline Research Center: Year 7 Annual Report/Proposal

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE
$300,000	12 months	September 1, 1998

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NOTE: THE FULLY SIGNED CERTIFICATION PAGE MUST BE SUBMITTED IMMEDIATELY FOLLOWING THIS COVER SHEET

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CERTIFICATION PAGE

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I certify to the best of my knowledge that:

(1) the statements herein (excluding scientific hypotheses and scientific opinions) are true and complete, and
(2) the text and graphics herein as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision. I agree to accept responsibility for the scientific conduct of the project and to provide the required progress reports if an award is made as a result of this application.

I understand that the willful provision of false information or concealing a material fact in this proposal or any other communication submitted to NSF is a criminal offense (U.S.Code, Title 18, Section 1001).

Name (Typed)	Signature	Date
PI/PD Henry Liu	Henry Liu	5/15/98
Co-PI/PD Thomas R. Marrero	Thomas R. Marrero	5/15/98
Co-PI/PD Brett Gunnink	Brett Gunnink	5/15/98
Co-PI/PD Charles Lenau	Charles Lenau	5/15/98
Co-PI/PD Yuyi Lin	Yuyi Lin	5/15/98

Certification for Authorized Organizational Representative or Individual Applicant

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding Federal debt status, debarment and suspension, drugfree workplace, and lobbying activities (see below), as set forth in the *Grant Proposal Guide (GPG)*, NSF 98-2. Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U.S. Code, Title 18, Section 1001).

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The undersigned certifies, to the best of his or her knowledge and belief, that:

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(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, and officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure of Lobbying Activities," in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
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Proposal No. 9811639-1

ABSTRACT

The mission of the CPRC (Capsule Pipeline Research Center) has been focused on the coal log pipeline (CLP) technology for transporting coal. Great strides have been made by CPRC in the last 6½ years in research, development, technology transfer, and education/training. A significant milestone reached during the current (7th) reporting year is the installation of a new machine designed by CPRC for rapid production of 5.4-inch diameter logs. The machine has unique features that can produce high-quality logs rapidly. No current commercial machine can do that. Other key accomplishments during this year include completing: a 3-D finite element model to predict coal log properties, and the verification of the model by experiments; a drag reduction study in an 8-inch-diameter pipe; a rapid compaction study, a scale up study and a compaction optimization study. New projects initiated this year include pneumatic capsule pipeline for transporting mail, and compaction of biomass waste materials—sawdust, wood chips, waste paper, etc. Also, design has been completed for a proposed 3,000-ft long pilot plant coal log pipeline. Completion of the pilot plant study in the next year will pave the way for commercialization of the CLP technology. Technology transfer activities of the current year include publication of journal articles, presentation of results at technical conferences, exhibition at a coal technology conference, work sessions held with industry experts, and demonstration of a pipe interior grinder in Tulsa, Oklahoma. A patent has been granted during this year. Three Ph.D., four M.S. and three undergraduates working on CPRC projects received their degrees this year.

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EXECUTIVE SUMMARY

A. Rationale for the State/IUCRC

Capsule pipeline is an emerging transportation technology of far-reaching implications for Missouri, the nation and the world. The purpose of the Capsule Pipeline Research Center (CPRC) is to conduct extensive research, development and technology transfer in coal log pipeline and other types of capsule pipelines so that this emerging technology can be used in Missouri and the rest of the nation as soon as possible for transporting coal, solid wastes, grain, mail and parcels, and many other products. Benefits to Missouri and the nation include lower-cost freight transport, economic development, and reduction in the need for trucks and freight trains which in turn causes reduction in traffic jam, accidents and air pollution caused by trucks and trains.

The Center's mission for the first five years was focused solely on **coal log pipeline (CLP)** for transporting coal. Starting the sixth year (9/1/96), the Center gradually expanded its program to include some other types of capsule pipelines designed to transport other materials such as biomass, wasted coal fines and municipal solid waste. The Center successfully compacted waste paper, alfalfa hay, sawdust, soy bean hulls and wood chips as part of a new biomass compaction study. Coal log pipeline development remains the main focus of the Center until 8/31/99—the end date for NSF and State funding and target date for completion of a pilot plant demonstration of the coal log pipeline technology.

The reasons for continued focus on CLP are: (1) Coal is the largest freight product in the United States; production rates are over one billion tons per year. Sixty percent (60%) of the electricity in the nation, and 70% in Missouri, are generated from coal. Coal is usually transported hundreds of miles before it is used. (2) Once CLP is developed, the knowledge generated can be applied to other types of capsule pipelines. In other words, the early development of CLP accelerates other applications of capsule pipelines. (3) The Center has been supported mainly by electric utilities, coal and pipeline companies; their main interest has been transporting coal, not other products. (4) The development of CLP is not yet complete. The remaining year will call for intensive R&D and testing a pilot plant CLP to ready the technology for commercial use.

There is a need for gradual expansion of the Center's R&D program to include capsule pipeline transportation of solid wastes and other cargoes. The public has a strong interest in applying the capsule pipeline technology for transporting not only coal but also other products, especially solid wastes and grain, mail, etc. The CPRC being heavily supported by State funds (from Missouri Department of Economic Development) and federal funds (from National Science Foundation) has a duty to respond to this public interest, and to answer the concerns of its public-sector sponsors. More than once in the past, NSF and MDED officials have urged the Center to include some of those applications as proclaimed in the Center's original mission statement. However, care must be exercised in phasing in these new areas without diluting resources and distracting and slowing down the development of CLP for coal transport.

Therefore, these new areas are being phased in gradually with additional resources from new sponsors interested in those applications.

Capsule pipeline will be a major freight transportation technology in the 21st Century. The Center's program will make the United States the world's leader in capsule pipeline. Having a lead in any advanced technology enhances national competitiveness. The technology is exportable and gives U.S. companies an edge in winning future freight pipeline contracts in the international market. Furthermore, the use of CLP and other types of capsule pipelines in the U.S. will reduce the transportation costs of coal and many other cargoes, making U.S. products more economically competitive in the world market. Application of coal log compaction technique to other materials represents a major spin-off of the Center's CLP research.

B. Current-Year Accomplishments and Plans

Accomplishments (Current Year):

The long-awaited 250-ton coal log compaction press has been designed, constructed and installed in Columbia, Missouri for testing. It has already produced high-quality coal logs as well as biomass logs. The machine is so unique that it has attracted immediate national and international attention. For instance, the December 1997 issue of the American Society of Mechanical Engineers featured a long story about this coal log machine in its monthly magazine, MECHANICAL ENGINEERING, circulated to more than 100,000 members—see attachment in Appendix 2. Articles about CPRC research also appeared in PUBLIC POWER, The COLUMBIA DAILY TRIBUNE as well as a University of Missouri research magazine, ILLUMINATION—Appendix 2.

The new metal building housing the coal log machine is completed.. Located 10½ miles from campus, it is adjacent to the University of Missouri's Holstein Farm.

CPRC has completed the following studies pertaining to coal log pipelines: (1) predicting the behavior of coal log compaction in mold and ejection from mold; (2) the effect of coal moisture on rapid compaction of coal logs; (3) drag reduction in coal log flow in an 8-inch-diameter pipeline; (4) optimization of four parameters in coal log compaction; (5) the effects of slopes and bends on coal log pipeline; (6) coal log pipeline effluent water treatment; (7) a set of experiments to analyze the scale-up of coal log test results.

The Center made substantial progress in the PCP (Pneumatic Capsule Pipeline) study sponsored by Sumitomo Metal Industries and Mid-America Transportation Center. Completed the derivation of the equations needed for analyzing PCP and for the LIM (Linear Induction Motor) needed for powering PCP. These equations are being used at present (May '98) for optimizing the performance of PCP and LIM. Also, conducted an analysis of an off-line loading/unloading system of PCP based on LIM. The proposed new system is expected to revolutionize the PCP technology—greatly enhancing system

throughput, reducing unit transportation cost, and making the system more economically competitive with train, truck and conveyer belt.

In the solid waste compaction research area, the Center conducted some preliminary experiments to compact several biomass waste materials including sawdust, wood chips, waste paper and so forth. They were tried out successfully in both small (1.91-inch-diameter) and large (5.4-inch-diameter) sizes. The large logs were produced by using the new coal log compaction machine.

During the period of this reporting year (9/1/97-8/31/98), three CPRC research assistants received Ph.D., four received M.S., and three undergraduates doing honors projects in capsule pipeline received B.S. One U.S. patent was granted and three are pending.

Technology transfer activities include: (a) two work sessions with industry experts to plan the pilot plant design; (b) demonstration of a pipe interior grinder at the Williams Pipe Line terminal in Tulsa, Oklahoma; (c) exhibition of new compaction machine pictures and products (5.4-inch-diameter logs) at an international coal technology conference; (d) a newsletter; (e) visiting companies and government agencies with interest in CPRC work; (f) reporting result at national and international conferences.

Future Plan:

The Center plans to complete R&D in CLP by 8/31/99 so that the CLP technology can be used commercially before the Center ends its second 4-year term. Plans for the final year of CLP research under the sponsorship of the National Science Foundation's State/IUCRC Program include:

- Conduct extensive tests with the new coal log machine.
- Complete construction of the 3,000-foot-long closed loop pilot plant CLP. Conduct extensive tests with this new pipeline.
- Select the first commercial demonstration project. Help the owner of the project to plan for the project.
- Submit full proposal to NSF for converting CPRC into an ERC (Engineering Research Center) on Pipelines Infrastructure. Submit several other proposals to fund the Center's future research.
- Conduct another round of surveys to determine 10 promising commercial CLP projects.
- Complete revision of CLP economics analysis report.
- Complete revision of Manual of Practice of CLP.

ACCOMPLISHMENTS, INFRASTRUCTURE CHALLENGES, PARTNERSHIPS AND CONTRIBUTIONS TO EDUCATION

A. Most Significant Accomplishments

Since the inception of the Capsule Pipeline Research Center in 1991, the most significant accomplishments toward development of the coal log pipeline are as follows:

1. Cost Model

Along with the technical development of CLP is the assessment of the economic and market potential of CLP. Central to this assessment is the development of an engineering cost model to determine the cost effectiveness of CLP as compared to competitive current modes of coal transportation including rail, truck and coal slurry pipeline. This cost model is detailed in a 180-page report. An abbreviated version is published in 1998 as an article in TRANSPORTATION RESEARCH (A), (Vol. 32A, No. 4), an international journal. This report (article) defines unit freight transportation cost as the cost of transporting a ton of coal for any prescribed distance in $/T (dollars per ton). It includes not only capital and operational costs, but also a reasonable built-in profit for the investor. Thus, the unit freight transportation cost of coal log pipeline can be compared with the current tariffs for coal transportation charged by railroads, trucks and other competing modes to determine whether it is economically competitive in a given situation. The study was conducted for different transportation distances and throughputs. Based on this comparison, conditions are established under which coal log pipeline is more economical than slurry pipeline, truck and train. The model also establishes a novel new approach to assess the cost effectiveness of new transportation technologies which can be used to assess the cost-effectiveness of other new freight transportation technologies.

2. Demonstration Site

A national site survey for CLP demonstration was conducted in 1995-96 of more than 100 coal and utility companies. These companies were asked to provide site data for coal transportation for distances less than 100 miles, and throughputs less than 5 million tons per year. Out of 14 sites submitted, seven were judged to be either economical or marginally economical. They were studied in detail by the Williams Technologies, Inc., which is contributing in-kind services to the Center. The detailed study revealed that the two most promising sites for CLP demonstration in the United States are: a 23-mile-long coal log pipeline for the Potomac Electric Power Company (PEPCO) in Maryland, and a 90-mile-long pipeline for the Southwestern Public Service Company (SWPS) in Texas. Discussions are in progress with these two companies.

3. Coal Log Manufacture

Initially, a number of potential coal log manufacturing processes were investigated. Exploratory study of each resulted in the finding of the most promising process for in-depth studies. Several highly promising manufacturing processes have been developed based on laboratory tests. They are all based on mold compaction rather than extrusion.

Coal log manufacture has been studied for both bituminous and sub-bituminous coals. Compaction tests were conducted at different temperatures, pressures, hold times, moisture contents, binder concentrations, mold exit shapes, compaction time, mold lubricants, and so on. It was found that water-resistant and wear-resistant coal logs can be made either without binder or with a small amount of hydrophobic binder. Many ways to produce strong logs were discovered. These include using maximum packing density for coal particle size distribution, heating the coal to an optimum temperature, using a small amount of hydrophobic binder, neutralizing zeta potential of coal, use of chrome-plated or surface-treated molds, use of certain types of lubricants, use of tapered-exit or round-exit molds, use of back-pressure during coal log ejection, and so forth.

Important one-dimensional and three-dimensional theories on coal log compaction have also been accomplished, helping greatly to advance the state-of-the-art in powder compaction.

4. Machine Design

Because coal logs cannot be manufactured at sufficiently low cost by using existing commercially available machines, CPRC developed its own coal log manufacturing machine that can make satisfactory coal logs at low cost for transportation by CLP. During the second year of CPRC, Dr. Yuyi Lin started to design such a machine for coal log manufacturing. The design evolved in several stages, each time representing an improvement over the previous design. Outside consultants including T. J. Gundlach Machine Company, FLOPRODUCTS, Erie Press Systems, and Ramer Associates participated in different phases of the design.

In 1995, Lin's team designed a fast compaction machine system to supply coal logs for a hypothetical 8-inch-diameter commercial CLP. The design was again reviewed by Erie Press Systems, and certain changes were made based on the reviewer's comments. Meanwhile, a rotary press similar to a tableting machine for manufacturing 2-inch-diameter coal logs (for test purpose) was designed and sent for review by Automation Resources.

In May, 1996, a 300-ton-force hydraulic press test machine was designed and bids (proposals) were invited. The bid winner was T. J. Gundlach Company—a Small Business participant of CPRC. The Company delivered the machine to the CPRC Field Station in October of 1997. The machine was tested in January-March 1998 and was found to perform as designed. Only a minor problem was discovered involving some oil leak. Efforts are underway to conduct extensive tests of this machine—to determine the optimum back pressure during ejection and many other optimum conditions.

5. Hydrodynamics of CLP

During the first 6½ years of the Center, important accomplishments were made in the hydrodynamics of CLP, including the following:

a) Development of a theory and a set of equations to predict the pressure gradient, capsule velocity, capsule drag and lift, and capsule incipient velocity. The theory and equations,

based on the four regimes of capsule flow, are far more logical and accurate than previous empirical equations.

b) Demonstrated that by using a small amount of polymer such as polyethylene oxide, as much as 75% drag reduction (i.e., fourfold reduction in energy consumption) can be accomplished in coal log pipelines.

c) Explored and clarified the mechanism of coal log wear in pipeline. Found many ways to reduce such wear, such as by using logs of beveled tail-end, having aspect ratio greater than 1.5 and so forth, operating the pipeline at a velocity between 80% and 90% of lift-off velocity.

d) Developed hydrodynamic models for analyzing the unsteady flow of coal logs in pipelines using the method of characteristics. Verified the model through small-scale laboratory tests.

e) Tested coal slurry suspension of coal logs. Found that the pressure drop of the two-phase flow of coal logs in coal slurry is almost identical to that of slurry flow alone. Use of slurry to suspend coal logs may be needed when pipeline diameter is greater than 20 inches, or when applying the coal log technology to transport heavy ores such as iron concentrate.

f) Further improved the theory to predict pressure drop and capsule velocity in pipelines, and extended the theory to cover coal log trains.

g) Found an improved way to inject powdered Polyox into pipeline for drag reduction.

h) Found that immersing coal logs in water under high pressure (say 1,500 psi) strengthens the logs, and reduces log wear significantly.

i) Tested coal logs in dilute slurry containing 1% to 8% coal. Wear loss of coal logs was found to double at about 8% concentration.

j) Assessed the effects of bends and slopes on coal log pipeline and other types of capsule pipeline.

6. Injection, Ejection and Pumping of Coal Logs

A fully automated, computer-controlled small model of CLP was designed, tested and demonstrated in the laboratory. The system was demonstrated to visitors and sponsors many times, and it works smoothly and reliably. Experience gained from this model system was extremely valuable for designing larger commercial systems.

7. Test in Commercial Pipelines

In September, 1994, coal logs were tested in a 6-inch-diameter, 5-mile-long, commercial pipeline in Conway, Kansas. The coal logs were made with and without binder.

Twenty four coal logs were run through the pipe three at a time; some went through the pipe twice. The best (strongest) logs lost less than 1% weight due to abrasion; the worst broke in the pipe but did not cause jamming. The results indicate that coal logs can be made robust to withstand travel for miles, even at a velocity as small as 60% lift-off. The test also revealed the need for eliminating weld protrusions in future commercial coal log pipelines.

8. Legal Study

A thorough research in the legal issues associated with the use of CLP was conducted in the first five years of the Center. Issues explored include eminent domain rights for coal pipelines, water rights and water permits, rights to cross railroads, and possibility of using the easement of a liquid or natural gas pipeline for coal pipeline. Research results were published in legal journals and reported at engineering conferences. A legal manual for coal log pipeline has been completed. No further legal research has been done since the 6th year.

9. Heating and Drying of Coal Logs

Detailed study (analysis) was conducted during the 5th year and completed during the 6th year to determine the most practical method to heat coal for compaction. Several approaches were compared and the most practical method was found to be fluidized-bed heating. A separate study was also performed to determine how to predict the cooling and drying rates of coal logs. A sophisticated mathematical model was developed which couples heating with moisture change.

10. Education/Training

In the past 6½ years, more than a hundred students (64 graduate students, 38 undergraduates and 2 exceptionally qualified high school students) were trained by CPRC—see Table 1. The Center's outputs and outcomes in education and publication for the current year are given in Table 2.

<u>Most significant accomplishments during the current year</u> (9/1/97-8-31/98) include the following:

1. The new coal log machine has been installed and tested in Columbia in the new building (Field Station) on Holstein Farm. The machine was able to perform as designed including the 3-second compaction time. Reasonably good-quality coal logs were produced even without the back-pressure-control feature. Back-pressure control requires sophisticated reprogramming of the PLC (Programmable Logic Controller) which is currently underway. Parts of the coal feeding system and a coal log removal system have been installed.

2. Completion of a Ph.D. research that developed a 3-D finite-element model for predicting the variation of the density and stresses in coal logs during compaction and ejection. The model can be used to optimize coal log compaction conditions, and predict conditions conducive to crack formation and capping. Using the tested

Table 1. Student Research Participants (9/1/91-8/31/98)

Graduate	*Graduate (cont.)*	*Undergraduate (cont.)*
Mary Foster Barnes, M.S.	Bainin Tao, M.S.	Ryan Malsch, B.S.**
Marcus Bahr, M.S.	Shensheng Wang	Rebecca Miller
Dave Berg, M.S.	Wenwei Xu, M.S.	Andrew Rockabrand, B.S.
Daniel Carney, B.S., M.S.	Dai Wang	Becky Clarkson-Smith, B.S., M.S.
Feng Chen, M.S.	Liqing Wang, M.S.	Rosa Camp-Soldano, B.S.
Susan Chen, M.S.	Brent Ward, M.S.	Josh Summers, B.S.
Chih-Chaing Cheng, Ph.D.	Gouping Wen, Ph.D.	Angela Tartar, B.S.
Nicole Cress, J.D.	Jon Wilkinson, M.S.**	Andy Thiel, B.S.
Qinwen Deng, M.S.	Dave Woerner, Ph.D.	Keith Thomas, B.S
Yungchin Ding, Ph.D.	Gangwei Wu, Ph.D., M.S.**	Jean Tietjens, B.S.**
Hongliu Du, Ph.D., M.S.	Jianping Wu, Ph.D., M.S.	Warrick Wadman, B.S.
Majaed El-Bayya, Ph.D., M.S.	Gang Xu, M.S.	James Wilbur, B.S.**
Lauren Abbott Garber, M.S., B.S.	Kang Xue**	Chris Yates, B.S.
Xiang Gao, M.S.**	Shiping Yang, M.S.	Hui Zhu, B.S.
Randall Harris	Eng-Seong Yap	Robert Zuniga, B.S.
Xin Huang, M.S.	Kevin York**	*No. of Students* 38
Gouping Ji, M.S.	Dongquing Zhai, M.S.	
Kai Jiang	Bing Zhao, M.S.**	***High School***
Robert Jones	Yue Ying Zhong	Clark Darrah, B.S.
Jayanth Kananur, M.S.	*No. of Students* 64	Anne Tillema
Jim Kelly, J.D.		*No. of Students* 2
Mark Kersting, B.S.	***Undergraduate***	
Glenn Kuhlman, M.S.**	Catrina Allison, B.S.	
Huachao Li, M.S.	Dwayne Bargrede, B.S.	
Wei Li**	Jeff Bennett, B.S.	
Yin Li, Ph.D.	Justin Bhansali, B.S..	
Zhouxing Liang, M.S.	Ivan Bird	
Pamela Luchon, M.S.	Jim Burris, B.S.	
Saad Merayyan, M.S.	Erika Carter, B.S.	
Sanjay Mistry, Ph.D.	Gordon Carter, B.S.	
Sermsak Outangoun	Kevin Clark, B.S.	
Nicole Pagano, M.S.**	Wilunder Deadmon	
Pituk Paksanonda, M.S.	Thomas Eckhoff, B.S.	
Phimjaichon, R., M.S.	James Eichelberger, B.S.	
Chai Plodpradista**	Erik Erickson, B.S.	
Eileen Petito, J.D.	Anthony Eves	
Elizabeth Phillips, J.D.	Raeann Gorden, B.S.	
Paul Rechenberg, J.D.	Allison Hjelmfelt, B.S., M.S.	
James Richards, M.S.	Michael Holder, B.S.	
Choung-Yaw Shieh, M.S.	Mohamed Kabbani	
Trent Stober, M.S.	Richard Kaufmann, B.S.	
Pat Sullivan, J.D.	Bill Knowles, B.S.	
Ssu-Hsueh Sun, Ph.D.	Dawn Kraettli	
De-Xiang Sun, M.S.	Brent Leonard, B.S.	
Jun Jun Tang, M.S.	Tracie Loar, B.S.	**Total Number of Students = 104**

Note: (1) Current Year (9/1/97-8/31/98) participants are indicated by **
(2) Degrees indicated are those received while working for the Center.

Table 2: Quantitative Center Outputs and Outcomes in Education and Publications for the Current Reporting Period

CENTER GRADUATES	
Bachelor's degrees granted:	4
Master's degrees granted:	4
Doctoral degrees granted:	2
GRADUATE OUTCOMES	
Industrial employment - at Corporate site:	
- at National Lab.:	
- site unknown:	6
- U.S. industry:	2
- foreign industry:	
- Center members:	1
Center graduates hired by academia:	
Government employment - at National Lab.:	
- not at National Lab.:	
- site unknown:	
Graduate or professional school:	1
Unknown outcome:	
CENTER INFLUENCE ON CURRICULUM	
New courses based on Center research:	
Courses modified to include Center research:	1
New textbooks based on Center research:	
New degree programs:	
PUBLICATIONS THAT ACKNOWLEDGED NSF SUPPORT	
Peer reviewed technical journals - by Center personnel:	6
- with industrial co-authors:	0
Peer reviewed conference papers - by Center personnel:	14
- with industrial co-authors:	0
Trade journals - by Center personnel:	1
- with industrial co-authors:	0
Technical reports – by Center personnel:	20+
- with industrial co-authors:	
Books - by Center personnel:	1 chapter
- with industrial co-authors:	

properties of small logs, the model can predict the behavior of large logs—enabling scale-up of test results. It has significantly enhanced the state-of-the-art in compaction of coal logs.

3. Completion of a M.S. research to explore the effect of coal moisture on rapid compaction of coal logs. The test result shows that rapid compaction of coal logs can produce strong logs only if the moisture of the coal mixture is at or below the equilibrium moisture which is a function of compaction pressure. When the mixture moisture is higher than equilibrium, longer compaction time is needed to squeeze out the excess water before strong logs can result. The experiments verified hypotheses to these effects.

4. Completion of a Ph.D. research on drag reduction in coal log pipeline in an 8-inch-diameter pipe. The experiments, using simulation coal logs made of resin, showed that 45% drag reduction is possible for logs moving through an 8-inch pipe at 88% lift-off velocity and with Polyox concentration of 25 ppm approximately. Higher values of drag reduction is expected with Polyox concentration exceeding 25 ppm, and at velocity approaching lift-off. The experiments also found that when fiber (pulp) is used in combination with Polyox, it does not help in reducing drag nor in reducing the degradation of Polyox. This research also tested a new Polyox dissolution/injection system that may revolutionize drag reduction and other use of Polyox and certain other powders.

5. Completed an analysis of the effects of horizontal bends and vertical slopes of coal log pipelines on the behaviors of coal log trains including the possibility of jamming.

6. Derived the equations for predicting PCP using LIM. Optimization of design will be achieved from these equations before the end of this reporting year.

7. Completed experiments on optimizing the compaction pressure, moisture content, amount of binder (Orimulsion) and particle top size for coal log compaction.

8. Rolla team conducted further study of coal quality variations with several parameters for both small (1.8-inch-diameter) and large (5.4-inch-diameter) logs—the scale-up effect. The team also completed a coal log pipeline effluent water study, and winterized the 6-inch-diameter outdoor pipeline facility.

9. Important technology transfer activities include (a) exhibition of new compaction machine pictures and products at an international coal technology conference; (b) held two work sessions with industry representatives on pilot plant design; (c) gave presentation on CLP at several companies; (d) presented results at several technical conferences; and (e) publication of results in journals.

10. Important commercial developments include: (a) participated in SBIR proposal on portable compaction machines; (b) a small business participant of CPRC constructed

the new coal log machine; (c) six licensing agreements with industry participants of CPRC.

11. Dr. Tom Marrero, Associate Director of CPRC, received promotion to Professor of Chemical Engineering, and Dr. Yuyi Lin, received tenure and promotion to Associate Professor of Mechanical and Aerospace Engineering. Both cases reflect an essential milestone in faculty development in CPRC related research.

B. Partnerships

Since the establishment of the CPRC, strong partnership has been forged between the Center and a group of companies interested in the development of the CLP and other capsule pipeline technologies. This partnership is reflected by providing industry matching fund for the NSF and State funds, by providing guidance to the Center through the IAB (Industry Advisory Board), by frequent contacts and visits with individual companies, by industry participation in CPRC research, and by helping to build major test facilities for CPRC. For instance, the Williams Technologies, Inc. has helped the Center to develop a good cost model for CLP, and has evaluated more than ten potential CLP demonstration sites. The MAPCO Company allowed the Center to test coal logs in a 5-mile-long pipe in Conway, Kansas, free of charge. The Williams Pipe Line Company constructed a 340-ft long pipeline at Rolla, Missouri, for the Center's UMR team. The Gundlach Machine Company, a small business participant of CPRC, constructed a new coal log compaction machine for CPRC. Most recently, the Williams Pipe Line Company demonstrated a special pipe grinder in Tulsa intended for construction of coal log pipelines with smooth joints. The Company has also committed to send a construction crew to Columbia, Missouri to build a 3,000-ft long coal log pipeline (the Pilot Plant) for CPRC as part of its in-kind contribution. All these demonstrated strong partnership between CPRC and its industrial sponsors. All these contributed greatly to the success of the Center's R&D.

C. Integration of Research and Education

All the graduate students who serve as research assistants on any CPRC project are required to write a thesis (for M.S.) or dissertation (for Ph.D.) on a coal log or capsule pipeline topic closely related to their work. This policy has resulted in close integration of research with graduate education. Many undergraduates also wrote honor's reports on coal log related studies. For instance, Bill Knowles, a former undergraduate in Chemical Engineering, studied vacuum dissolution of Polyox in water as an honors project. The study resulted in an invention disclosure. Bill is now employed by the Dow Chemical Company. Research results on CLP and HCP have also been incorporated in teaching CE/MAE 345 Pipeline Engineering. Chapter 7 of the course is on capsule pipelines.

Finally, a national survey on pipeline education at U.S. universities was conducted during the current year. The survey found that few schools in the U.S. cover pipeline engineering topics in classes. The survey results will be presented at the 1998 International Conference on

Engineering Education, and will have a strong impact on future pipeline education in the U.S. and around the world.

D. Efforts to Increase Participation of Women and Underrepresented Minorities

During the 6½ years of the Center, many efforts have been made to increase participation of women and underrepresented minorities. They resulted in the hiring of two women as post doctoral fellows, one as research associate and laboratory manager, two as Patricia Harris Fellows, and several as research assistants. Limited success was also encountered in involving a few minorities (blacks and Hispanics) as research assistants, work-study students, and secretary. The Associate Director of the Center is Hispanic and legally "handicapped."

NUGGETS

1. Coal Log Pipeline Approaching Commercialization

One of the earliest State/Industry University Cooperative Research Centers established by the National Science Foundation (NSF) is the Capsule Pipeline Research Center (CPRC) at the University of Missouri--both Columbia and Rolla campuses. The Center's mission includes research, development, and commercialization of the emerging technology of coal log pipeline (CLP) for transporting coal, and other types of capsule pipelines for transporting solid wastes, mail, parcels, grain, and many other cargoes.

Since its establishment in 1991, the CPRC has succeeded in developing several processes for manufacturing coal logs (large cylinders made of coal) that are both water-resistant and wear-resistant. A process to produce strong coal logs has been granted a U.S. patent. Three other patents are pending. A sophisticated economic model containing more than one hundred equations was developed to calculate the life-cycle cost of the CLP system, and to compare the costs of transporting coal by CLP with those by unit train and trucks. The model showed that over a certain range of conditions (windows of opportunity), it is more economical to use CLP than to use truck or train to transport coal. The CLP technology was tested extensively in laboratory pipeline loops, and a successful field test was conducted in Conway, Kansas in a 5-mile-long existing underground pipeline owned by the Mid America Pipeline Company (MAPCO).

Most recently, a new field station was built to house the new CPRC-designed machine for mass production of coal logs. Initial testing has been completed and quality logs have been produced. In a commercial setting, the machine will mass produce coal logs at a cost much below that of any contemporary machine. The same machine can also be used to compact wasted coal fines at coal mines and power plants, and other waste materials such as flyash, sawdust and refuse (municipal solid waste). They represent spin-offs from the coal log R & D.

Utilities and coal companies from across the nation have submitted 20 projects to CPRC for evaluation as possible commercial demonstration project. Using the economic model developed by CPRC, these sites were evaluated and the most economical ones were selected for negotiation with the owners. The Williams Technologies, Inc., an industrial sponsor of CPRC, is conducting further investigation of these projects to determine which is the most promising project for commercial demonstration. The Center's current plan calls for construction of the demonstration project in 1999. Director Henry Liu expects that before the turn of the century, the first commercial CLP will be in operation in the United States.

2. Center Initiates Research in Pneumatic Capsule Pipeline (PCP)

The Capsule Pipeline Research Center (CPRC) is one of a dozen of State/Industry University Cooperative Research Centers (State/IUCRC) sponsored by the National Science Foundation (NSF). The Center is based in Columbia, Missouri, at the University of Missouri-Columbia. The purpose of the CPRC is to conduct extensive research and development (R&D) in various types of capsule pipelines for transportation of coal, grain, solid wastes, mail and many other types of products. Different types of products require different types of capsule pipelines.

While CPRC's research has been focused on coal log pipeline (CLP) technology for transporting coal, in 1997 the Center started to investigate pneumatic capsule pipeline (PCP). PCP uses air instead of water for transporting freight in capsules moving through underground pipelines. The capsules are wheeled vehicles propelled by air. In the 1997 study, CPRC researchers planned a dual-pipe PCP system between Washington, D.C. and New York City. The pipeline is to be laid along existing highway right-of-ways. The PCP technology used is one developed by Sumitomo Metal Industries (SMI) in Japan. SMI has considerable experience in operating commercial PCP systems in Japan. A cost analysis of the system showed that by using a 4-ft-diameter pipeline, the PCP system can transport freight (mail, vegetables, etc.) at cost of $11 per ton per 100 miles. Since this is less costly than the freight tariff charged by trucks along this East-Coast corridor, the PCP technology appears promising for use along this route. The use of PCP along this route will also reduce the number of trucks on congested highways, contributing to traffic safety, reduced noise and air pollution generated by truck, and more efficient use of energy.

CPRC has also succeeded in winning support from both SMI and the Mid-America Transportation Center (MATC) for research to improve the current PCP system by using linear induction motors (LIM) to propel the freight capsules. The outcome of the research will be a revolutionized PCP system powered by linear motors and controlled by a computer. Freight capsules traveling through the pipe will be identified by a special bar-code scanner for processing.

CONTRIBUTIONS TO STATE AND LOCAL ECONOMIC DEVELOPMENT STRATEGIES

The CLP technology must be developed first before the Center can contribute to the economy of the State, region and the nation. Once the coal log pipeline technology is developed through the Center's R&D program, the technology can be used to transport any type of coal over both long and relatively short distances.

Approximately, 70% of Missouri's electricity is generated from coal. Most of the coal used in Missouri is now imported from Illinois, Colorado, and Wyoming, involving transportation distances between 100 and 1,000 miles. The cost of coal transportation greatly affects the price of coal at the utility plant. For instance, each ton of low-sulfur coal sold in Wyoming, excluding transportation cost, is about $4. When transported to Missouri by train,

the cost rises to $15 per ton, approximately. The $15 includes not only the tariff paid to the railroads but also additional cost invested by utilities in terminal facilities and rental or purchase of a fleet of railroad cars. This means that 2/3 to 3/4 of the cost of Wyoming coal used in Missouri is transportation cost. Even for coal mined in Missouri and trucked to Missouri power plants within a distance of 100 miles, the transportation cost is still about $8 per ton. From an economic analysis of CLP conducted by the Center in 1995, the use of CLP instead of train (for long distance) and truck (for short distance) can cause substantial savings to electric utilities. For a single 20-inch-diameter coal log pipeline which transports 18 million tons of coal per year, the savings accomplished can be close to $50 million dollars per year. This shows the huge cost savings that can be accomplished by using coal log pipelines in Missouri. Thus, the potential economic value of coal log pipelines to Missouri and many other states is enormous.

Furthermore, once the coal log pipeline technology is developed in Missouri, the state will be the nation's and the world's leader in the coal log pipeline technology. A new industry will be generated in Missouri which will provide design, construction and consulting services not only to Missouri but also to other states and nations. This again provides economic development to Missouri, and can generate many new jobs in the state.

The development of the capsule pipeline technology for transporting grain and other agricultural products, solid wastes and so forth will have even a greater positive impact on the state's economy. For instance, Missouri is located in the nation's "Grain Belt." Not only must Missouri's grain be shipped to its markets, large quantities of grain produced in neighboring states also pass through Missouri to reach their destinations. For years, transportation of grain has been a serious problem for farmers. The development of the HCP technology for transporting grain will greatly benefit farmers in the Grain Belt, especially in Missouri if the State becomes the nation's leader in grain pipeline technology.

Missouri and other states have increasing problems with solid waste handling and transport. Based on a study conducted by the Stanford Research Institute (Ref. 1)*, capsule pipeline is the most promising way for transporting municipal solid waste from waste processing plants to incinerators or power plants for combustion. Large cities in Missouri, such as St. Louis and Kansas City, will especially benefit from such pipelines. Furthermore, due to the development of such a new pipeline technology in Missouri, it is reasonable to expect that a solid waste pipeline industry will be created in Missouri, to serve not only Missouri but other states. That will again generate jobs in the State and contribute to the State's economic well-being. The possibility of such an industry being located in the vicinity of St. Louis is likely due to recent interest in solid waste compaction and transportation in that area.

A spin-off of the Center's R&D is the coal log machine designed. The same machine can be used to compact many other waste materials such as coal fines (which is a waste problem in Missouri and nationwide), sawdust, flyash, refuse, and so on. Once compacted, the

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* References are listed on page 66.

waste-material logs can be transported by trucks to incinerators or power plants for combustion, or landfills for disposal. This has great economic and environmental values to the State.

Although most of the economic benefits to Missouri and the nation produced by the Center's R&D program are long-term in nature, there are also some immediate or short-term benefits. For instance, a small business in the suburb of St. Louis, the Floproducts, Inc., assisted in the construction of CPRC's 230-ton compaction machine. Gundlach Machine Company in Belleville, Illinois as the machine's primary builders will hold a prominent lead in the marketing and technical leadership of future production. Synercon Construction Company of Columbia, Missouri enhanced their reputation in meeting the special requirements of the 2-story compaction machine. Mobil Oil, Inc. donated $14,000 worth of high-performance hydraulic oil for the compaction machine. The use of this oil, a new vegetable based synthetic product called Enviosyn 46H, will be in great demand if it proves to be the best product for the machine operation. Marketing of the compaction machine will generate new business for many industries.

Present research in biomass compaction has generated interest from lumber and recyclable waste management businesses. Utilities also would benefit from mixing biomass waste materials with coal because it would reduce sulfur content and cause less acid-rain problems. Unlike coal which is not recycled and hence not renewable, biofuels are recycled and renewed through the growth of trees and other plants. The utilization of these new fuels can effectively lower emissions of CO_2 and other greenhouse gases. The use of biofuel reduces the need for disposing of certain waste materials (municipal solid waste) at landfills, thereby reducing groundwater pollution and reducing the pressure on increased land use for landfill purposes.

Using the knowledge gained from CLP technology, a special machine based on the modern technology of the rotary press (tableting machine) can be modified to convert high-quality biofuel into logs (slugs) which can be mass produced at low cost. Research in biomass compaction and pipeline transportation could lead to several new business opportunities in Missouri, making the Show-Me State a showcase and world stage for the new technologies needed to conserve our natural resources by providing cleaner fuels at lower costs.

The strategy used by the Center to develop the State's economy is to encourage more Missouri companies to become involved in the Center's activities. Missouri companies, plus selected companies from out-of-state, will form the backbone of the nation's freight pipeline industry in the 21st Century. As the coal log pipeline technology is approaching commercialization, more and more companies are considering investment in this new technology. Because all the test facilities and expertise in CLP and HCP are located in Missouri, it is logical to expect that much of the future investment will be in Missouri. Finally, three different investment groups have contacted the CPRC for possible investment--two on coal log pipelines, and one on solid waste transport. The Center's policy is to encourage them to first become an industrial sponsor (CLP Consortium Member).

RESEARCH PROGRAM

A. Intellectual/Infrastructure Challenges and Changes

The capsule pipeline field has come a long way since the establishment of CPRC in 1991. Through tireless efforts of many individuals associated with CPRC, the coal log pipeline (CLP) has advanced from a mere concept to a major technology. Volumes of information on CLP has been written and published. A large body of new knowledge has been generated. With the completion of the planned pilot study, the CLP technology will be ready for initial commercial use in year 2000. The greatest intellectual/infrastructure challenges over the next year or two are: to construct the CLP pilot plant and to execute the pilot plant study so that most of the technical information needed for designing a commercial CLP can be generated from the pilot plant study; to conduct thorough tests of the new coal log machine and, based on the test results, to design a new machine for commercial CLP use; to encourage and convince an electric utility to become the first user of CLP; to complete a good operation manual of CLP; to complete the analysis, design and test of a new PCP (Pneumatic Capsule Pipeline) system based on LIM (Linear Induction Motor); and to enter into other new research areas including PCP, grain pipelines, solid waste (biomass) compaction research and so on.

B. Plan

The Center's research program was planned to accomplish the stated goal which, for the first four years, is to research and develop the CLP (Coal Log Pipeline) technology for early commercial use. To attain this goal as soon as possible, and with the Center being the only institute in the nation engaged in CLP and HCP (Hydraulic Capsule Pipeline) research, all the unknown areas and unsolved problems pertaining to CLP have been studied simultaneously. This called for a wide range of research projects, and the mobilization of a large number of faculty and students from different fields. Even greater interdisciplinary involvement is required for the final year of the Center's research in capsule pipeline for transporting grain, solid wastes, and other freight. Starting Year 7, the Center initiated some research in solid waste compaction (into logs), and pneumatic capsule pipeline (PCP) for transporting mail and general cargoes. They are being phased in slowly so that they will not slow down the development and commercialization of CLP.

Unlike ordinary academic research which is unsolicited and initiated by individual researchers, the CPRC's research program is carefully planned and designed by the Center Director with input from individual faculty members, the Industry Advisory Board, the government sponsors, and technical consultants--especially the Williams Technologies, Inc. which is serving as the Center's Principal Consultant. This approach in research planning is necessary in order to accomplish the stated mission of the Center. Several planning documents were issued by the Center in the last seven years. The Center's R & D plan has been updated periodically to reflect advancement in technology and changing circumstances.

C. Research Thrusts

C.1. Core Program (1st 7 Years):

The research under the Center's Core Program for the first 7 years can be classified into eight broad areas (thrusts) as follows:

1. Hydrodynamics of CLP

The hydrodynamics of CLP must be clearly understood before one can design an appropriate CLP system and expect it to work without difficulties. Prior to the establishment of the Center, many areas of the hydrodynamics of CLP were either unexplored or inadequately explored. This includes prediction of energy loss, capsule lift-off, capsule velocity, capsule train behavior, effect of slopes and bends on capsules, abrasion (wear) of coal logs in pipeline, capsule jamming, capsule pumping and injection, effect of drag-reducing additive on the pressure drop of CLP and HCP, and so forth. Research conducted by the Center in the last 6-1/2 years was focused in these areas. It has greatly enhanced the knowledge and state-of-the-art in these previously poorly understood subjects. This research is led by the Center's Director Dr. Henry Liu, Professor of Civil Engineering, who is an expert in hydrodynamics. Two other faculty members currently involved in this research are Dr. Charles W. Lenau, Professor of Civil Engineering, and Dr. John Miles, Professor of Mechanical & Aerospace Engineering. Dr. Lenau has been the P.I. of projects involving predictions of unsteady flow and pressure surges (water hammer) in CLP and HCP. He is also instrumental in the design of the pilot plant CLP. Dr. Miles is supervising a project in drag reduction in large (8-inch-diameter) pipe.

Major accomplishments in the hydrodynamic research in the past 6-1/2 years include the following:

(a) Theory for Predicting HCP Flow Behavior:

Based on the concept that there are four distinctly different regimes of HCP flow, equations have been derived for each regime to predict the hydrodynamic behavior of HCP flow. The theory can accurately predict the capsule pressure gradient, capsule velocity, capsule drag and lift, capsule incipient velocity and capsule lift-off velocity (Ref. 2 & 3). Current or on-going research in this area focuses on predicting capsule train behavior, and the behavior of capsules (or logs) in bends and slopes.

(b) Coal Slurry Suspension and Transport of Coal Logs:

A study was completed to test coal slurry suspension of coal logs. The test was done using the coal slurry prepared for the Black Mesa Pipeline which is a slurry that contains 50% solids by weight. The study found that the pressure drop (headloss) of the two-phase flow of coal logs in slurry is almost identical to that of slurry flow alone. Other interesting features of this type of flow were also found (Ref. 4 & 5). The coal-log/slurry

flow was found to have some special advantages such as it transports more coal and uses less water than either the coal slurry pipeline or the ordinary coal log pipeline. Furthermore, the slurry provides larger buoyancy than water to suspend coal logs, and this lowers the lift-off velocity and reduces contacts between the logs and the pipe. It is a technology that may play a role in future transportation of large-diameter, heavy coal logs over long distances.

(c) Drag Reduction in Coal Log Flow:

A study was completed in a 2-inch pipe to determine the effect of a conventional drag-reducing polymer (polyethylene oxide, trade named "Polyox") on the headloss (energy consumption) of HCP and CLP. It was found that at polymer weight concentration of 25 ppm (parts per million), the Polyox can produce as much as 75% drag reduction which is equivalent to four-fold reduction in the pressure gradient or energy consumption (Ref. 6). This finding has strong implications to future operation of CLP and HCP systems. It makes long-distance transportation of coal logs and capsules far more economical than realized before. Degradation of Polyox due to shear in flow can be minimized by injecting polymers downstream of each pumping station, as practiced in ordinary pipelines, such as the Trans-Alaska Pipeline. Current on-going research in this area involves testing the effectiveness of polymer drag reduction in a large HCP--the 8-inch-diameter pipeline test loop in the UMC Research Park.

(d) Coal Log Jamming in Pipe:

Research has been conducted to study different ways that coal logs may jam in a pipe. The research has led to a good understanding of the different jam mechanisms and causes, and effective strategies to prevent jamming (Ref. 7). Ways to unclog a coal log pipeline once it jams have also been developed. Future research will focus on verifying the effectiveness of jam prevention strategies in a long (3,000 ft.) test pipeline to be built.

(e) Coal Log Wear in Pipeline:

The phenomenon of coal log wear has been studied extensively during the first five years of the Center (Ref. 7), and is still receiving continued attention in research. Many factors contributing to coal log wear in pipeline have been identified. Findings include: coal logs made of subbituminous coal are more wear resistant than those made of bituminous coal; logs with large diameter ratio and large aspect ratio are more wear-resistant; logs with beveled rear end suffer less wear; minimum coal log wear is produced when fluid (water) velocity in the pipe is approximately 85% lift-off velocity; coal slurry increases wear of coal logs; high pressure in the pipe decreases coal log wear; and the wear is minimum over a wider range of velocities than realized previously--between 80% and 90% of lift-off.

2. Unsteady and Transient Flow in CLP

The operation of CLP requires periodic closing and opening of valves, and startup and shutdown of pumps. Such unsteady operations generate pressure surges, whose effect on the coal logs, pipes, valves and pumps must be carefully evaluated. The evaluation can be done by using a specific mathematical technique called the **"method of characteristics"** commonly used for analyzing water hammer effects. As a result of this research, a technique (including equations and computer programs) has been developed that can analyze the behavior of coal logs and the pressure waves in a coal log pipeline under various operational conditions such as capsule injection, pump startup, shutdown, and valve switching at both the intake and at pump bypasses (booster stations) (Ref. 8 & 9). The accuracy of the theory has been validated by experiments (Ref. 10). The technique and analyses enable us to improve and optimize CLP system design and operations. Dr. Charles Lenau, Professor of Civil Engineering and an expert in hydraulic transients, was the P.I. of this completed research. Future research in this area includes further improvement of the accuracy of the theory by improving the way headloss and contact friction are predicted, and application of the theory to investigate various scenarios of pump startup and shutdown. This project was not active during years 6 and 7; Dr. Lenau focused his attention in designing the large (3,000-ft-long) CLP test loop.

3. Coal Log Manufacturing

During the last 6-1/2 years, several promising ways to fabricate good coal logs have been investigated. These include binderless underwater extrusion, hot-water compaction of binderless, high-strength coal logs, making hydrophobic coal logs and so forth. Seven faculty members (Butler, Gunnink, Lin, Luecke, Marrero, Miles and Wilson), two post-doctoral fellows (Ding at UMR and Li at UMC), four visiting scholars (Yu Lin of the Southern Metallurgic Institute in Ganzhou, Jiangxi China; Kyoung-Hoon Rhee, Assoc. Prof. of Civil Engr., Chonnam Nation University, Korea; Jihuai Xu and Zhengwang Li of the Central Coal Mining Research Institute, Tangshang, Hebei, China), three research associates (Burkett, Smith and Lin) and more than twenty students worked in this area during the last 6-1/2 years.

This area has been given the greatest emphasis in the last three years due to its practical importance and insufficient previous knowledge and know-how in making good, economical coal logs. As a result of this intensive effort, Gunnink's group in Civil Engineering has succeeded in developing a hot-water drying process to produce binderless logs that maintain strength in high-pressure water and that have passed an abrasion resistance test (Ref. 11 & 12). Lin's group in Mechanical Engineering was able to extrude binderless logs that retain strength in high-pressure water (Ref. 13). Marrero/Burkett's group in Chemical Engineering has succeeded in extruding good logs using a large ram-extruder installed in 1993 (Ref. 14). Wilson/Ding's group (UMR Mining Engineering) has succeeded in making water-resistant, durable coal logs at low (less than 80 °C) temperature with no more than 2% emulsified asphalt or Orimulsion--a low-cost substitute for emulsified asphalt (Ref. 15). Liu and Lin have demonstrated that the strength of binderless logs made at room temperature can be increased 50% by neutralizing the zeta potential (Ref. 16). Luecke/Smith/Bahr have demonstrated that good quality coal logs can be made with fast compaction and with little excess water. And Li's

group has demonstrated that much better coal logs can be produced by either using a solid lubricant to lubricate the mold, or by treating the mold with a special surface conditioner. A theory has also been proposed with equations derived to predict the behavior of compaction of coal logs in a cylindrical mold (Ref. 17). During the 7th year (current year), research in coal log manufacturing resulted in the development of a 3-D model to predict the variation of density and stresses in any coal log under compaction, and when the log is being ejected. This theory enables the optimization of mold design and prediction of the properties of coal logs before they are compacted. It has great practical values.

4. Coal Log Water Absorption

During the first two years of the Center's operation, three methods of coal log surface treatment were investigated: using coal/water slurry to seal the surface pores of dry logs (Ref. 18), impregnating coal log surface with an impermeable material such as wax or asphalt (Ref. 19), and heat treatment of coal log surface (Ref. 20). All three methods did not result in a practical way of treating dry logs. Consequently, this area of research was abandoned, and efforts were directed towards making coal logs that are already saturated with water so that upon entry into pipe, the logs will not absorb additional water and hence are able to maintain their strength and integrity. The new approach turned out highly successful, and it forms the basis of current practice. This approach has resulted in a U.S. patent. The effect of water pressure on coal log quality has been studied.

5. Coal Log Machine Design

Conventional briquetting and extrusion machines cannot make coal logs fast enough for commercial CLP transportation of coal. It was important that a special machine be designed to make good logs at a fast rate so that the number of machines required to supply a single pipeline can be kept to a minimum. Dr. Yuyi Lin, Associate Professor of Mechanical and Aerospace Engineering, with the help of three graduate students, successfully designed a rapid-compaction coal log machine (Ref. 21). The machine design focused on compaction rather-than extrusion. The design was revised several times as the coal log compaction process continued to evolve. The final designs were based on two concepts: hydraulic press and rotary press. Both designs were reviewed by outside consultants, before final revisions were made. Note that the hydraulic press is considered the first generation coal log machine for commercial use, whereas the rotary press is considered the second generation.

During Year 7, the CPRC-designed coal log compaction machine was constructed by the Gundlach Company with Flo-Products as the principal subcontractor. The machine performance was tested and researchers determined that it met design objectives, especially in terms of speed and maximum force. A coal material feeder and coal log removal device was manufactured and installed. Log removal devices included a slide, soft-landing chute and conveyor belt. The machine was designed to produce one coal log in every 20 seconds. Tests conducted this year will help researchers obtain important data needed for improvement of the rotary press--the second generation machine. Other machine design research involves

investigating the optimum shape of molds and pistons (punches) used for compacting coal logs, and the best material that the molds and pistons should be made of.

6. Automatic Control of CLP System

Automatic control is a must for CLP systems. Operation of any future commercial CLP system, including the injection, pumping and ejection of coal logs, can best be controlled by a centralized computer called SCADA (Supervisory Control and Data Acquisition) system interacting with microprocessors or small computers scattered at different locations to control individual components such as a booster station or an injection station. Because coal log pipelines operate quite differently from ordinary liquid or gas pipelines, the control hardware and strategies are also different. This calls for the design of special hardware and software for the control of CLP systems.

It should be realized that proper control of a CLP system depends not only on proper use of signals derived from transducers and use of computers, it also depends on a good knowledge of the hydrodynamic behavior of coal logs and the flow. Some hydrodynamic equations must be included in the computer software for controlling the coal log pipeline. For this reason, the hydrodynamic group and the control group members have been working closely together in their research. Dr. Satish Nair, Associate Professor of Mechanical and Aerospace Engineering (MAE), led the automatic control research area.

Major accomplishments in this area of research during the last 61/2 years include the completion of three reports on automatic control of CLP (Ref. 22-24), and the construction of a computer-controlled, automated CLP system in the laboratory which has proven to work very well. A coal log train separator was also designed and tested successfully in 1995. Work during Year-6 focused on designing the control system for the CLP pilot plant—the 3,000-ft pipe loop.

7. Legal Research

The legal research is to identify legal and institutional obstacles that may impede the future implementation of coal log pipelines, and to suggest ways to remove or reduce such obstacles. Subjects under legal research include water rights, eminent domain rights, the right to cross railroads, conversion of ordinary oil or gas pipelines to coal log pipelines, and others. Dr. Peter Davis, MU Professor of Law, directed this research. Good progress has been made (Ref. 25). A Legal Manual of Practice on Coal Pipelines was prepared (Ref. 26). Due to much money spent on equipment and facilities in Years 5-7, legal research was discontinued.

8. PCP Research

During the current (7th year), research has been initiated on PCP (Pneumatic Capsule Pipeline). PCP is an existing technology with limited success in commercial use in Japan. The main problem with the current PCP systems is their cost effectiveness when compared with truck and other competing transportation modes. CPRC has discovered that the cost

effectiveness of PCP can be greatly enhanced by increasing the throughput of PCP. The throughput can be increased several times by using a LIM (Linear Induction Motor) based propulsion system and off-line loading/unloading. A totally new (revolutionary) PCP system is being investigated at CPRC based on LIM and off-line loading/unloading. The project is sponsored jointly by the Sumitomo Metal Industries, Ltd. in Japan, and the Mid-America Transportation Center. The current (7th year) work is focused on deriving the equations for predicting the behavior of the new PCP system., and design optimization. Good progress has been made in these areas.

C.2. Non-Core Program (1st 7 Years):

1. Economic Research

A rigorous study has been completed on the economics of coal log pipeline (CLP) as compared to other freight transportation modes including truck, train and slurry pipeline. The study resulted in a detailed report. This report defines unit cost as the cost of transporting a ton of coal for any prescribed distance in $/T (dollars per ton), and it includes not only capital and operational costs, but also a built-in profit for the investor. The unit cost of coal log pipeline can be compared with the current tariffs for coal transportation charged by railroad, truck and other competing modes to determine whether it is economically competitive in a given situation. The study was conducted for different transportation distances and throughputs. Based on this comparison, conditions are established under which coal log pipeline is more economical than slurry pipeline, truck and train. An abbreviated version of this report is published in 1998 in TRANSPORTATION RESEARCH (A), an Elsevier Science published journal.

The economics of coal log pipeline is not only an important subject itself, it also affects the direction of technical research and developments. For instance, in a study completed by Liu et al. in 1993 (Ref. 27), it was found that the economics of CLP depends greatly on the amount of binder used in fabricating coal logs. The binder amount must be less than approximately 3% by weight or else the coal logs produced would not be economical in many situations. Based on this finding, the coal log manufacturing research was adjusted to making logs with less than 2% binder, or better yet without any binder--the binderless process. Also, a low-cost binding (Orimulsion) was identified as a substitute for asphalt emulsion.

The 1995 economic model has been used by Williams Technologies, Inc., for analyzing potential commercial projects of CLP. This constitutes an important technology transfer to industry.

2. End-of-Pipeline Study

At the power plant end of a CLP, how should coal logs be handled (i.e., dewatered, dried, crushed, stored and transported within the power plant), and how should the effluent water be treated before it is discharged into natural streams or reused at the power plant, are matters of strong interest to utility companies. This research was supported by a Non-Core

contract from EPRI (Electric Power Research Institute); the research was completed in 1992. A report was issued (Ref. 28), and key findings of this study were published and reported at technical conferences (Ref. 29-30). Dr. John Wilson and Dr. Thomas Marrero were co-directors of this project. Additional research to determine how to best treat the effluent water from coal log pipeline was completed by two Environmental Engineering students supported by the Patricia Robert Harris Fellowship, U.S. Department of Education (Ref. 31 and 32). During the 7th year, a UMR student (Nicole Pagano) completed an M.S. research on the CLP effluent water treatment.

3. Rationale for Non-Core Program (1st 7 Years)

The Non-Core research projects are closely tied to the Core program, and in certain cases, they coincide with the goal and tasks of the Core program. They provide additional support to needed research, development and technology transfer (RD&T) activities of the Center. The only reason they are called **"Non Core"** is their funding mechanism. Instead of being four-year support such as provided by NSF, the State Department of Economic Development (MDED) and industry (the CLP Consortium), the Non-Core projects are short-term grants or contracts of lesser amounts than each Core contribution. Nonetheless, they are as valuable as Core program on a per-dollar basis.

Two Non-Core projects completed during the first two years of operation of the Center are a two-year grant of $80,000 from the Energy Related Inventions Program, U.S. Department of Energy **(DOE)**, to study the economics and commercialization of CLP, and an 8-month contract from the Electric Power Research Institute **(EPRI)** to study handling of coal logs and treatment of effluent at power plants--the so-called **"End-of-Pipeline Study."**

The DOE Energy Related Invention grant expired on July 1, 1992. A final report was submitted near the end of 1992. The three tasks of this project were: (1) improving coal log fabrication so that adequate logs can be made with less than 8% binder, (2) constructing and demonstrating a small model of the most promising injection system for coal log pipeline, and (3) conducting an economic analysis of coal log pipeline--improve/revise the 1990 economics report. All three tasks were successfully completed by January 1, 1993.

The EPRI grant (End-of-Pipeline Study) was to investigate the handling and treatment of coal logs reaching a power plant from a pipeline, including dewatering, crushing, drying, grinding and storage. Also investigated was the effluent water quality at the plant and how to treat the effluent water in order to meet EPA standards for discharge into streams and to meet utility standards for reuse of the water at power plants. The project was completed in January 1993.

The Non-Core projects are also closely tied to the technology transfer program of the Center. For instance, the demonstration of a small coal log pipeline system and the economic study mandated by the DOE Energy Related Invention project are a must for technology transfer. One cannot transfer a technology unless and until it is demonstrated at least at small

scale and the economics of the system is known at least approximately. The end-of-pipeline study is needed before one can transfer the technology to electric utilities.

A third Non-Core project was funded by DOE Pittsburgh Energy Technology Center in August 1993. This project provides additional money to study the same areas of the Core Program listed before, plus research in the economics of CLP. Also, in 1993 the Center was awarded by the U.S. Department of Education two fellowships called the Patricia Robert Harris (PRH) Fellowships. The fellowships were awarded to two Civil Engineering students, (Allison Hjelmfelt and Lauren Abbott Garber, both majoring in environmental engineering). They conducted research on different aspects of the treatment of CLP effluent at power plants, and received M.S. degrees in May 1995. Finally, during the current (7th) year, a new non-Core project was initiated. This is the PCP study described before sponsored by the Mid-America Transportation Center (MATC). As shown in Table 3, the total funding from non-core projects received in the past 6-1/2 years is $621,442. Other proposals totaling about 1.8 million dollars have also been submitted which may result in additional Non-Core projects before the end of the 7th year--see Table 4.

Table 3. Non -Core Projects During First 7 Years of CPRC (9/1//91-8/31/98)

Project Title	*Sponsor*	*Periods*	*$ Amount*
Coal Log Pipeline System Development	DOE Energy Related Inventions Program	8/24/90-6/30/92	80,000
End-of-Pipeline Study	Electric Power Research Institute (EPRI)	1/13/92-12/31/92	50,000
Used Energy Related Lab Equipment DE-FGOG-93RL12514	DOE	1/23/93-1/22-94	1,997*
Used Energy Related Lab Equipment DE-FG21-93MC30110	DOE	1/21/92-2/21/94	6,400*
Used Energy Related Lab Equipment DE-FG09-93SR183-09	DOE	1/15/93-1/15/94	1,620*
Used Energy Related Lab Equipment DE-FG06-93RL 12571	DOE	1/22/92-12/21/93	4,060*
Consortium for Coal Log Pipeline Research	DOE Pittsburgh Energy Technology Ctr.	8/10/93-8/9/96	218,000
Patricia Robert Harris Fellowships	U.S. Department of Education	1/1/84-12/31/89	210,000
Advanced PCP System for Transporting Freight –Phase 2 Study	U.S. Department of Transportation Mid-America Transportation Center	10/1/98-9/30/99	49,365
		Total	621,442

*Acquisition Cost & In-kind contribution

Table 4. Pending Proposals of CPRC (Non-Core Projects)

P.I.	Title	Agency	Amount $	Date Submitted
Liu/Blase/Maynard	Grain Pipeline Feasibility Study	USDA	71,021	1/30/98
Marrero	Modular Portable Compaction System for Biomass	MDNR	125,000	2/27/98
Liu/Marrero	Compacting Biomass and Municipal Solid Wastes to Form an Upgraded Fuel	U.S. DOE	1,500,000	3/2/98
COMPACTCONSULT & CPRC (as independent research partner)	Small Business Innovation Research Program Proposal "High-Pressure Mobile Press for Compacting Solid Wastes"	U.S. DOE	75,000	4/20/98
	TOTAL		**1,771,021**	

C.3. Projects for Year 7 (9/1/97-8/31/98):

The projects for Year 7 are listed in Table 5. Details of each project are given in Appendix 1.

Table 5. Projects for Year 7 (9/1/97-8/31/98)

Project Title	P.I. (Last Name)	Purpose
Coal Log Manufacturing Machine	Lin	Test a coal log machine for rapid production of 5.4-inch diameter coal logs. Design other machines.
Design Coal Log Pipeline	Lenau	Design a 6-inch-diameter, 3,000-ft-long pipeline to test coal logs.
Coal Log Compaction Scale-Up	Wilson	Fabricate and test 5.4-inch-diameter coal logs to scale up results based on 1.9-inch- diameter coal logs.
Rapid Compaction of Coal Logs	Gunnink	Demonstrate ability to produce good-quality coal logs very rapidly--in less than 5 seconds. Study rapid compaction.
Slope and Bend Effect on Coal Log Train	Liu	Derive equations for predicting coal log train behavior in CLP with bends and slopes.
Polymer Drag Reduction in CLP	Miles/Marrero	Investigate polymer drag reduction.
PCP-LIM	Liu/O'Connell	Design a more effective PCP system to enhance commercial competitiveness.
Optimization of Coal Log Compaction	Marrero	Optimizing four key parameters in coal log compaction.

C.4. Projects for Next (8th) Year (9/1/98-8/31/99):

The planned projects for the next (8th) year are described as follows:

1. Manufacturing and Testing 5.4-Inch-Diameter Coal Logs

The long awaited machine that can rapidly produce 5.4-inch-diameter coal logs is in place and tests are being conducted to perfect the production of coal logs. The quality of the coal logs produced will be assessed by first circulating them through the 6-inch-diameter, 320-ft-long pipe in Rolla, and later through the 3,000-ft-long pipe loop to be built on the Holstein Farm in Columbia. The weight loss of the coal logs will be measured as a function of the number of cycles recirculated through these pipes. Faculty who will use this new facility for coal log research include Yuyi Lin, Brett Gunnink and Bill Burkett. Professor Lin and his students will use this new facility to test the performance of this new coal log machine. Professor Gunnink and his students will use this new machine to study fast compaction. And, Mr. Burkett with students will run miscellaneous tests with this machine and compare results with those obtained in Rolla loop and the small (2-inch-diameter) UMC loops. Furthermore, if the biomass compaction proposal submitted to DOE under DOE Grand Challenge on Biofuel is funded by DOE, Professor Henry Liu and Tom Marrero will also be using the new coal log machine for biomass compaction.

A parallel study will be conducted at the University of Missouri-Rolla using the 6-inch-diameter, 320-ft-long pipeline loop to test the coal logs fabricated by the new machine in

Columbia. The Rolla study is to be headed by Dr. John Wilson, Professor and Chairman, Mining Engineering Department.

The 6-inch-diameter pipeline test at the Field Station in Columbia will use coal log trains with a maximum of 100 logs in each train. Due to the long and relatively straight pipe and the absence of jet pumps in the system, the tests will provide realistic coal log wear rates equivalent to those of future commercial CLP of the same diameter. Tests will also be conducted on the various factors affecting coal log quality, including mold exit shapes, mold interior materials, compaction pressure, back-pressure during ejection from mold, lubricants, etc. All these tests require a large number of coal logs. The new coal log machine at the Pilot Plant in Columbia can produce a large number of coal logs in a short time for these tests.

Close coordination will be maintained between the Columbia team and the Rolla team so that there will be no duplication of work.

2. Compacting Solid Wastes and Biomass

Different solid wastes (including municipal solid wastes, flyash, bottom ash, and water treatment plant sludges) and different biomass materials (including sawdust, wood chips, alfalfa, soybean hull and chickweeds) will be compacted by both a small (1.9-inch-diameter) mold and a large (5.3-inch-diameter) mold, and the results will be compared. The logs produced will be subjected to both dry tests and wet tests. The dry tests include drop tests, tumbling tests, and tensile and compressive strengths tests. The wet tests include water absorption test (in 500 psi water) and wear test (circulation test). This study will be conducted if DOE funds the Grand Challenge proposal on biomass fuel.

3. Design of Coal Log Manufacturing Plant

A hypothetical commercial coal log manufacturing plant that can produce sufficient quantity of coal logs to supply an 8-inch-diameter coal log pipeline will be designed. The system will include not only coal log compaction but also preparation of coal such as crushing, screening, mixing, heating and conveying within the plant. The capital cost and operation/maintenance cost of the system will also be determined. Dr. Yuyi Lin, Associate Professor of Mechanical and Aerospace Engineering, will be in charge of this project with the help of one research assistant.

4. Design of Injection and Pump Bypass

The injection and pump bypass systems of a hypothetical commercial 8-inch-diameter coal log pipeline will be designed. The system will include not only hydraulic calculations but also selection of pumps, valves, valve actuators, Y-joints, diverts (inverse Y-joints), and so on. The capital and operation/maintenance costs of the system will be determined. Dr. Charles W. Lenau, Professor of Civil Engineering, will be in charge of the project.

5. Hydrodynamics of Coal Log Pipeline

Continued research is required to explore areas of hydrodynamics of CLP hitherto unexplored or insufficiently explored. These include coal log train behavior in pipe, effect of pipe slope and curvature on coal log train, and prevention of jamming. Tests will be carried out both in a 2-inch-diameter pipe loop in the Hydraulic Laboratory, and in the 6-inch-diameter 3,000-ft-long pipeline at the Holstein Farm. Comparison of the results obtained in these two different sizes of pipe will allow determination of our ability to scale up results so that what will happen in large commercial systems of CLP can be predicted. Dr. Henry Liu, Professor of Civil Engineering, will head this research with the help of two students.

6. Drag Reduction Study

Although CPRC has established the effectiveness of drag reduction in HCP by using Polyox, it was not possible to determine the degradation rate of Polyox in HCP because the current facilities (both the 2" and 8" pipelines) are too short. With the new pilot-plant CLP, the Center will conduct Polyox degradation tests in the 3,000-ft-long pipe.

7. Market of CLP

Increased efforts will be made to determine the market of CLP, and to contact potentials users of CLP for possible sponsorship of the Center's R&D. Mr. Terry Maynard, currently with the University of Missouri Business School, will be in charge of this effort. His involvement will allow the Director (Henry Liu) and the Associate Director (Tom Marrero) to have more time devoted to R&D and other technical matters.

8. Pneumatic Capsule Pipeline (PCP)

The PCP research is focused on the use of linear induction motor (LIM) to improve the operation of PCP. Tasks during the current year include: (1) derive the equations that govern the use of LIM in PCP, (2) use the equations derived to analyze and optimize PCP-LIM, (3) design an efficient PCP-LIM for testing. The tasks for the next year are laboratory tests of a PCP model, and cost analysis of the PCP-LIM system. Professor Bob O'Connell with the help of one electrical engineering student will conduct the laboratory tests, whereas Professor Henry Liu will do the system design and economic evaluation. Liu and O'Connell will collaborate closely in this project.

C.5. Publications and Intellectual Properties: 7th Year (9/1/97-8/31/98)

During the current (7th) year of operation of the Capsule Pipeline Research Center, numerous publications resulted. They are listed below:

1. Theses/Dissertations and Student Papers:

Kuhlman, G.S., Polymer Slurry Drag Reduction in Capsule Pipelines, M.S. Thesis, Department of Chemical Engineering, August 1998, (Adviser: Thomas R. Marrero).

Li, W., Progress in Faster Compaction of Coal Logs, M.S. Thesis, Department of Civil Engineering, University of Missouri-Columbia, August 1998, (Adviser: Brett W. Gunnink).

Li, W. and Gunnink, B.W. "Fast Compaction of Coal Logs," Proc., State/Industry University Cooperative Research Center Symposium, University of Oklahoma, Norman, Oklahoma, September 3-5, 1997, pp. 2-8 to 2-15.

Pagano, N., Coal Log Pipeline Wastewater Evaluation and Treatment Alternative Evaluation, M.S. Thesis, Department of Mining Engineering, University of Missouri-Rolla, December 1997, 65 pages, (Adviser: John W. Wilson).

Pagano, N., "Coal Log Pipeline: Effluent Treatment Handling and Discharge," Proc. of State/IUCRC Symp., University of Oklahoma, Norman, OK, Sept. 3-5, 1997, pp. 2-16 to 2-19.

Wen, G., Ph.D. Thesis, Finite Element Modeling and Machine Design for Powder Compaction in a Cylindrical Mold, Department of Mechanical and Aerospace Engineering, University of Missouri-Columbia, May 1998, 259 pages, (Adviser: Yuyi Lin).

Wilkinson, J. E., Optimization of Pressure, Moisture Content, Binder, and Particle Top Size on Coal Log Compaction, M.S. Thesis, Department of Chemical Engineering, University of Missouri-Columbia, August 1998, 100 pages, (Adviser: Thomas R. Marrero).

Wilkinson. J.E., and Marrero, T.R., "Optimizing Pressure, Moisture Content, Binder, and Top Particle Size on Coal Log Compaction," Proc., State/Industry University Cooperative Research Center Symposium, University of Oklahoma, Norman, Oklahoma, September 3-5, 1997, published 1998, pp. 2-20 to 2-23.

Wu, G., Drag Reduction in Large Diameter Capsule Pipeline, Ph.D. Thesis, Department of Mechanical Engineering, University of Missouri-Columbia, August 1998, 280 pages, (Adviser: John B. Miles and Henry Liu).

Wu, G. and Xu, J., "Drag Reduction in Large-Diameter Hydraulic Capsule Pipelines," Proc. State/Industry University Cooperative Research Center Symposium, University of Oklahoma, Norman, Oklahoma, September 3-5, 1997, published 1998, pp. 2-24 to 2-32.

Yates, C., "Compacting Biomass and Other Materials to Produce Power Plant Fuel: A Preliminary Investigation," Proc., State/Industry University Cooperative Research Center Symposium, University of Oklahoma, Norman, Oklahoma, September 3-5, 1997, pp. 2-33 to 2-39.

Zhao, B., "Experimental Studies on Commercialization of Coal Log Pipeline Technology," Proc., State/Industry University Cooperative Research Center Symposium, University of Oklahoma, Norman, Oklahoma, September 3-5, 1997, pp. 2-40-2-48.

2. Faculty Publications (in Journals and Conference Proceedings):

Gunnink, B.W. and Li, W., Progression in Rapid Compaction of Coal Logs for Freight Pipelines," Proc. of the 23rd International Technical Conference on Coal Utilization and Fuel Systems, Clearwater, Florida, March 1998, pp. 901-910.

Lin, Y. and Liu, H., "Electrokinetic Properties of Coal on the Quality of Compacted Coal Logs," Proc., 2nd Int. Conf. on Material Handling, Beijing, China, pp. 606-610, October 20-22, 1997.

Lin, Y.Y., Liu, H., Wen, G., Burkett, W., and Zhengwang, Li, "Test of a New Machine to Compact Coal, Coal Fines and Solid Wastes," Proc., 23rd International Technical Conference on Coal Utilization and Fuel Systems," Clearwater, Florida, March 1998, pp. 923-931.

Lin, Y.Y., Xue, K. and Shen, Y., "DFM Case Study in Research and Development Environment," Proc., National Manufacturing Week Conference '98, March 16-19, 1998, pp. 13-19.

Lin, Y.Y. and Marrero, T.R., 1997, "An Innovative Rotary Press Design for Compaction of Large Objects," Proc., 25th Biennial Conference, Institute of Briquetting and Agglomeration, October 1997, Charleston, South Carolina, pp. 1-11.

Lin, Y.Y., Marrero, T.R., Xue, K., Zhang, M., 1997, "Research and Design of a Rotary Press for the Fast Compaction of Powdered Materials," Proc., 2nd International Conference on Material Handling, April, Beijing, China.

Lin, Y.Y. and Marrero, T.R., "Recent Results About the Compaction of Coal Logs and the Economic Feasibility for the Transportation of Coal by Pipeline," Proc., 14th Annual Pittsburgh Coal Conference and Coal Utilization Symposium, Taiyuan, People's Republic of China, September, 1997.

Lin, Y.Y., Marrero, T.R., Xue, K., Zhang, M., "Research and Design of a Rotary Press for the Fast Compaction of Powdered Materials," Proc., 2nd International Conference on Material Handling, Beijing, China, October, 1997, 5 pages.

Lin, Y. and Liu, H., "Electrokinetic Properties of Coal on the Quality of Compacted Coal Logs," Proc., 2nd Int. Conf. on Material Handling, Beijing, China, October 20-22, 1997, pp. 606-610.

Liu, H. "Capsule Pipeline Research at University of Missouri-Columbia Under an NSF State/IUCRC," International Conference on Engineering Education (ICEE-98), Rio de Janeiro, Brazil, August 17-20, 1998, accepted for publication in proceedings, 12 pages.

Liu, H. "Pipeline Engineering Research and Education at Universities in the United States," International Conference on Engineering Education (ICEE-98), Rio de Janeiro, Brazil, August 17-20, 1998, accepted for publication in proceedings, 15 pages.

*Liu, H., Gandhi, R.L., Carstens, M.R. and Klinzing, G., "Freight Pipelines: Current Status and Anticipated Use," (Report of ASCE Task Committee on Freight Pipelines), ASCE Journal of Transportation Engineering, Vol. 124, No. 4, Jul/Aug. 1998.

**Liu, H. "Pipelining in the 21st Century," No-Dig Engineering Journal, 1st Qtr., Vol. 5, No. 1, May 1998.

*Liu, H., Noble, J. S., Wu, J. P. and Zuniga, R., "Economics of Coal Log Pipeline Transporting Coal," Transportation Research (A), Vol. 32A, No. 4, Elsevier Science Publication, May 1998.

Liu, H. and Marrero, T.R., Coal Log Pipeline Project: An Update," Proc., Ninth Internl. Freight Pipeline Society Symposium, Monterrey, Mexico, April 21-23, 1998, CD-Rom publication, MEXprogm.pdf file, Session 10-1 C, 6 pages.

Liu, H., "Six Years of Progress at the Capsule Pipeline Research Center," Proc., State/Industry/University Cooperative Research Center Symposium, University of Oklahoma, Norman, Oklahoma, September 3-5, 1997, published 1998, pp. 2-1 to 2-7.

Liu, H. "Pipelining in the 21st Century," Invited Keynote Address, Second Annual Conference on Pipeline Design & Construction for Sewer, Water and Gas Applications, St. Joseph, Missouri, November 6-7, 1997.

Liu, H., "Coal Log Pipeline: Development and Progress," Proc. of 2nd Int. Conf. on Material Handling, Beijing, China, October 20-22, 1997, pp. 600-605.

*Liu, H. and Marrero, T.R., "Coal Log Pipeline Technology: An Overview," Powder Technology, Vol. 94, 1997, pp. 217-222.

*Liu, H. and Lin, Y., "Effect of Exit Shape of Compaction Mold on Coal Log Quality," Powder Technology, Vol. 90, 1997, pp. 267-271.

*Sun, S-H. and Marrero, T.R., 1998, "Extensible Finite Element Analysis Framework Approach for Heat and Mass Transfer Problems," Computers & Chemical Engineering (awaiting proofs).

*Sun, S-H. and Marrero, T.R., 1998, "Experimental study of simultaneous heat and moisture transfer around single short porous cylinders during convection drying by a psychrometry method," Int. J. of Heat and Mass Transfer, Elsevier Science Ltd., accepted for publication.

Wu, G., Xu, J. and Miles, J., "Polymer Drag Reduction in Large Diameter Coal Log Pipeline," Proc. of 23rd Internatl. Technical Conference on Coal Utilization and Fuel Systems, Clearwater, Florida, March 1998, pp. 889-900.

3. Internal Reports

Lin, Y.Y., Wen, G. and Xue, K., PLC Control of the 250-Ton Hydraulic Press for Rapid Compaction of Coal Logs, CPRC Internal Report 97-2, December 22, 1997, 57 pages.

Wilbur, James G., Practical Conveying Systems for Biomass, May 6, 1998 (Adviser: Thomas R. Marrero).

Wilkinson, Jonathan, Performance of the 2-Inch Diameter (#2) Coal Log Pipeline Test Loop, CPRC Internal Report, No. 98-2, January 1998, 15 pages (Adviser: Thomas Marrero).

York, K., "Design Analysis, Construction and Cost Estimate of an Improved Pneumatic Capsule Pipeline System," CPRC Internal Report, No. 97-3, October 1997, 4 pages (Adviser: Dr. Henry Liu). Submitted to Mid America Transportation Center.

York, K., "Fluid Mechanics of a Pneumatic Capsule," CPRC Internal Report, No. 98-3, February 1998, 18 pages (Adviser: Dr. Henry Liu).

*Refereed professional Journals

**Invited publication in trade journal

York, K., "Fluid Mechanics of a Pneumatic Capsule," CPRC Internal Report, No. 98-3, February 1998, 18 pages (Adviser: Dr. Henry Liu).

York, K., "Analysis of the Drag Coefficient Equation," CPRC Internal Report, No. 98-4, February 98, 16 pages (Adviser: Dr. Henry Liu).

York, K., "Pneumatic Capsule Acceleration," CPRC Internal Report, No. 98-5, 8 pages (Adviser: Dr. Henry Liu).

York, K., "Capsule Acceleration Inside a Linear Induction Motor (LIM), CPRC Internal Report, No. 98-6, 4 pages (Adviser: Dr. Henry Liu).

(Note: Many other internal reports are unlisted here).

4. Patents and Invention Disclosure:

Since CPRC's inception in 1991, five inventions have been made: one resulted in a patent, one in conditional patent approval, two patents are pending, and one patent is to be filed. They are:

(a) "Process for Forming Coal Compacts Without a Binder," by Henry Liu, Yuyi Lin, Thomas R. Marrero and Bill Burkett, U.S. Patent 5,658,357.

(b) "Process for Forming Coal Compacts and Product Thereof," Brett Gunnink, Zhûoxing Liang and Jayanth Kananur, U.S. Patent Application on file.

(c) "Apparatus for Forming an Aggregate Product from Particulate Material," by Yuyi Lin, Henry Liu and Yu Lin, U.S. Patent Application on file.

(d) "Apparatus for Dissolution of Powders in Liquids," by Henry Liu, Thomas R. Marrero and William Knowles, (University of Missouri rights released to the National Science Foundation).

(e) "Capsule Train Separator System for Fluid Capsule Pipeline Transportation," by Nair, S.S. and Du, Hongliu, Provisional U.S. Patent Application on file.

In addition to the above, a licensing agreement on U.S. Patent No. 4,946,317 ("Coal Log Pipeline System and Method of Operation") has been completed by Connie Armentrout, Director, Office of Patents and Licensing, University of Missouri. The agreement has been sent to the six companies that joined the CLP Consortium in 1991. The license will become effective as soon as it is signed. While one company has already signed the agreement, others are waiting until the technology of CLP is ready for commercial use before signing the agreement.

D. Comparative Analysis

In this Center, there is little difference in the nature of research between Core and non-Core projects. Both are equally important; both are equally effective. The only difference between the two types are funding mechanism. Core projects are those funded by the NSF

State I/UCRC State Matching Fund and Industry fees. The University waives overhead (indirect cost) for the Core projects. All other sources of funding such as contracts from DOE are treated as non-Core. The University charges 46% overhead to non-Core funds.

INDUSTRIAL COLLABORATION/TECHNOLOGY TRANSFER

A. General Description

There are three types of companies supporting the Capsule Pipeline Research Center: those that provide financial support (cash) to the Center, those that provide in-kind contribution, and those that contribute both. The in-kind service is usually in the form of providing needed equipment or special services for research, development or technology transfer (R, D &T).

Several industrial participants have been involved in the Center's R, D &T during the current year (9/1/97-8/31/98). They are described as follows:

The Williams Pipe Line Company (WPL) Company helped CPRC in designing the pilot plant CLP. The Company has committed to send a crew to Columbia, Missouri, to construct the pilot plant for CPRC as in-kind contribution. WPL also arranged a demonstration of a special device to grind the interior of steel pipe for future CLP use. The device was demonstrated in Tulsa, Oklahoma, by its manufacturer (CUES) in Florida. Dr. Liu attended the Tulsa demonstration. Dr. Liu found the test to be potentially useful and suggested some modifications which may lead to future collaboration with the manufacturer. WPL also assisted Center Director Henry Liu by sending John Ha as Professor-for-a-Day to lecture in Dr. Liu's pipeline engineering class.

The Williams Technologies, Inc., being the Center's Principal Consultant, reviewed the Center's R&D plans, budget priorities, and quarterly and annual reports, and provided both oral and written comments.

The Sumitomo Metal Industries, Ltd. (SMI) participated in the Center's PCP research by providing cost data for a hypothetical PCP system between Washington, D.C. and New York City. This enabled the Center to estimate the unit freight transportation cost of such a pipeline. The results suggest that such a pipeline can be quite cost competitive in comparison with train and truck. SMI pipeline manager Dr. Sanai Kosugi attended two meetings with CPRC researchers to discuss PCP research. He also reviewed three CPRC reports on PCP research, and provided detailed comments on each.

Two engineers of the TDW Pigging Products participated in CPRC research aimed at developing a special electrode (probe) to sense coal logs in pipelines. They reviewed the CPRC design and provided both oral and written comments. Furthermore, they spent a day in Columbia, Missouri to discuss this sensor with CPRC researchers. Preliminary test results of

this probe appears promising. Continued involvement of TDW Pigging Products in this project is anticipated. TDW also donated several pipeline pigs to CPRC for special use.

Note that prior to the establishment of the Center, there was little industry involvement in the R, D & T of CLP. The Center has fostered industry interest in this new technology, as demonstrated by growing industry involvement. The Center encourages industry involvement in its work, especially in areas that companies have interest and expertise. The Center's policy encourages direct contact between faculty researchers in specific areas and companies with expertise in such areas. Such contacts have been frequent. A summary of industrial participation is given in Table 6.

Since its beginning in 1991, CPRC has held two Industry Advisory Board (IAB) meetings each year, to report semi-annual progress in R&D, and to exchange opinions between Center personnel and IAB members. These meetings contributed greatly to the Center's progress in R&D, and to maintaining the long-term interest of the IAB members in the Center's work. IAB members also utilize this opportunity to discuss timely issues with each other, and provide advice to the Center Director. During the current reporting year, IAB meetings were held on both October 29, 1997 and March 31, 1998. A copy of the minutes of the latest (March 31) meeting is listed in Appendix 2. At this meeting, the IAB asked the Center Director to send each IAB member a list of materials and equipment needed for constructing the pilot-plant coal log pipeline, so that each member can determine whether his (her) company can contribute anything on the list. Following the meeting, the Center Director has mailed such a list to all IAB members. As a response, the Senior Vice President of the Williams Pipe Line Company, Mr. Steve Ball, came to Columbia, Missouri with Mr. Dennis Turner, to determine and discuss possible help from the Williams Pipe Line Company—now reorganized as "Williams Energy Group."

B. Small Business

Small Business participants make essential contributions to the Center's research as can be seen from the following examples:

The T. J. Gundlach Company fulfilled its contractual obligations by building and delivering the 250-ton compaction press to CPRC's new Field Station 10½ miles from Campus on the University-owned Holstein Farm, near Midway. Gundlach Machine Company representative Jim Compton supervised the installation and testing of the machine. He and John Reed of Flo-Products (subcontractor for hydraulic system) reviewed all the machine's mechanical components and made adjustments as needed, working closely with the College of Engineering shop technicians. Mr. Reed supervised in programming the machine for the automatic cycle or sequence while producing coal logs. The machine was demonstrated at the March 31, 1998 Industrial Advisory Board meeting. Since then, further improvements in coal log production have been made.

Another example is COMPACTCONSULT, which provides in-kind consulting service to the Center's coal log compaction research. In a proposal submitted to the U.S. Department of Energy's Small Business Innovation Research Program, COMPACTCONSULT proposes to

design a portable coal log compaction machine. Phase I is the design of the machine based on rotary press to produce 2" diameter solid-waste pellets. Phase II calls for the construction of this mobile press which can be carried by truck to various sites to compact waste materials such as sawdust, woodchips, waste paper and tree trimmings. The press will utilize CLP developments of round-edged mold and back-pressure control to produce high-quality compacts. The manufacture of this machine will create new businesses nationwide working to reclaim wasted resources, reduce the size of landfills, and create a unlimited supply of biofuels for certain power plants. Greenhouse gas will be reduced because for each ton of solid wastes use as power-plant fuel, almost the same amount of coal is saved (not burned). Coal that is not burned can be stored underground. Unlike coal, solid wastes such as sawdust and waste papers, if left in landfills, will decay and generate greenhouse gas.

A third example is Nova Tech, Inc. in Kansas City. It has been helping the Center in the design of the automatic control system of the pilot plant CLP. No doubt this company will be involved in future CLP commercial projects, due to its unique experience.

Table 6. Industrial Participation (Year 7)

Company	*State or Country*	*Member Category*	*Company Size*			*Fortune 500*	*Joint Research Project*	*Funds to be Provided $ ($1,000)*
			Yrs. of Partic.	*Small Bus.*	*Mid Size*			
Associated Electric Coop.	MO	Principal	1-7		x		No	30
COMPACTCONSULT	FL	Sm. Bus.	5-7	x			Yes	5
T. J. Gundlach Machine Co.	IL	Sm. Bus.	2-7	x			Yes	5
Nova Tech, Inc.	KS	Sm. Bus.	2-7	x			Yes	5
PERMALOK	MO	Sm. Bus.	3-7	x			Yes	5
Pro-Mark Co.	MO	Sm. Bus.	2-7	x			Yes	5
STI International Associates	CA	Sm. Bus.	6-7	x			Yes	5
Southwestern Public Serv. Co.	TX	Principal	5-7		x		No	30
Sumitomo Metal Industries	JAPAN	Principal	6--7			x	Yes	30
T. D. Williamson	OK	Sm. Bus.	3-7	x			Yes	5
Williams Pipe Line Co.	OK	Member	1-7		x		Yes	30
Williams Technologies	OK	Member	2-7		x		Yes	15

1. Annual fees are $30,000 for Principals, $15,000 for Members, and $5,000 for Small Business.
2. Funds listed are for Core Projects
3. Not all of the funds listed in the last column have been received. They are commitments to be paid by 8/31/98—the end of the current (7th) year.
4. Names of Missouri companies are boldfaced.

C. Strategy for Membership Growth

It should be pointed out at the outset that there is substantial difference in the philosophy on membership growth between government sponsors (NSF and the State) on the one hand, and our existing industry sponsors (CLP Consortium Members) on the other. While the government sponsors want the Center to grow and have more and more new members, the general feeling of our industry sponsors is that growth should be controlled and limited so that the Center Director

and staff can concentrate on performing R&D rather than recruiting new members. Besides, too many members in a Center also becomes difficult to manage.

The Center's philosophy represents a balance between the two different positions. We feel that some growth should occur to bring in more resources to the Center so that there will be adequate resources to accomplish the stated goal of developing the CLP technology as soon as possible. Growth also allows bringing in companies with expertise in various areas to help advance the Center's research agenda. Yet, once the Center has reached the level of funding and help needed from companies to accomplish the Center's goal, we should no longer divert our energy and spend our time in fund raising or recruiting. The Center should rather concentrate on research, development and technology transfer.

Based on the aforementioned philosophy, the Center Director, Associate Director, and Dr. John Wilson at UMR have actively sought to recruit some new industry participants during the current year. The strategy used for recruiting is first to write letters or call potentially interested companies, inviting them to join. When it appears that a company has sufficient interest, the Director or Associate Director will arrange to visit the company, or preferably, invite appropriate company officials to Columbia for an on-site visit and meeting. As a result of such efforts, several additional companies have joined since the formation of the Center in 1991. This includes Erie Press Systems, Nova Tech, Pro-Mark Company, T. J. Gundlach Machine Company, Willbros Engineers, T.D. Williamson, Inc., Permalok, Gifford-Hill-American, Inc., and STI International. Several others are actively considering to join either during the current year or next year. A complete list of Year-7 participants together with the fees received is given in Table 6. Because this report is submitted to NSF four months before the end of the current year, the list in Table 6 may be incomplete. A more complete list will be sent to NSF in August, 1998, toward the end of this reporting year.

The Electric Power Research Institute (EPRI) also has been helping the Center to recruit some utility companies to support the Center under a Tailored Collaboration (TC) Program. In January 1997, EPRI sent an announcement (Host Utility) to its members (over 1000 utilities) informing them about the CLP technology and inviting them to participate in a TC project on CLP—the pilot plant study. This resulted in a few inquiries and one willing participant—Arkansas Electric Cooperative. However, a long delay has been encountered in implementing the EPRI-TC project.

Recruitment for new members will be stepped up during the next 16 months for two reasons: (1) The Center's future mission for the next year will be broadened to cover not only CLP but also other types of capsule pipelines for transporting solid wastes and mail. This calls for broader supports for the Center. (2) Both NSF and the State agency supporting the Center want the Center to be self-sufficient (entirely supported by industry and government contracts) by the end of 8/31/99. This mandates a growth in industrial sponsorship. Therefore, a much stronger effort will be made during the next 16 months to seek additional industry sponsors. More proposals will also be submitted to NSF and other agencies to seek funding for special projects or new programs.

D. Industry Use of Research Findings

Because coal log pipeline is a not-yet-fully-developed (emerging) technology, industry is yet unable to use this technology for coal transportation. However, all the companies participating in the Center's programs plan to use the CLP technology or benefit from its use once it is developed. Some are already using the knowledge gained from collaborating with CPRC; others are benefiting from association with CPRC.

For instance, the Williams Technologies, Inc. (WTI) has been using the economic model developed by the Center's research program to evaluate the economic feasibility of potential CLP commercial projects. This can grow into an important new consulting business for WTI. Also, those electric utilities which are long-term supporters of the Center's CLP research are enjoying the lowest coal transportation tariff in the nation offered by railroads. A possible factor contributing to this low rate is railroads keeping the tariff low so that these Missouri companies will not switch to CLP. Small business participants are also using the knowledge they gained in CLP as described in the previous section.

Moreover, some spin-off has occurred. The knowledge CPRC generated in coal log compaction and the new compaction machine developed are being considered by many companies interested in solid waste compaction. For instance, COMPACTCONSULT, a Small Business Participant of CPRC, has submitted a proposal to the U.S. Department of Energy to build and test a portable (truck-mounted) solid waste compactor using the 2-inch-diameter log rotary press designed by CPRC. A major pipeline company, headquartered in Atlanta, Georgia, is considering to use an existing petroleum product pipeline to transport other types of freight by using capsules. Finally, a company in Florida is attempting to perfect a custom -built mobile pipe interior grinding system for coal log pipelines.

Another spin-off involves the use of Polyox for drag reduction. The Center has developed a vacuum dissolution technique to inject powdered Polyox into pipeline which greatly enhances the state-of-the-art. It can be used not only for CLP but also for other liquid pipelines. A patent is being pursued on this vacuum dissolution technique. This new invention may find many applications in the power industry.

A summary of technology-transfer-related activities during the 7th (current) year is given in Tables 7 & 8. More details are listed in the next section, **E. Technology Transfer Activities of Year 7.**

Table 7: Quantitative Center Outputs and Outcomes in Technology Transfer (Year 7)

Spin-off companies started:	0
Inventions disclosed:	0
Patent applications filed:	4
Patents granted:	1
Patent licenses:	5
Software licenses:	0
Copyrights:	0
Research developments (1)	8
Transfer developments (2)	5
Commercial developments (3)	3

(1) Indicate the number of important research developments during the past year, and provide a brief summary description in Section 5.a in the report.
(2) Indicate the number of events involving transfer of knowledge, processes or technology to industry and provide a brief summary description in Section 5.a in the report.
(3) Indicate the number of significant commercial developments during the past year, and provide a brief summary description in Section 5.a in the report.

Table 8: Quantitative Data on Special Technology Transfer Activities (Year 7)

Company Name	Size L/M/S	Foreign (Y/N)	FS (1)	FI (2)	IC (3)	JP (4)	LS (5)	LT (6)	GH (7)	SS (8)	TB (9)	PA (10)	OT (11)
COMPACTCONSULT	S	N	--	--	1	1	--	--	--	--	--	--	1
Gundlach Machine Co.	S	N	3	1	2	1	--	--	--	2	1	1	--
Nova Tech, Inc.	S	N	--	--	1	1	--	--	--	--	--	--	--
Southwest Public Serv. Co.	L	N	2	--	--	--	--	--	--	--	--	--	--
Sumitomo Metal Ind. Ltd.	L	Y	--	1	2	1	--	--	--	--	--	--	1
TDW Pigging	M	N	1	1	2	--	--	--	--	--	--	1	--
Williams Pipe Line	L	N	2	1	--	--	--	1	--	--	--	--	2
Williams Technologies	M	N	--	--	--	--	--	1	--	--	--	--	--

(1) Faculty on Site at industry
(2) Faculty Instruction to industry
(3) Individual on Campus from industry for more than just advisory board meetings
(4) Joint Projects with Center personnel
(5) Licensed Software
(6) Licensed Technology (other than software)
(7) Graduate Hired by industry
(8) Student on Site at industry
(9) Used Center's TestBed or developed a tesbed to try center-developed technology
(10) Developed Prototype of Application of Center-developed technology
(11) Other Technology transfer (explain in Section 9 of annual report)

E. Technology Transfer Activities of Year 7 (9/1/97 to 8/31/98)

Technology transfer activities have been conducted by various methods. The following list organizes these activities according to: (1) direct contact, (2) specific publications, and (3) general publications, including computer internet.

DIRECT CONTACTS:.

◊ (Pittsburgh, PA, 9/5/97), Dr. Thomas R. Marrero participated in a workshop entitled, "The United State Department of Energy's Solid Fuels & Feedstocks Program—Are We Servicing Our Stakeholders?" sponsored by DOE's Federal Energy Technology Center. Dr. Marrero was invited to provide input on the Solid Fuels and Feedstocks program direction.

◊ (Research Triangle Park, NC, 9/15/97) Dr. Marrero visited Reichhold Chemicals, Inc. regarding possible participation in CPRC's industrial consortium. Charlie McClaskey, Vice President of Business Development declined consortium membership, but volunteered to continue providing materials and technical assistance. They also offered lab support for the formulation of dummy coal logs out of resin.

◊ (Taiyuan, China, 9/23-27/97), Dr. T.R. Marrero attended the 14th Annual International Pittsburgh Coal Conference and Workshop held in Taiyuan, Shanxi, China. He presented a paper on recent results about coal log compaction and the economic feasibility of CLP. He talked to several academic and industrial leaders about the advantages of coal log pipeline and how it could benefit China's transportation system for coal.

◊ (Columbia, MO, 9/30/97), Dr. Bob Carstens, a pioneer in pneumatic capsule pipeline (PCP), conducted a seminar on PCP design on Campus. As Professor of Mechanical Engineering at Georgia Tech University in the 1960s, Dr. Carstens conducted extensive research in PCP. He designed, constructed and tested a major test loop of PCP for the Tubexpress Systems, Inc. in Houston, Texas in the 1970s. He is also recipient of the Distinguished Lecturer Award given by the International Freight Pipeline Society. During his visit to CPRC, Dr. Carstens consulted with CPRC researchers working on a PCP project sponsored by the Mid-America Transportation Center and the Sumitomo Metal Industries, Ltd.

◊ (Muscle Shoals, AL, 10/07/97), CPRC Associate Director attended Southeastern Regional Biomass Energy Program (SERBEP) contractor's meeting for all successful proposers as required by the sponsoring organization, Tennessee Valley Authority. Dr. Marrero was asked to give a brief overview of a proposed compaction-combustion tests of biomass-coal-coke mixtures. The proposal was accepted in August, 1997, but TVA withdrew the offer November 25, 1997 because of lack of funding.

◊ (Ganzhou, China, 10/13-14/97), Dr. Liu lectured at Southern Metallurgic Institute as part of a two-week lecture tour in China. As the largest producer of coal in the world, China is particularly interested in converting coal fines into a useful fuel. The coal log machine may

help solve the problem of handling fines which currently causes pollution to their land and waters.

◊ (Taiyuan, China, 10/16-17/97), Dr. Liu conducted lectures and visited with Taiyuan University Administrators about consortium membership. The Vice Governor of Shanxi received Dr. Liu, and discussed possible collaboration in compacting coal fines and coal log pipeline.

◊ (Beijing, China, October 20-24), Dr. Liu chaired sessions and presented papers at 2nd International Conference on Materials Handling. The conference was supported by 25 professional organizations and well-known experts from more than 10 countries and regions. More than 300 delegates attended this international forum for scholars, engineers and production managers to exchange ideas, knowledge and information in the field.

◊ (Columbia, MO, 10//29/97), CPRC Director, Associate Director and faculty hosted annual Industrial Advisory Board meeting providing information about the Center's progress and future plans to sponsors and other interested parties from both industry and government offices.

◊ (Amarillo, TX, 11/3-4/97), Dr. Liu gave presentation on coal log pipeline to Southwestern Public Service Co. updating this sponsor on CPRC progress and goals.

◊ (Charleston, SC, 11/3-5/97), CPRC Senior Research Associate Bill Burkett attended the 25th International Briquetting Association Conference to learn more about briquetting procedures. The trip was most beneficial to Mr. Burkett who supervises compaction procedures in CPRC's coal log lab.

◊ (Tulsa, OK, 11/10-11/97), Dr. Henry Liu met with Williams Pipe Line Vice President Steve Ball and others to discuss CPRC progress in coal log pipeline development and discussed future support.

◊ (Carbondale, IL, 11/17-18/97), Dr. Liu and Center Analyst Terry Maynard visited College of Engineering Dean Juh W. Chen of Southern Illinois University to discuss future research collaboration and presented a seminar on coal log compaction. The State of Illinois has a need for coal log technology and had issued a public statement concerning the need for research in better management of the coal resource.

◊ (Columbia, MO, 12/4/97), Dr. Zhong (David) Xu, Professor of Mechanical Engineering at Taiyuan University of Technology (TUT), visited CPRC. He gave a seminar on his University's research program in surface technology. TUT is a major technical university of the People's Republic of China located in Taiyuan, the capital city of Shanxi. Dr. Xu was particularly interested in the Center's ability to make quality coal logs from the anthracite coal in the Shanxi province. Possible collaboration between MU and TUT was discussed.

◊ (Columbia, MO, 2/19/98) CPRC Research Assistant Kevin York spoke at an Mid-America Transportation Center (MATC) Seminar on the UMC Campus. His remarks covered the historical development of PCP technology, improving current PCP technology by developing a Linear Induction Motor (LIM), calculation of pneumatic capsule drag coefficient, and calculation of pneumatic capsule acceleration.

◊ (Columbia, MO, 3/31/98) CPRC Director, Associate Director and faculty hosted annual Industrial Advisory Board meeting providing information about the Center's progress and future plans to sponsors and other interested parties from both industry and government offices. A demonstration of the new coal log compaction machine was conducted at the CPRC Field Station after the meeting.

◊ (Columbia, MO, 4/4/98) Two engineers of TDW Pigging Products, Inc., Tulsa, Oklahoma, visited CPRC, to see a new sensor that CPRC had invented and was developing for detecting coal logs passing through pipe. The device may also be applicable for detecting pipeline "pigs." The two visitors were Dennis Smith and George Gurr.

◊ (Monterrey, Mexico, 4/22-4/23/98) Dr. Liu and Dr. Marrero attended the 9th International Freight Pipeline Society's Symposium. Dr. Liu and Dr. Marrero presented a paper. Dr. Marrero was elected president of this international organization which has a membership spanning six continents. Dr. Liu is a past president of IFPS.

◊ (Tulsa, OK, 4/28-29/98) Dr. Liu traveled to Williams Pipe Line to view demonstration of a mobile remotely operated internal pipe grinding machine Manufactured by CUES of Orlando, Florida, the machine's application to coal log pipeline was discussed. Dr. Liu found the machine to be potentially useful and suggested some modifications which may lead to future consortium collaboration with the manufacturer.

SPECIFIC PUBLICATIONS:

◊ Faculty had 23 publications in journals or conference proceedings (See Research Program, C.5, p. 29).

◊ Students had 4 M.S. theses and 2 Ph.D dissertations. (See Research Program, C.5, p. 30).

GENERAL PUBLICATIONS:

◊ In December 1997, MECHANICAL ENGINEERING, the prime magazine of the American Society of Mechanical Engineers (ASME), featured an article on the coal log machine designed by Dr. Yuyi Lin and his students. The magazine has over 100,000 subscribers.

◊ The November-December issue of PUBLIC POWER, a national magazine subscribed and read by hundreds of thousands of people in the power industry, featured an article on CPRC's

research in CLP. The article is entitled: "Getting Off the Coal Train—Coal Compaction Technology Offers New Transportation Possibilities."

◊ The April 27 issue of FEEDSTUFFS, a national farm publication based in Minnesota, published an article on the grain pipeline proposal submitted to USDA by CPRC. The article is entitled "Corn-Filled Capsules, Moving Beneath the Frost Line—University Seeks Grant to Study Grain Pipeline." The article is a boost to the proposed research.

◊ A Missouri magazine entitled IDEAS invited Dr. Henry Liu to write an article on freight transportation by pipelines. Dr. Liu wrote the article, "Not Just a Pipe Dream," which was published in the March 15 issue.

◊ The University of Missouri started a new magazine on the University's research. In its first issue, capsule pipeline research by MU faculty is featured prominently. The magazine won several national awards.

◊ CPRC Newsletter (Vol. 6, No. 1, Fall, '97): was sent to about 2,500 individuals.

F. Other Accomplishments and Contribution to Education

In addition to the aforementioned accomplishments made in research to advance the state-of-the-art of CLP and HCP, and in technology transfer to disseminate information to industry and the engineering community, during the 7th (current) year, the Center also accomplished and contributed the following:

International Exchange: Two visiting scholars from the People's Republic of China participated in the Center's coal log research. The two scholars came from the Tangshan branch of the Central Coal Research Laboratories, China Ministry of Coal Industry. The Tangshan branch has been the center of China's coal slurry pipeline research.

An additional visiting scholar, a professor from the Taiyuan University of Technology, will join CPRC in July 1998 to study coal log pipeline. A senior faculty from TUT, Professor Zhong Xu, visited CPRC in December 1997 and brought with him coal samples to compact using CPRC's log compactors. The coal was compacted successfully, and Professor Xu will lead a large delegation to visit Missouri in August 1998 to discuss Chino-America cooperation in coal log research..

Student and Faculty Participation: Due to heavy investment of the Center's resources in physical facilities (large coal log machine and a building), the number of students and faculty supported by CPRC reduced during the current year. Ten graduate students, three undergraduates, and eight faculty members, including those at UMR, have been supported by CPRC during the current year.

Education: As in the past, pipeline engineering was taught this year to 17 students. The course was linked to Kansas City by ISDN—a state-of-the-art teleconferencing system. A discussion of this course and the ISDN experience appears in a paper accepted for presentation in the 1998 International Conference on Engineering Education (ICEE). A survey of pipeline engineering education at U.S. universities also has been completed during this current year, and the survey result is described in the ICEE paper. An engineer of the Williams Pipe Line Company, John Ha, served as guest lecturer (Professor-for-a-Day) in the pipeline engineering class in March 1998.

G. Industrial Advisory Board Activities

The Center being involved in mission-oriented research relies heavily on the guidance received from its Industry Advisory Board (IAB). The IAB members consist of large, medium and small companies each contributing between $5,000 to $30,000 a year. The Chairman of the IAB is elected by members. The current Chairman is Hank Brolick, President of Williams Technologies, Inc. The Board met twice during the current year—on October 29, 1997 and March 31, 1998 in Columbia, Missouri. Past meetings were held on the following dates: 5/21/925 10/8/92, 5/18/93, 10/5/93, 5/19/94, 10/12/94, 5/4/95, 4/24/96, 10/23/96, and 4/23/97. The minutes of the latest Board meeting is attached in Appendix 2.

H. Commercialization Plan

The Center's plan for commercializing the CLP and HCP technologies is a three-prong program consisting of a **commercial demonstration project, a full-scale test/demo facility** and a **medium-size pilot plant**. They are discussed separately next.

1. Commercial Demonstration:

In 1994, the Center sent a questionnaire to all the major electric utilities and coal companies in the nation. The purpose of the questionnaire was to determine the most promising site for commercial demonstration of the coal log pipeline (CLP) technology. Each company was requested to submit one or two potential sites for consideration. The questionnaire asks many questions pertaining to the practicability of building a coal log pipeline, such as the quantity (throughput) of coal that needs to be transported, the transportation distance, whether the power plant or coal mine is currently served by railroads or trucks or not, what the current transportation tariff is, etc.

A total of 17 projects were received and evaluated. Based on a preliminary evaluation, seven projects were selected to receive further considerations. These projects were evaluated by the Williams Technologies, Inc., the Principal Consultant of CPRC and an engineering consulting firm with extensive experience in pipeline and power plant projects. Two projects were judged to be most promising. One is from the Southwestern Public Service Company (SPS), and the other from the Potomac Electric Power Company (PEPCO). Additional projects are being considered, and another round of project solicitation will be issued to find additional promising projects. Based on project economics and negotiation, a project will be selected in 1998 as the targeted CLP commercial demonstration project. The Center will then assist the company that has been selected and is willing to pay for the project, to plan and design the coal log pipeline. The Center will also assist this company (or a consortium interested in the project) to apply for possible subsidy from the U.S. Department of Energy (DOE). The Agency has indicated an interest to consider cost sharing such a project. Such subsidies will enhance the economic attractiveness of the demonstration project, and reduce the financial risk to private companies participating in the demonstration. It is planned that the final project will be selected by 8/31/98, so that planning and design can take place in 1998.

2. Full-Scale Test/Demo (Large Pilot Plant) Facility:

The Center has planned a large pilot plant (full-scale test/demo) facility consisting of a 12-mile-long, 8-inch-diameter coal log pipeline (CLP). The proposed pipeline will have all the components of a commercial CLP, including a coal log manufacturing plant, a capsule injection system, a capsule ejection system, a booster pump station (the pump bypass), and a computer system for automatic control of the CLP system. The total cost of the project, including 3 years of operation and overhead, is estimated to be $15 million.

The aforementioned large facility is needed for testing the whole system of CLP at full-scale. The facility makes it possible to obtain test data on important aspects of CLP that cannot be obtained from laboratory test of scale models of the whole system, and from testing large (full-scale) components alone. The facility can be used for testing not only CLP but also other types of HCP (Hydraulic Capsule Pipelines) for transporting solid wastes, grain and other materials or commodities. Once a special type of HCP such as CLP is tested and demonstrated in such a full-scale facility, industry will then be more willing to use or try this technology. This shows that although this is not a commercial demonstration facility, it greatly enhances the likelihood of early commercial use of CLP and HCP.

The Center plans to locate this large facility on the inactive coal mines near the Thomas Hill Power Plant in Missouri located 50 miles north of Columbia. The Associate Electric Cooperative, which owns the power plant and the coal mine, helped the Center plan this facility. The company offered to donate some land and the right-of-way for this pipeline pending detailed negotiations, but lack of funds has put this project on hold indefinitely.

3.<u>Medium Size Pilot Plant CLP</u>:

This pilot plant is being actively pursued at present. It involves: (1) an automated coal log compaction machine that can mass produce 5.4-inch-diameter coal logs at the rate of one log per 20 seconds, (2) coal preparation equipment and coal log handling equipment associated with this machine, (3) a metal building to house the equipment and machine, and (4) a 3,000-ft-long 6-inch-diameter pipeline recirculation loop CLP complete with a coal log injection system, pump bypass, coal log ejection system, and an effluent water treatment system. Parts of this pilot plant have been constructed. Items (2) and (4) will be constructed later this year when sufficient funds have been raised. A massive test program will be carried out with this facility in Year 8 to meet commercialization goals.. This is the only prong of the three prong commercialization plan that can be completed prior to the expiration of the NSF and State support for CPRC, with the resources committed by current sponsors and with expected additional donation from industry. Also the requested funding from NSF and State for the next year is increased to $300 K from each partner in order to pursue this costly project. Completion of this prong will allow commercial demonstration or use of CLP for relatively short transportation distances, within approximately 100 miles.

Note that all the three parts or prongs of the Center's commercialization plan can be pursued independently and simultaneously. They reinforce rather than duplicate each other. While the success of any one of the three prongs will lead to commercialization of CLP and HCP, having succeeded in more than one prong will speed up the commercialization process. The full-scale test/demo facility and the commercial demonstration should follow (not precede) the medium-size pilot plant.

MANAGEMENT AND STRUCTURE

The Center planning involves every researcher. Each week there is a meeting for each group such as the Hydraulics/Control Group, and the Coal Log Fabrication Group. Besides reporting on the progress made each week, the meetings also involve planning. Each researcher is required to reveal his (her) plan for the next week and for more distant future, and each group leader is required to tell the others about the group plans. All such plans are discussed and debated in details at such weekly meetings. Then the Center Director remarks on the course of action to be taken, and the responsible individuals carry out the plan according to decisions reached at such meetings.

The Center also has a carefully prepared written R&D plan which has been revised periodically, at least once a year. The Industry Advisory Board (IAB) is closely consulted in preparing and formulating the plan. The new R&D plan for Year 8 will be prepared in Summer 98.

Management issues are also often discussed at weekly meetings with faculty and students, and twice a year at the IAB meetings. The Center Director seeks advice on key management issues not only from the Associate Director but also from other Center workers, IAB Chair, industry members, government sponsors, and the Center Analyst. For matters involving University policies, the Center Director seeks guidance from the Dean of Engineering, the Engineering Research Director, the Vice Provost for Research, the Director of Sponsored Programs Administration (in matters about contracts or grants), and the Director of Patent and Licensing (in patent related matters). A "CPRC University Policy Committee" exists to guide the Center, and the Committee meets at least once a year.

The current organizational chart of the Center is given in Figure 1. The Center Director and the Associate Director share administrative duties. The Associate Director has been tremendously helpful in reducing the Director's administrative chores such as supervising laboratory and shop services, signing purchase orders, dealing with personnel problems, and recruiting industrial members. This has made it possible for the Director to concentrate on his teaching and research, planning and coordinating R&D, preparing quarterly and annual reports, writing some proposals and recruiting industrial members. An additional staff person (half-time market analyst) has been added during Year 6 to expand the Center's marketing/commercialization program—see ANALYST'S REPORT in the next section for details. The type of personnel associated with the Center, and the personnel characteristics (statistics) are reported in Table 9.

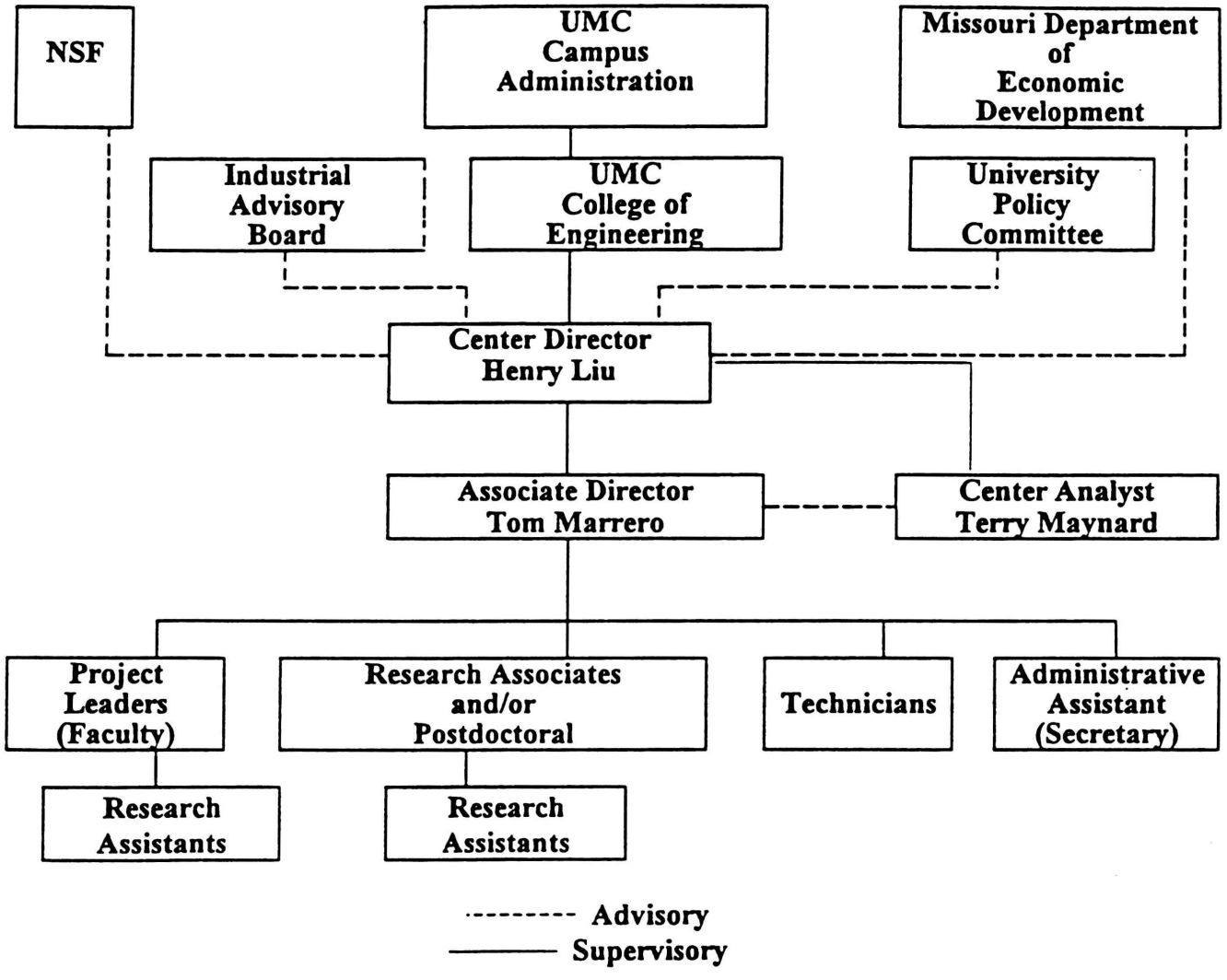

Fig. 1 Organizational Chart of Capsule Pipeline Center

Table 9. STATE/IUCR: Personnel Year 7 (9/1/97-8/31/98)

		Sex		Minority Status (1)					Disabled	Disciplines
	#	M	F	1	2	3	4	5		
Faculty	9	9	0		3		1	5	1	Engineering
Research Staff (2)	1	1	0					1		Engineering
Visiting/Foreign Faculty (2)	4	4	0		4					Engineering
Industry Researcher (4)	0	0	0							None
Post Doctoral	2	1	1					2		Engineering
Management/Administration	3	3	0		1		1	1	1	Business
Technical Staff	1	1	0					1		Engineering
Students: UG	5	3	2			1		4		Engineering
Students: MS	5	4	1		2			3		Engineering
Students: Ph.D	5	5	0		5					Engineering

(1) Designations for minority are 1-Native American; 2-Asian or Pacific Islander; 3-Black, not of Hispanic origin; 4-Hispanic; 5-White, not of Hispanic origin.
(2) Faculty level persons employed directly by State/IUCRC, not on regular faculty.
(3) Visits of 1 week or more.
(4) Industry researcher working at the Center.

ANALYST'S REPORT
CAPSULE PIPELINE RESEARCH CENTER

by Terry Maynard
CPRC Center Analyst
University of Missouri-Columbia

Role of Analyst

Starting in 1996, the Analyst of CPRC has become a half-time position with the following expanded duties: (1) to provide an objective program review and analysis on CPRC once a year with a written report included in each annual report to NSF, (2) to keep vital statistics of CPRC—the Data Base, and (3) to promote commercial interest in and commercialization of the various technologies developed or being developed by CPRC. Most of the daily activities of the Center Analyst are commercialization related activities. This year the analyst contacted industrial prospects to make them aware of Center research and the possible benefits available to them by joining the Center's industrial consortium. For instance, the analyst has helped develop interest in hydraulic capsule pipeline technology at the US Department of Agriculture (USDA), Missouri Department of Agriculture and companies such as MFA which is a farm cooperative headquartered in Columbia, MO. The fruition of the activity was the application by the Center for a Federal State Marketing Improvement Program grant from USDA. The grant will be used to assess the economic viability of grain pipelines. The Center Analyst has also worked with other companies that might be potential partners in municipal waste compaction projects and with companies that may possibly supply needed equipment and materials for completion of the coal log pilot plant.

The Analyst's commercialization duty also includes keeping the CPRC's pipeline cost model on his Personal Computer, and occasionally performing a computer cost analysis of a pipeline project of interest to any potential sponsor. In 1997, he helped the Center Director assess the cost effectiveness of a proposed PCP (Pneumatic Capsule Pipeline) to transport mail and other commodities between Washington, D.C. and New York City. The result, documented in this report, generated considerable interest in PCP in the U.S. and Japan.

The Center Analyst has reviewed the activities of the Center during the current (7th) year. What follows is an analysis of those activities.

Introduction

The Capsule Pipeline Research Center (CPRC) at the University of Missouri-Columbia is in its seventh year of operation. The accomplishments of this year were critical to the commercialization process for Coal Log Pipeline (CLP) technology. After six years, sponsors are anxious to see tangible results - coal logs that can withstand miles of travel from mine to power plant. This year the CPRC made great progress in meeting those expectations. It had a new, unique coal log compaction machine fabricated and installed in a new coal processing facility being built on University of Missouri-Columbia property near the campus. The

completion of these facilities marked the beginning of the final phases of the CLP commercialization process.

Financial Issues

The CPRC was successful in maintaining its financial situation this year through the combined efforts of the center Director, NSF, university administration, industrial partners, legislative supporters and others interested in capsule pipeline research. The state of Missouri and NSF have each contributed $250, 000 for the current fiscal year. This support, along with the commitment of the University of Missouri, should help the CPRC attract new industrial members needed for the final phases of CLP commercialization.

One member deferred payments this year because unexpected market conditions caused budget tightening. This is not the first time this has happened to this member. The last time it happened, after business conditions improved, the member renewed its CPRC commitment which included the prior payment too. Throughout the year, a number of potential new members have been contacted. Current negotiations with two of those contacted may yield significant contributions to the Center this year.

Financially, 1997 was a crucial year for Center. The Center contracted for the fabrication of a unique $260, 000 coal log compaction machine. To keep costs down, the Center designed this machine in-house. Additionally, another $280, 000 was spent to construct a building to house the new coal log compaction machine and the coal processing and research facility. So, about half of the budgets of 1997 and 1998 was committed to building the new machine and the new pilot plant building. Operations and expenses were curtailed to the bare minimum, yet, research projects were kept on schedule.

In December of 1997, the Center Director called for a review of the Center's projected income and costs over the remaining one and one-half year of the Center's operation. In particular, the review was focused on the amount of funding necessary to complete the CLP pilot plant - the first major components of which were the coal log machine and the coal log processing building. The analysis showed that the center would be short approximately $500, 000. The pilot plant would not be completed because the remaining funds would not cover the costs of purchasing and installing coal preparation and handling equipment, a 3,000 ft. pipeline, pump by-pass stations and operating control system. The Director notified NSF, the state of Missouri and the IAB members of the projected shortfall. He initiated meetings with University of Missouri-Columbia executives to see if the University could help make up the difference. He met with a major CPRC IAB sponsor to see if it would be able to support funding of the rest of the pilot plant construction. To date, there have been no definite commitments made. Tentative commitments of materials and labor have been made to help get the pilot plant pipeline completed but they fall short of the total amount needed to finish the facility so that it can be fully operational as a coal log pipeline pilot plant.

The Center has also applied for grant funds from DOE and USDA. The proposals that the Center has submitted to DOE call for the compaction of biomass waste materials by using the Center's new machine. The proposals to USDA calls for a feasibility study of grain pipelines.

Faculty Update

The Center personnel roster has remained stable. Due to budget constraints, fewer faculty and students were employed this year than anytime in the past; however, there were no unexpected losses. The stability of the staff and faculty helped the center meet the research goals that had been set for the year.

Future Planning

The Center's commercialization plan calls for testing the new coal log machine and completion of the 3,000 ft. pipeline and coal processing system. They are the final components necessary to complete the CLP pilot plant.

The CPRC continues to be receptive to the testing of alternative pipe materials, e.g. concrete, stainless steel and plastic. Manufacturers of these products have been invited to sponsor research relevant to alternative pipeline materials. The Center may be negotiating in the near future with a major trade association. The association has expressed interest in having the Center conducting research on the suitability and performance for use in capsule pipelines of the material its members produce.

The Center is also developing application of capsule pipeline technology for transporting agricultural products, mail and other commodities, including municipal waste. Last year the Center completed a preliminary feasibility study for the United States Postal Service validating the possible use of pneumatic capsule pipelines to transport mail between Washington, DC and New York City with four intermediate stops. A formal proposal was not funded. However, the application looks promising as a way to reduce transportation costs, traffic congestion and pollution. So the benefits of this application will be promoted to secure development funds when the opportunity arises again.

In 1997, the CPRC won a grant from TVA to test biomass which would be compacted in the new coal machine. The biomass logs were to be test burned in power plants to evaluate the fuel value and improved handling of the logs. Unfortunately, the project got canceled when TVA research funds were severely reduced. However, the center has submitted proposals for other projects of similar nature and plans to continue developing this application because it may represent an excellent opportunity for productive use of the capsule pipeline technology.

Interest in CLP has been strong outside the US. The Coal Ministry of China has sent two coal experts to CPRC for a year to study CLP. And numerous inquiries have received from all parts of the world. The Center Director and Associate Director are pursuing potential relationships with universities, companies and governments in China, Venezuela and Eastern Europe.

Finally, the Center will be submitting a preproposal for an NSF Engineering Research Center (ERC) on pipeline infrastructure. If funded, the ERC would become the nation's lead institute in pipeline infrastructure research, education and technology transfer.

Technology Transfer

Technology transfer activities continue to be a high priority of the Center. Technological information has been disseminated through presentations at national and international meetings and during visits to agencies and companies interested in capsule pipeline technology. Findings from researchers are presented in the Center's annual and quarterly reports which are shared at presentations with industry, presented at short courses, publicized in national journals and featured in the CPRC newsletter, the Center videotape and on the Center World Wide Web site. During the year, the Center Director, Associate Director and Researchers have made presentations to organizations in Washington, DC; Clearwater, FL; St. Louis, Columbia and Jefferson City, MO; Pittsburgh, PA; Amarillo, TX; Tulsa, OK; Carbondale, IL; Taiyuan, China; Monterrey, Mexico and Rio de Janeiro, Brazil.

Summary

1997 was a year of significant accomplishments for the Center. Major milestones were reached when the new coal log machine and the new coal log building were completed. Without the machine and the building to house it the Center would not be able to accomplish its mission of demonstrating that CLP is commercially ready.

The Center Director and Associate Director have been persistent in seeking funds for the completion of the CLP pilot plant. Without completion, the Center will not be able to finish its mission of making CLP ready for commercial application. The obstacles have been and will continue to be formidable. However, the optimism, strong research program and perseverance have already produced substantial progress in 1997/98. Continuation of this progress is anticipated in 1998/99 with the new machine and facility available for research and demonstration of the potential of CLP.

SUPPORT, FINANCIAL MANAGEMENT & BUDGET

Data on industrial support and characteristics are shown in Table 10. Sources of support are listed in Table11.

The Functional Budgets for the current year and the next year are given in Tables 12 and 13, respectively. The requested budgets from NSF, State and industry for the eighth year (9/l/98-8/31/99) are given in Tables 14-17. Note that $300,000 is requested—an increase of $50,000 from the current year to pay for the cost of constructing the costly pilot plant pipeline. The $300,000 will be matched by the State, and industry. So the Center will have a budget $150,000 higher than this year.

Industrial support for the current year (9/l/96-8/31/97) is listed in Table 10. Only those that have either paid or committed as of the time this report is prepared (in May) are included in Table 10. Additional industrial support from new sponsors for the remaining four months (May, June, July and August) of the current year is expected but cannot be predicted and listed. They will be reported to NSF as soon as the current fiscal year ends. The total industrial support by the end of the current year (8/31/98) is expected to exceed the required minimum of $250,000.

Most of the current industrial sponsors are expected to continue supporting the CPRC for the next year. As in the past, the industrial sponsors reevaluate their commitments each year, and the decision to continue participation usually is made at the beginning of each participating year, not in advance, Therefore, it will be in July or August or even later before the P.I. will know for sure how many existing industrial sponsors will continue to support CPRC for the coming year. Also, it is expected that at least one or two additional companies will join membership (pay $30,000 a year) during the next year. Therefore, next year's industry participation is expected to be somewhat stronger than the current year. In addition, large donations of equipment from several sources are expected for building the pilot plant pipeline. This will greatly boost the in-kind contribution to the Center. This is needed in order to pay for the cost of large scale testing and commercialization of CLP. The fee from the Sumitomo Metal Industry is to pay for the research in PCP rather than CLP.

As to the State matching fund, the Center was always able to receive it in the past six years, but not without a great deal of agony, confusion and delays. This is due to the fact that CPRC matching fund has always been a line item in the budget of the MDED (Missouri Department of Economic Development). Even though MDED recommended it and the Governor approved it, the budget often got lost in the State Legislature during budget reshuffling.

The past problem of CPRC with the Missouri Legislature appears to be the lack of knowledge by most legislators as to what a capsule pipeline is and what its merits are. However, due to extensive hearings and debates in the Legislature last year and in 1996 on the CPRC, the Legislature is now much better educated on CPRC and capsule pipeline than in previous years. Consequently, the $250,000 budget for the next fiscal year (8th year) was approved by the Legislature this year after the Governor sent the request to the Legislature. An extra $100,000 will be asked from the legislature for the period 7/1/99-8/31/99. Relations with the Missouri

Department of Economic Development has also improved during the last three years since the agency assigned a new official (Bill Borgmeyer) to oversee the operation of CPRC. A letter on State cost share from Mr. Borgmeyer is attached on page 57.

Statement on University Cost Share

As approved two years ago in the University Cost Sharing Budget for Years 4-8 (9/1/94-8/31/99)--see page 42b of the 3-Year Progress Report--University cost sharing is based on faculty time charged to the three sponsors (NSF, State, and Industry). The University cost shares one month of the faculty's time for each month charged to the sponsors." The University also provides other supports such as waiver of the indirect cost for the Core Program Funding--the University's normal rate of indirect cost is 46% of the direct cost, free use of rooms and laboratory space, etc.

Statement on Other Research for Senior Personnel

Dr. Henry Liu, Director, has given up entirely on other research (such as wind engineering which he was very active prior to 1991[1]), in order to concentrate on capsule and coal log pipeline research, and to coordinate the activities of the Center. Dr. Thomas R. Marrero, Associate Director, also has ceased to continue research in other areas since the formation of the Center, to concentrate on coal log research and to help manage the Center. Most other faculty members participating in the Center's research are involved in other research, but to a lesser extent than prior to the formation of the Center. The Center encourages participating faculty members to do more and more research in capsule pipeline.

UPDATE OF CONTACT INFORMATION FOR CENTER

(Provided in Appendix 1)

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[1] For instance, Liu is the author of WIND ENGINEERING--A HANDBOOK FOR STRUCTURAL ENGINEERS, Prentice Hall Publishing Company, 1991.

MISSOURI
DEPARTMENT OF ECONOMIC DEVELOPMENT

Mel Carnahan
Governor

Joseph L. Driskill
Director

Business Development Group
301 W. High Street, P.O. Box 118
Jefferson City, MO 65102
(573)751-4241
(573)751-7384 FAX

Dennis Roedemeier
Director

May 12, 1998

Dr. Henry Liu, Director
Capsule Pipeline Research Center
University of MO – Columbia
College of Engineering
E2421 Engineering Building East
Columbia, MO 65211-2200

Dear Dr. Liu:

This will confirm the allocation of $250,000 from the State of Missouri to the University of Missouri during FY1998. There also is a $250,000 appropriation for this purpose during FY1999.

Should you have any further questions, please don't hesitate to contact me.

Best regards,

Bill Borgmeyer

Bill Borgmeyer
Coordinator
Office of Productivity

BB/sw
FAX: 573/884-4888

Table 10: Industrial Support and Characteristics (Year 7)

Company Name	Size L/M/S	Foreign Y/N	In-State Mfg. or R&D Site (Y/N)	"Core" Cash Support ($)	In-Kind Support ($)	Total Core Support ($)	Non-Core Cash Support ($)
Associated Electric Company	L	N	Y	30,000*	0	$30,000	0
COMPACTCONSULT	S	N	N	0	5,000	5,000	0
Gundlach Machine Co.	S	N	N	0	5,000*	5,000	0
Nova Tech	S	N	N	0	5,000*	5,000	0
PERMALOK	S	N	Y	0	5,000*	5,000	0
Pro-Mark Co.	S	N	Y	0	5,000*	5,000	0
STI International Assoc.	S	N	N	0	6,000	6,000	0
Southern Public Service	L	N	N	30,000	0	30,000	0
Sumitomo Metal Ind., Ltd.	L	Y	N	30,000	8,460	38,460	0
T.D.W. Pigging Products	M	N	N	0	5,000	5,000	0
Union Electric (Ameren)	L	N	Y	0	0	0	0
VALVTECHNOLOGIES, Inc.	M	N	N	0	130,000*	130,000	0
Williams Pipe Line Co.	L	N	N	15,000	39,765*	54,765	0
Williams Technologies, Inc.	M	N	N	0	15,000*	15,000	0
Total	NA	NA	NA	**105,000**	**229,225**	**334,225**	**0**

*Committed amount: expected to receive before 8/1/98

UNIVERSITY ADMINISTRATION CERTIFICATION:

Richard J Otto, Director
Office of Sponsored Program Administration
University of Missouri-Columbia
310 Jesse Hall, Columbia, Missouri 65211
(573) 882-7560

Name and title of Authorized Institutional Official

5-14-98

Date

Table 11 - NSF Budget (Each year)

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
AWARD NO.		

ORGANIZATION: Curators of the University of Missouri

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR:

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACA	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. Henry Liu		1	1	$ 25,404	$
2. T. R. Marrero, Co-P.I.		1	1	17,232	
3. C.W. Lenau			1	7,146	
4. Y.Y. Lin			1	6,663	
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. ( ) TOTAL SENIOR PERSONNEL (1-6)		1	4	56,445	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POST DOCTORAL ASSOCIATES (0.5 FTE)	12			20,000	
2. (1) OTHER PROFESSIONALS (TECHNICIAN, ~~PROGRAMMER, ETC.~~) 1 FTE	12			25,000	
3. (4) GRADUATE STUDENTS 2 MS, 2 Ph.D (0.5 FTE, 12 mo.)				60,936	
4. (3) UNDERGRADUATE STUDENTS 1,000 hrs. at $7.50/hr.				7,500	
5. (1) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY) 0.5 FTE, 12 mo.				9,500	
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A + B)				179,381	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS) 25% of A1-4; B1, 2, 5; 8% of B3; tuition for B3				47,731	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				227,112	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) NONE					
TOTAL EQUIPMENT					
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				8,000	
2. FOREIGN					
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 2. TRAVEL 3. SUBSISTENCE 4. OTHER					
( ) TOTAL PARTICIPANT COSTS					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES for construction of pilot plant				55,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				5,888	
3. CONSULTANT SERVICES				4,000	
4. COMPUTER SERVICES					
5. SUBAWARDS					
6. OTHER				15,120	
TOTAL OTHER DIRECT COSTS				64,888	
H. TOTAL DIRECT COSTS (A THROUGH G)				300,000	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)					
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				300,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)					
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				300,000	$

M. COST-SHARING: PROPOSED LEVEL $	AGREED LEVEL IF DIFFERENT: $			
PI/PD TYPED NAME AND SIGNATURE*	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/97) *Supersedes All Previous Editions*

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)

Table 12. State Matching Fund
Year 8 (9/1/98 - 8/31/99)

Expense Category	Amount ($)
A. Personnel (Full Time)	
1. H. Liu, 1 ss mo., 1 ay mo.	25,404
2. T. Marrero, 1 ss mo., 1 ay mo.	17,232
3. C.W. Lenau, 1 ss mo.	7,146
4. Y.Y. Lin, 1 ss mo.	6,663
5. Post doctoral associate, 0.5 FTE, 12 months	20,000
6. Secretary, 0.5 FTE, 12 mo.	9,500
Total A	***85,945***
B. Personnel (Part-time, or temp)	
1. Graduate Research Assistant, 1 MS level - 0.5 FTE, 12 mo.	14,412
2. Hourly personnel (part-time)	5,000
Total B	***19,412***
C. Fringe Benefits	
1. 25% of A	21,486
2. 8% of B	1,553
3. Tuition for B1	3,780
Total C	***26,819***
Total A + B + C	**132,176**
D. Pilot Plant Equipment	51,824
E. Travel	10,000
F. Materials and Supplies	5,000
G. Consultant	8,000
H. Patent Application	10,000
I. UMR portion (Dr. Wilson)	80,000
J. Miscellaneous (communication costs, newsletters, etc.)	3,000
Total Direct Costs	**300,000**

Note: 1. Travel for UMC is for 5 personal trips to visit potential industrial sponsors, and 5 personal trips to present findings at national meetings.

Table 13. Industrial Budget
Year 7 (91/97 - 8/31/98)

Expense Category	Industry Amount
A. Personnel (Full Time)	
1. H. Liu, P.I.,1 ss mo	25,404
2. T. Marrero, Co-PI, 1 ay mo., 1 ss mo	17,232
3. B. Gunnink, 2 ss mo	15,355
4. Post Doctoral Fellow, 1 FTE, 12 mo	40,000
5. Technician, 0.5 FTE,12 mo	12,500
6. Manager, 0.5 FTE, 12 mo	24,250
Total A	***134,741***
B. Personnel (Part-time, or temp)	
1. Graduate Research Assistants, 2 MS, 2 Ph.D.	60,936
2. Hourly personnel (part-time)	5,000
Total B	***65,936***
C. Fringe Benefits	
1. 25% of A	33,685
2. 8% of B	5,275
3. Tuition for B1	15,120
Total C	***54,080***
Total A + B + C	**254,757**
D. Equipment/Material (Pilot Plant CLP at Holstein Farm)	6,743
E. Travel	8,000
F. Materials and Supplies	3,000
G. Shop Service	10,000
H. Consultant	5,000
I. Coal Slurry Association Membership	2,500
J. Patent Application	10,000
Total Direct Costs	**300,000**

Note: This budget reflects a combination of cash and in-kind contributions. The in-kind donations will be in the form of needed equipment and materials for construction of the pilot plant CLP.

Table 14. Summary Budget (Amounts are in dollars)
Year 8 (9/1/98 - 8/31/99)

Expense Category	NSF Amount	Industry Amount	State Amount	Total of External Sources	University Cost Share
A. Personnel (Full Time)					
1. H. Liu					
3 ay mo & 3 ss mo	25,404	25,404	25,404	76,212	76,212
2. T. Marrero				-	
3 ss mo, 3 ay mo	17,232	17,232	17,232	51,696	51,696
3. Y. Lin				-	
2 ss mo	6,663	0	6,663	13,326	13,326
4. C. Lenau				-	
2 ss mo.	7,146	0	7,146	14,292	14,292
5. B. Gunnink				-	
2 ss mo.		15,355		15,355	15,355
6. Post Doctoral Associate				-	
2 FTE, 12 mo	20,000	40,000	20,000	80,000	
7. Manager				-	
0.5 FTE, 12 mo		24,250		24,250	
8. Secretary					
1 FTE, 12 mo	9,500		9,500	19,000	
9. Technician				-	
1.5 FTE, 12 mo	25,000	12,500		37,500	
Total A	110,945	134,741	85,945	331,631	
B. Personnel (Part-time, or temp)				-	
1. Graduate Research Assistants				-	
5 MS level - 0.5 FTE, 12 months	28,824	28,824	14,412	72,060	
4 Ph.D level - 0.5 FTE, 12 months	32,112	32,112		64,224	
2. Hourly personnel (part-time)	7,500	5,000	5,000	17,500	
Total B	***68,436***	***65,936***	***19,412***	***153,784***	
C. Fringe Benefits				-	
1. 25% of A	27,736	33,685	21,486	82,907	42,720
2. 8% of B	4,875	5,275	1,553	11,703	
3. Tuition for B1	15,120	15,120	3,780	34,020	
Total C	***47,731***	54,080	***26,819***	***128,630***	
Total A + B + C	**227,112**	**254,757**	**132,176**	**614,045**	
D. Equipment	0	6,743	51,824	58,567	
E. Travel	8,000	8,000	10,000	26,000	
F. Materials and Supplies	55,000	3,000	5,000	63,000	
G. Publication Costs	5,888			5,888	
H. Shop Service		10,000		10,000	
I. Consultant	4,000	5,000	8,000	17,000	
J. Coal Slurry Association Membership		2,500		2,500	
K. Patent Application		10,000	10,000	20,000	
L. UMR portion			80,000	80,000	
M. Miscellaneous (communication costs, Technology Transfer Workshop)			3,000	3,000	
Total Direct Costs	**300,000**	**300,000**	**300,000**	**900,000**	**213,601**
Indirect Costs (for Core Program)	0	0	0	0	448.575
Project Costs (Direct Plus Indirect)	**300,000**	**300,000**	**300,000**	**900,000**	**662,116**

* University waiver of indirect cost for the Core Program is calculated from 46% of modified total direct cost from all three sources.

Table 15: Functional Budget and Sources of Support: Current Year (9/1/97-8/31/98)
(Amounts are in $1,000)

Functional Category	State	Industry	NSF	University	Other Support	Total
Core Research)	168	130	125	78	0	501
Non-Core Research	0	0	0	0	34	34
Total Research	168	130	125	78	34	35
Equipment	55	80	55	0	0	190
Facilities	0	0	0	0	0	0
Industrial Collaboration & Technology Transfer	0	0	0	0	0	0
Management	27	40	70	32	4	173
Indirect Cost	0	0	0	262	11	273
Total	**250**	**250**	**250**	**372**	**49**	**1,171**

Note: This table give the targeted amount from each source for each category, for the current year (9/1/97-8/31/98). The next table (Table 16) gives the "actual" amount from each source for each category for the current year. However, since the "current year" does not end until four months from this reporting date, the "actual" amounts represent a combination of the amounts spent plus the expected expenditures prior to 9/1/98.

Table 16. State/IUCRC Functional Budget: Current Year (9/1/97-8/31/98)
(Amounts are expenditures in $)

	SOURCES OF SUPPORT					
	State	Industry[1]	NSF	University[2]	Other[3]	Total
"Core" Research Salaries[4], Supplies & Services/Other[5]	161,000	28,000	176,500	78,000	0	443,500
Non "Core" Research	0	0	0	0	33,973	33,973
Total Research	**161,000**	**28,000**	**176,500**	**78,000**	**33,973**	**477,473**
Equipment[6]	40,000	100,000	100,000	0	0	240,000
Facilities	140,000	120,000	10,000	0	0	270,000
Industrial Collaboration and Technology Transfer[7]	20,000	0	20,000	0	0	40,000
Management[8]	20,000	5,000	40,000	32,000	4,000	101,000
Indirect Cost	0	0	0	262,000	11,392	273,392
GRAND TOTAL[9]	**381,000**	**253,000**	**346,500**	**372,000**	**49,365**	**1,401,865**

(1) Industrial Membership fees plus industry augmented "core" funds.
(2) Cash and In-kind.
(3) Federal Agencies, Foundations, gifts, etc.
(4) Include fringe benefits.
(5) Travel, consultant, publications.
(6) No more than 10% of total "core" funds.
(7) No more than 30% of total "Core" funds of the State and Industry, to support costs for workshops, training courses, experimental test.
(8) Center Director's time in management, administrative costs, travel, etc.
(9) The current year grant total for NSF and State far exceed the current year budget of $250,000 from each source. The extra amounts came from money saved from the last year's budget to pay for the machine and building paid this year.

Note: Since the current year does not end until four months from this reporting date, the expenditures listed in this table include both the amounts already spent and committed, plus the expected additional expenditures needed prior to 9/1/98.

Table 17. State/IUCRC Functional Budget: Next Year (9/1/98-8/31/99)
(Amounts are planned for next year in $1,000)

	SOURCES OF SUPPORT					
	State	Industry [1]	NSF	University [2]	Other [3]	Total
"Core" Research Salaries, [4] Supplies & Services/Other [5]	146	196	186	133	0	661
Non "Core" Research	0	0	0	0	60	60
Total Research	**146**	**196**	**186**	**133**	**60**	**721**
Equipment[6]	54	7	0	0	0	61
Facilities	20	20	55	0	10	105
Industrial Collaboration and Technology Transfer [7]	20	20	20	0	0	60
Management [8]	60	57	39	80	10	246
Indirect Cost	0	0	0	449	37	486
GRAND TOTAL	**300**	**300**	**300**	**662**	**117**	**1,679**

(1) Industrial Membership fees plus industry augmented "core" funds.
(2) Cash and In-kind.
(3) Federal Agencies, Foundations, gifts, etc.
(4) Include fringe benefits.
(5) Travel, consultant, publications.
(6) No more than 10% of total "Core" funds.
(7) No more than 30% of total "Core" funds of the State and Industry, to support costs for workshops, training courses, and experimental test.
(8) Center Director's time in management, administrative costs, travel, etc.

Note: Since the current year does not end until four months from this reporting date, the expenditures listed in this table include both the amounts already spent and the expected expenditures prior to 9/1/98.

REFERENCES

1. Boettcher, R.A. (1971). "Pipeline Transportation of Solid Waste," Paper presented at the 64th Annual Meeting of AICHE, San Francisco, California, 17 pages.

2. Liu, H. (1993). "Hydraulic Behaviors of Coal Log Flow in Pipe," Freight Pipelines (Editor: G.F. Round), Elsevier Science Publisher, pp. 215-230.

3. Liu, H. and Richards, J.L. (1994). "Hydraulics of Stationary Capsule in Pipe," Journal of Hydraulic Engineering, ASCE, Vol. 120, No. 1, pp. 22-40.

4. Xu, G. (1993). Behavior of Capsules in Slurry Medium in a Pipe, M.S. Thesis, Department of Mechanical & Aerospace Engineering, UMC, 106 pages. (Adviser: James Seaba).

5. Seaba, J.P. and Xu, G. (1994). "Capsule Transport in Coal Slurry Medium," Journal of Fluids Engineering, ASME, Vol. 117, pp. 691-695.

6. Huang, X. (1994). Polymer Drag Reduction in Hydraulic Capsule Pipeline (HCP), M.S. Thesis, Department of Civil Engineering, UMC, 137 pages. (Adviser: Henry Liu).

7. Cheng, C.C. (1994). Wear and Damage of Coal Logs in Pipeline, Ph.D. Dissertation, Department of Civil Engineering, University of Missouri-Columbia, 347 pages. (Adviser: Henry Liu).

8. Lenau, C.W. and El-Bayya, M. (1993). "Unsteady Flow in Hydraulic Capsule Pipeline," Journal of Engineering Mechanics, ASCE (submitted).

9. Lenau, C.W. and El-Bayya, M. (1993). "Treatment of Unsteady Flow through Capsule Pipeline: Capsule-Water Interaction," Proc. of the 7th International Symposium on Freight Pipelines, Wollongong, Australia, pp. 215-219.

10. El-Bayya, M. (1994). Unsteady Flow of Capsules in a Hydraulic Pipeline: Theory and Experiment, Ph.D. Dissertation, Department of Civil Engineering, UMC, 189 pages. (Adviser: Charles W. Lenau).

11. Liang, Z. (1993). Compaction of Binderless Coal for Coal Log Pipelines, M.S. Thesis, Department of Civil Engineering, 132 pages. (Adviser: Brett W. Gunnink).

12. Gunnink, B.W. and Liang, Z. (1994). "Compaction of Binderless Coal for Coal Log Pipelines," Fuel Processing Technology, Elsevier, Amsterdam, pp. 237-254.

13. Lin. Y.Y. and Wang, L.Q. (1993). Binderless Coal Log Extrusion, CPRC Internal Report, 14 pages.

14. Marrero, T.R., Liu, H., and Burkett, W.J. (1994). "Coal Log Fabrication: State-of-the-Art for Pipeline Transportation," Proc. of the 11th Annual International Pittsburgh Coal Conference, Pittsburgh, Pennsylvania, pp. 841-847.

15. Wilson, J.W., Ding, Y, Smith, R.J. and Marrero, T.R. (1994). "Moisture Reduction of Coal in Coal Log Pipeline Technology," Proc. of the 11th International Coal Preparation Conference, Lexington, Kentucky, pp. 167-175.

16. Liu, H., Lin Y. and Marrero, T.R., (1996). "Effect of Zeta Potential on Strength of Compacted Coal Logs," Industrial & Engineering, Chemistry Research, Vol. 35, No. 1, pp. 263-268.

17. Liu, H. (1994). Analysis of Coal Log Compaction in a Cylindrical Mold, CPRC Internal Report, 18 pages.

18. Smith R. (1994). "Slurry Impregnation of Binderless Coal Logs," M.S. Thesis, Chemical Engineering Department, UMC, 97 pages. (Adviser: Thomas R. Marrero).

19. Carney, D. (1996). "Impregnation of Coal Logs," M.S. Thesis, Chemical Engineering Department, UMC, (Adviser: Richard Luecke).

20. Sun, S.H. (1993). Microwave and Radiation Surface Heat Treatment of Coal Logs. Project Completion Report, CPRC, 20 pages. (Adviser: Thomas R. Marrero).

21. Lin, Y.Y. and Ji, G. (1993). Coal Log Manufacturing Machine Design Report: Capped Mold Approach, CPRC Report, 23 pages, 5 drawings.

22. Shieh, C.Y. (1993). Computer Control of a Small-Scale Capsule Pipeline System, M.S. Report, Department of Mechanical Engineering, UMC, 120 pages. (Adviser: Satish Nair).

23. Sun, D.X. (1993). Design of Certain Mechanical Subsystems for an Automated Capsule Pipeline, M.S. Report, Department of Mechanical Engineering, UMC, August 1993, 101 pages. (Adviser: Satish Nair).

24. Du, H., Issues Related to Reliable Operation of Pump Bypass System for Capsule Pipeline., Ph.D. Report, Department of Mechanical Engineering, University of Missouri-Columbia, August 1996, 219 pages, (Adviser: Satish Nair).

25. Davis, P.N., Cress, N. and Sullivan, J.P. (1993). "Legal Aspects of Coal Pipelines in the United States--Preliminary Findings," Proc. of the 18th International Technical Conference on Coal Utilization and Fuel Systems, Clearwater, FL, pp. 735-746.

26. Davis, P.N. (1995). Coal Log Pipeline (CLP) Manual of Practice, Chapter 10: Legal Manual, 90 pages.

27. Liu, H., Zuniga, R. and Richards, J.L. (1993). Economic Analysis of Coal Log Pipeline Transportation of Coal, CPRC Report No. 93-1, two volumes, 248 pages.

28. Marrero, T.R. and Wilson, J.W. (1993). Coal Log Fuel Handling and Treatment at Power Plants, EPRI TR-102701, Electric Power Research Institute, Palo Alto, CA., 1993, 74 pages.

29. Wilson, J.W. (1992). "End-of-Pipeline Requirements for Coal Log Pipeline Technology," Proc. of the 7th International Symposium on Freight Pipelines. Wollongong, Australia, 1992, pp. 207-213.

30. Wilson, J.W. and Marrero, T.R. (1993). "Coal Log Pipeline Concept and Performance Characteristics," Journal of South African Institute of Mining and Metallurgy, Vol. 93, pp. 267-271.

31. Hjelmfelt, A., (1995). Water Quality and Treatment of Coal Log Pipeline Effluent, M.S. Thesis, Dept. of Civil Engineering, University of Missouri-Columbia, 70 pages (Advisor: Dr. Shankha Banerji).

32. Garber, L., (1995). Water Quality Effects of Drag Reduction Polymers, M.S. Thesis, Dept. of Civil Engineering, University of Missouri-Columbia, 61 pages (Adviser: Dr. Shankha Banerji)

33. Wu, J.P. (1989). Economic Feasibility of Using Hydraulic Capsule Pipelines to Transport Farm Products of the Midwestern States of the United States, M.S. Thesis, Department of Civil Engineering, UMC, 118 pages.

34. Liu, H. and Wu, J.P. (1992). "Economic Feasibility of Using Hydraulic Capsule Pipeline to Transport Grain in the Midwest of the United States," Freight Pipelines, Proc. of the 6th Int. Symp. on Freight Pipelines, Hemisphere Publishing Corporation, New York, pp. 135-140.

APPENDICES

APPENDIX 1

INDIVIDUAL CORE PROJECT DESCRIPTION: CURRENT YEAR (9/1/97-8/31/98)

Beginning on the next page, a description is provided for each individual project operating under the CPRC during the 7th year (9/l/97-8/31/98). The order of presentation is according to the alphabet of the last name of the P.I. (Principal Investigator). The expenditure listed for each project includes only major equipment and facility cost, salaries, wages and fringe benefits of the personnel working on the project, including the P.I., research associates (if any), post-doctoral fellows (if any), and students. The total is approximately $832,365, excluding University contribution. Other expenditures such as existing equipment and materials purchased, shop services, technicians costs, secretaries, general management, travel expenses and so on are not included because they are centrally managed and difficult to break down. The listed expenditures are approximately 80% of the total expenditure of each project. Note that not all the listed projects started at the same time; the expenditure listed for each project is the approximate amount during the current year ending August 31, 1998.

NOTE: All the following projects listed are for current year (9/1/97 - 8/31/98). Some will continue into the next year; some will be terminated. The dollar amounts indicated are approximate expenditures for salary and equipment (if any) paid by the Center; University contribution is not included.

PROJECT 1: RAPID COMPACTION OF COAL LOGS

P.I.: Brett Gunnink, Associate Professor of Civil Engineering
RESEARCH ASSISTANT: Wei Li
BUDGET: $25,000 (salaries and student tuition)

PURPOSE:

To determine the ability of producing good-quality coal logs with very short compaction time.

Accomplishments:

Experiments were completed to explore the effects of moisture on rapid compaction of coal logs. Results show that the rapid compaction of coal logs can produce strong logs only if the moisture of the coal mixture is at or below the equilibrium moisture which is a function of compaction pressure. When the mixture moisture is higher than equilibrium, longer compaction time is needed to squeeze out the excess water. Additional, short-term trials were completed on samples of anthracitic coal from the Shanxi Province of China; these coal logs were sent to Shanxi scientists and officials for evaluation and their decision is pending.

PLAN:

Explore the effect of compaction variables on the circulation performance of rapidly compacted coal logs, including size effects; ultimately, develop a model relating large and small log performance. Student on project will complete a M.S. degree in Summer 1998.

PROJECT 2: DESIGN OF A DEMONSTRATION/TEST OF COAL LOG PIPELINE

P.I.: Charles W. Lenau, Professor of Civil Engineering
CO-P.I.: Henry Liu, Professor of Civil Engineering
RESEARCH ASSISTANTS: None
BUDGET: $17,000 (Summer salary only)

PURPOSE:

Design a test loop for conducting coal log degradation and various other studies. This test loop is to have pump bypass and injection systems similar to those needed for a commercial coal log pipeline. Trains of coal logs with 100 logs in each train can be tested in this loop. The total length of the loop is to be 2,848 feet with a nominal diameter of 6 inches. This test loop will be built at the Holstein Farm (pilot plant) where the new 250-ton hydraulic press is installed that can produce 5.3-inch-diameter coal logs at the rate of 3 logs per minute. Hundreds of such logs will be tested in this pipe loop.

ACCOMPLISHMENTS:

The system has been designed and analyzed; materials and equipment selected, and cost estimates obtained. It is awaiting final acquisition of funding and donated equipment before construction will start.

PLAN:

Respond to any detailed design questions, and collaborate on the construction of test loop. The Williams Pipe Line Co. (WPL) has been closely involved in helping in the design of this unique pipeline test facility. WPL also has agreed to send a crew to Columbia to construct this pipeline as an in-kind contribution to CPRC.

PROJECT 3: COAL LOG MANUFACTURING MACHINE

P.I.: Yuyi Lin, Associate Professor of Mechanical & Aerospace Engineering
RESEARCH ASSISTANTS: Guoping Wen and Kang Xue
VISITING SCHOLARS: Jihuai Xu and Zhengwang Li
BUDGET: $540,000 for machine construction and building, and $43,000 for salaries and tuitions

PURPOSE:

Design, construct and test a coal log manufacturing machine that can produce three 5.4-inch-diameter high-quality coal logs every minute.

ACCOMPLISHMENTS:

The compaction machine (250-ton hydraulic press) was constructed, delivered, installed and satisfactorily tested in a new pilot-plant facility. The machine was constructed by the T.J. Gundlach Machine Company with Flo-Products, the subcontractor for the hydraulic and control equipment. Machine performance reached design criteria, especially in terms of speed and maximum compaction force. The hydraulic press was demonstrated to the Industrial Advisory Board in March 1998. The coal material feeder and coal log removal device have been designed, fabricated and installed. In addition to hardware, a 3-D finite element model for predicting the variation of the density and stresses in coal logs was developed. A student working on this project received Ph.D in Mechanical Engineering. One visiting scholar returned to China (Coal Ministry); the other is remaining. Chinese government paid for the training of these two scholars at CPRC.

PLAN:

Plan for next year (Year 8) is to test this machine under various conditions, including double-ended compaction, back-pressure control, and to improve the design based on the test results. A 2" rotary press will also be designed as a 2nd-generation machine.

PROJECT 4: HYDRAULICS OF COAL LOG TRAIN

P.I.: Henry Liu, Professor of Civil Engineering
RESEARCH ASSISTANT: Xiang Gao
BUDGET: $20,000 (salaries and tuition)

PURPOSE:

To derive the hydraulic equations for predicting the behaviors of coal-log or capsule train behaviors in slopes and bends; and use computational fluid dynamics (CFD) to solve the equations derived.

ACCOMPLISHMENTS:

An analysis was completed that determined jamming conditions for horizontal bends and vertical slopes of coal log pipelines. The analytical results show that jamming in pipe slopes is a function of contact friction coefficient. Conditions for no jamming were found, and available by a special equation. This equation requires a bend-radius-to-pipe-diameter ratio of approximately 4 for coal logs with diameter ratio $k = 0.92$ and aspect ratio $a = 1.8$.

PLAN:

Complete the theoretical analysis for flow of capsule trains in bends and design a set of laboratory experiments to verify the theoretical model. This project requires another 12 to 15 months before it can be completed.

PROJECT 5: POLYMER DRAG REDUCTION IN CLP

P.I.s: John Miles, Professor of Mechanical Engineering and
Thomas R. Marrero, Associate Professor of Chemical Engineering
RESEARCH ASSISTANT: Glenn Kuhlman and Gangwei Wu
BUDGET: $30,000 (salaries and student tuition)

PURPOSE:

The primary purpose of the project is to test CLP drag reduction using polyethylene oxide with and without fiber added to water using resin logs with cement to simulate coal logs. The secondary purpose is to conduct full scale implementation of the injection system for vacuum-aided Polyox dissolution.

ACCOMPLISHMENTS:

Experiments were completed on drag reduction in an 8-inch-diameter pipe. The experiments, using simulation coal logs of resin, showed that 45% drag reduction is possible for logs moving through an 8-inch pipe at 88% lift-off velocity and with Polyox concentration of 25 ppm, approximately. Higher values of drag reduction are expected with Polyox concentration exceeding 25 ppm, and at velocity approaching lift-off. The experiments also found that fiber (pulp) does not help to reduce drag when used in combination with Polyox. This research also tested a new Polyox dissolution/injection system that may revolutionize drag reduction and other uses of Polyox and certain other powders.

PLAN:

Complete the doctoral thesis and prepare manuscripts for publication. This project will be terminated in Summer 1998.

PROJECT 6: APPLICATION OF LINEAR INDUCTION MOTOR (LIM) AND COST ESTIMATION OF PNEUMATIC CAPSULE PIPELINE (PCP) SYSTEMS.

P.I.: Robert O'Connell, Associate Professor of Electrical Engineering
CO-P.I.: Henry Liu, Professor of Civil Engineering
RESEARCH ASSISTANTS: Wisuwat Plodpradista and Kevin York
INDUSTRIAL PARTICIPANT: Sumitomo Metals Industries, Ltd. (SMI)
GOVERNMENT SPONSOR: Mid-America Transportation Center (MATC)
BUDGET: $30,000 Core money from SMI; $49,365 Non-Core money from MATC

PURPOSE:

Derive and analyze the equations for PCP in general and for a tubular linear induction motor (TLIM) in particular. Optimize the system design by using these equations. Develop a general cost program to provide the technical and economic bases for the optimum design of a pneumatic capsule pipeline (PCP) system for freight transportation.

ACCOMPLISHMENTS:

The electromagnetic equations for a TLIM system have been developed. This set of equations determine the system performance parameters, including thrust, power and efficiency as a function of capsule speed. Equations were also developed to predict drag coefficients for pneumatic capsule flow, as well as capsule acceleration rates. A PCP system cost was estimated for mail transportation between New York City and Washington, D.C.

PLAN:

On basis of derived equations optimize the design of a PCP system and begin its initial design. During the next year, a LIM-driven PCP model will be constructed and tested in the laboratory to verify the predictions by the derived equations.

PROJECT 7: COAL LOG COMPACTION SCALE UP

P.I.: John Wilson, Professor and Chairman, Mining Engineering Depart., UMR
Co-P.I.: Jerry C. Tien, Assoc. Professor, Mining Engineering Dept., UMR
Co-P.I.: Suha Aksoy, Research Assistant Professor, Mining Engineering Dept., UMR
RESEARCH ASSISTANTS: Nicole Pagano, Bing Zhao
BUDGET: $78,000, approximate.

PURPOSE:

To fabricate and test 5.4-inch-diameter coal logs in an effort to determine the ability to scale up test results based on 1.9-inch-diameter logs under optimum conditions.

ACCOMPLISHMENTS:

A study was conducted to determine the coal log quality variations with several parameters for both small (1.8-inch diameter) and large (5.4-inch diameter) logs. It was found that under similar compaction conditions, the large logs had higher tensile strength than the small logs. The large logs suffered more percent weight loss due to wear in pipe per unit distance than do the small logs. Reasons for this anomalous behavior have been suggested. Experimental findings indicate that minimum abrasion happens between 80% and 100% of lift-off velocity. At relatively low compaction pressure (8,000 psi); more binder significantly enhanced the coal log strength. The UMR team also completed a CLP effluent water quality and treatment study, and winterized an outdoor facility.

PLAN:

Complete the coal log compaction scale-up study and conduct wear tests in the 6-inch pipeline (at UMR) by using the coal logs produced by the new machine at UMC. The first set of logs to be tested will be compacted under different back pressures during coal log ejection from the mold. The second set of coal logs to be tested will be on the effect of moisture and compaction time on the coal log wear rate. The UMC and UMR team will work closely together to complete the study. The tests are especially important before the pilot plant CLP is built in Columbia.

APPENDIX 2. ATTACHMENT

MEETING OF INDUSTRIAL ADVISORY BOARD (IAB)
CAPSULE PIPELINE RESEARCH CENTER (CPRC)
MARCH 31, 1998, COLUMBIA, MO

MINUTES

1. Meeting was held in the Missouri Room of the Holiday Inn East (Holidome), Columbia, Missouri.

2. All in attendance introduced themselves. Attendance list is attached.

3. Dr. Brady Deaton, Interim Provost, UMC, welcomed the participants to Columbia and thanked them for supporting the University's Capsule Pipeline Research.

4. Dr. Andy Blanchard, Director of Engineering Research, welcomed the participants on behalf of the College of Engineering.

5. Dr. Joy Pauschke of the National Science Foundation pointed out that CPRC fulfills all the four NSF core strategies: to develop intellectual capital, to strengthen the physical infrastructure, to integrate research and education and to promote partnership with industry. She also mentioned that the next national meeting of State/IUCRCs would be held in Raleigh, NC on October 13 and 14, and that new IGERT and ERC solicitations would be released soon. There are also on-going grant opportunities for academic liaison with industry and for combined research.

6. Mr. Bill Borgmeyer, Missouri Department of Economic Development (MDED), thanked CPRC's industrial supporters, noting their important role in providing unique insight and guidance to CPRC. He also briefly described some economic development activities in Missouri that MDED is currently involved in.

7. Hank Brolick, serving as the Chair of the Industrial Advisory Board (IAB), said that the industrial participants are looking for the best way to move forward with the coal log commercialization.

8. Dr. Henry Liu, Director of CPRC, gave a status report of the CPRC activities. He presented both the bad news and the good news. The **bad news** includes:
   - CPRC lost a TVA biomass grant after the grant was awarded, due to unforeseen agency budget cutbacks.
   - DOE/FETC declined to fund the unsolicited proposal to build the 3,000-ft pilot-plant pipeline.
   - U.S. Postal Service turned down the CPRC proposal to do a planning study for a pneumatic capsule pipeline from Washington, DC to New York, NY for

transporting mail and other products. However, Dr. Liu has appealed the decision to the Board of Governors of the Postal Service.

- CPRC's existing 8-inch pipeline test facility was struck by lightning, resulting in damage to some sensors and equipment.

The **good news** includes:

- The new 220-ton coal log compaction machine is working properly, albeit a minor oil leak problem that needs to be fixed.
- Research on CLP and PCP (pneumatic capsule pipelines) is progressing well.
- Williams Energy Group (formerly Williams Pipe Line Company) has committed to send a crew to Columbia to construct the 3,000-ft pilot-plant pipeline. The work will be counted as in-kind contribution to CPRC.
- Insurance covers the equipment loss due to the lightning strike.
- VALVTECHNOLOGIES, Inc., a company in Concord, California, has tentatively agreed to donate all the ball valves needed for the pilot plant CLP system as in-kind contribution and CPRC participation fee. The valves (with actuators) are valued at $136,000 approximately.
- In an important report, the U.S. Council on Science and Technology mentioned capsule pipelines as a strategy for streamlining freight movement.
- The Engineering Council of the United Kingdom published a report that calls for the use of pneumatic pipelines for moving freight in the next century.
- The new coal log machine was featured prominently in **MECHANICAL ENGINEERING**—the prime magazine of the American Society of Mechanical Engineers (ASME). Other accomplishments of CPRC are featured in **PUBLIC POWER**—an important magazine for the power industry, and in both local newspapers: **MISSOURIAN** and **COLUMBIA DAILY TRIBUNE**.

9. Dr. Liu presented major technical accomplishments that had been achieved since the Fall IAB meeting:
   - The new coal log machine passed the on-site tests, and the University approved the machine's performance pending fixing of a minor oil leak problem. So far, 90% of the machine cost has been paid to the machine's manufacturer—T.J. Gundlach Machine Company. During the next few weeks, the capability of the back pressure feature of this machine to produce high-quality coal logs will be tested.
   - A theoretical 3D-model that can predict large log properties: stress, strain and density was completed. This represents a significant advancement in the state-of-the-art of compaction theory. It will help greatly in optimizing the compaction process and minimizing the number of experiments needed to perfect the compaction process. It cannot, however, predict abrasion rates which must be done empirically. The work was done by Mr. G. Wen under supervision of Dr. Yuyi Lin.

- Tests of effluent water and the coal log abrasion scale-up tests were both finished at UMR (Wilson/Tien/Zhao).
- The 6-inch-diameter coal log pipeline at UMR was winterized.
- The Polyox drag reduction tests using the 8 inch pipe are nearly complete. It was found that maximum drag reduction of 75% is possible when coal logs are present in the pipe. However, the study does not answer a key question—how fast will Polyox degrade in a future commercial CLP? This can only be found in tests using a long pipe such as the one in the proposed pilot plant. This research is done by Mr. G. Wu under supervision of Professor John Miles.

10. Five faculty members and one graduate student reported on their research results:

(a) Dr. Yuyi Lin presented a report on the compaction machine's performance in terms of time, speed , etc. He also discussed what research was being done in compaction modeling and reviewed the importance of the back pressure feature.

(b) Dr. Henry Liu reported briefly on the study of the effects of slope and bends on CLP. He said that equations have been derived to analyze the problem. Some limited experiments with existing facilities will be used to check the theory. While it is difficult to generalize the results at this point, he said that long lines with steep slope requires special attention. It may cause jamming problem. Hank Brolick stated that the need for slopes of coal pipelines above 45 degrees seldom exists.

(c) Dr. Brett Gunnink presented the results of his rapid compaction research. The results show that if the coal used for compaction does not contain excess water, short compaction time is just as good as long compaction time. However, for wet coal containing excess water, a longer compaction time is needed to squeeze out the excess water in order to produce quality coal logs.

(d) Dr. Jerry Tien described the results from the effluent treatment study and from the coal log scale-up tests done at UMR. Comparing the data of large logs compacted under the same conditions of small logs, the large logs appear to have slightly higher strength. He also reported that the UMR test loop has been winterized, and he is waiting for UMC researchers to send him 5.3-inch diameter logs for testing.

(e) Dr. John Miles reported on the polymer drag reduction tests that Mr. Wu was conducting using the 8-inch pipeline -- the one struck by lightning. The study found a maximum drag reduction of 75%. It happened when capsules are present. Much smaller drag reduction was found without capsules. Addition of fiber to the flow had questionable beneficial effect.

(f) Mr. Kevin York (Graduate Student in Civil Engineering) presented results from research on use of Linear Induction Motors (LIM) for pneumatic capsule pipelines. While he works on the fluid mechanics and civil engineering aspects of the research, the LIM research is done by Electrical Engineering student Chai Plodpradista under supervision of Professor Bob O'Connell. The research is sponsored by Sumitomo Metal Industries, Ltd. and Mid-America Transportation Center (MATC). He reported that equations on LIM and on capsule fluid

mechanics have been derived and are being analyzed. The next step is to optimize the design by using these equations.

11. Dr. Liu presented the status of CPRC funding opportunities:
    - Proposal to USDA for grain pipeline feasibility assessment has been submitted.
    - Missouri Department of Natural Resources proposal for biomass compaction equipment (pending).
    - SBIR (Small Business Innovative Research) proposal to DOE was submitted by COMPACTCONSULT (Wolfgang Pietsch) with UMC as subcontractor. It proposes to construct a mobile machine (rotary press) to compact biomass at its sources.
    - DOE issued a Grand Challenge on using biomass to make solid fuel. The Center responded by submitting a proposal on biomass compaction using the new coal log machine. Phase 1 (first 18 months) involves laboratory tests. Phase 2 (2 years) involves power plant combustion tests at two Missouri power plants.
12. Dr. Liu discussed the importance of the proposed CLP pilot plant study: It is the last hurdle that must be crossed before commercial use of CLP can take place. However, the Center has insufficient funds to build the pilot plant. Additional contributions from industry is required before the pilot plant can be built. Liu mentioned that the pilot plant has already been designed and could be built in three months if money were available. If this facility is built now, tests can be conducted using NSF and State matching funds for the coming year. This is a large leverage of government funds. Since the NSF and the State matching funds will expire on 9/1/99, this leverage of funds for the pilot plant test will be lost if the pilot plant is not built now. After 9/1/99, industry will have to pay for both the pilot plant construction and the pilot plant test, before they can use CLP. Liu pleaded for help from existing sponsors. Mr. Brolick asked Liu to send all the existing industrial sponsors a list of the materials needed for the pilot plant, to see if most of the materials can be donated.
13. A field trip ensued following the IAB meeting. The new coal log machine was demonstrated by making three coal logs.

ATTENDEES OF THE IAB MEETING
(COLUMBIA, MISSOURI, MARCH 31, 1998)

GOVERNMENT SPONSORS

Mr. Bill Borgmeyer, Coordinator
Office of Productivity
Mo. Dept. of Economic Development
Jefferson City, Missouri

Dr. Joy Pauschke, Program Director
for State/IUCRC Program
National Science Foundation
Arlington, Virginia

CLP CONSORTIUM MEMBERS

Mr. Hank Brolick, President,
Williams Technologies
Tulsa, Oklahoma

Dr. Sanai Kosugi, General Manager
Pipeline Engineering
Sumitomo Metals Industries, Ltd.
Tokyo, Japan

Mr. Terry Pierce, Coal Transportation
Buyer for New Century Energies
Southwestern Public Service
Amarillo, Texas

Mr. Roy Plumb, Senior Project
Coordinator
Williams Pipe Line Company
Tulsa, Oklahoma

SMALL BUSINESS PARTICIPANTS

Mr. James Compton, Sales Engineer
T.J. Gundlach Machine Company
Belleville, Illinois

SPECIAL GUESTS

Mr. Tim Freeman
Office of U.S. Rep. Kenny Hulshoff
(Missouri's 9th District)
Columbia, Missouri

Mr. Richard E. Moss
Territory Manager
Mobil Oil Corporation

UNIVERSITY OF MISSOURI-COLUMBIA

Brady Deaton
Interim Provost

Dan Fancher
Vice Provost for Research

Dr. Andrew Blanchard
College of Engr. Director of Research

UMC FACULTY AND STAFF

Dr. Brett Gunnink, Civil Engineering,
Associate Professor

Dr. Charles Lenau, Civil Engr. Professor
Dr. Yuyi Lin, Mechanical Engr.
Associate Professor

Dr. Henry Liu, CPRC Director
Mr. Terry Maynard, CPRC Analyst
Dr. Tom Marrero, CPRC Assoc. Director

Dr. John Miles, Mechanical Engr.
Professor

Dr. Robert O'Connell, Electrical Engr.
Associate Professor

Mr. Xiang Gao, CPRC Research
Assistant, Grad. Student in CE

Mr. Wei Li, CPRC Research Assistant,
Grad. Student in CE

Mr. Guoping Wen, CPRC Research
Assistant, Grad. Student in MAE

Mr. Jon Wilkinson, CPRC Research
Assistant, Grad. Student in ChE

Mr. Gangwei Wu, CPRC Research
Assistant, Grad. Student in MAE

Mr. Kevin York, CPRC Research
Assistant, Grad. Student in CE

UMR FACULTY AND STAFF

Mr. Bing Zhao, CPRC Research Assist. &
Grad. Student in Mining Engr.

Dr. Jerry Tien, Associate Prof. of Mining
Engineering

Appendix 2(b)—Press Coverage of Current-Year Activities

Article in Following Magazines:

Getting Off The Coal Train

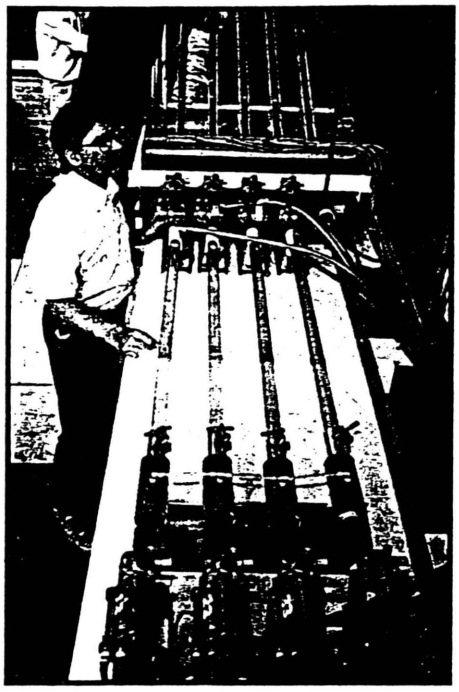
Coal compaction technology offers new transportation possibilities.

I can see them almost constantly from the deck of my home in Colorado Springs: Day and night, at about 20-minute intervals, long coal trains pass on their way from the huge coal fields of Wyoming to power plants in Texas, New Mexico, Oklahoma, Arizona and elsewhere. The trains consume large amounts of energy to climb the substantial grades in this part of the country. Often there are three diesel locomotives pulling and another three pushing what seems to be miles of coal cars. The coal trains pass through large cities and small towns, tying up traffic and adding to air pollution. A couple times a year, a train jumps the tracks. There has to be a better way.

Coal-fired power plants consume huge amounts of coal that normally must be transported long distances, most likely by train. Transportation is the biggest cost factor in the price of a ton of coal. For instance, Wyoming coal, which might cost less than $5 a ton at the mine, could cost over $25 a ton by the time it is delivered to Houston. Even so, Wyoming coal is the fuel of choice for many utilities because of its low-sulfur content and because it is still less expensive to use than higher sulfur coal that is closer, but requires costly scrubbers for clean up.

One alternative transportation technique, coal slurry pipelines, are already in use. The Black Mesa Pipeline, an 18-inch-diameter pipeline transports five million tons of coal per year from an Indian reservation in Arizona to the Mohave Power Plant in Laughlin, Nev., over a distance of 273 miles. The pipeline has operated successfully for 20 years.

A new concept, a coal log pipeline, has been under development for the last six years by the Capsule Pipeline Research Center at the University of Missouri-Rolla, a National Science Foundation-created State / Industry University Cooperative Research Center. The pipeline is designed to transport coal compacted into logs in a manner akin to the pneumatic tubes used at drive-through windows at banks. However, rather than pneumatic tubes and high-pressure air, the logs would be carried on a stream of water. The use of water reduces coal log abrasion and conserves energy.



Coal logs produced by a compaction machine are most economically transported over a pipeline.
But logs can reduce truck and rail shipping costs

Using the University of Missouri concept, the coal would be compacted into coal logs using special compaction machinery. A combination of heat and pressure is used to compact the material in molds or dies. The compaction machinery has to produce the logs at a very high rate of speed and for a very low cost. Both are necessary for a transportation method that is economically competitive with rail transportation.

The coal logs would be carried through the slightly larger diameter underground tubes filled with flowing water. The water velocity must be about 10 feet per second so the logs float, rather than slide, along the walls of the tube. This greatly reduces friction that leads both to abrasion and high power requirements. At these velocities, the logs lift off like an aircraft and fly above the water. Non-potable, brackish or even treated waste water can be used. This is important if the pipeline is to be viable in western states, where water is scarce and what is available is already spoken for through water rights established long ago. The coal log pipeline is three to four times more efficient in water usage than a coal slurry pipeline.

A key to the concept's success is the log compaction machine. So far the project has produced a prototype 250-ton coal compaction machine that produces a 5.4-inch-diameter, 12-inch-long coal log every 20 seconds. These logs will be tested in the CLP's six-inch-diameter, 3,000-foot-long pipeline test loop, to be built in Columbia.

While the main thrust of the program is transportation of coal logs, the researchers have shown that many other materials—cottonseed hulls, wood chips, sawdust, alfalfa hay, fly ash, sawdust, wasted coal fines and municipal solid waste—could be compressed into logs and sent through the log pipelines. More valuable commodities could be sent in cylindrical containers or capsules using the same technology. Indeed, the same pipeline could transport more than one material.

The compacted logs do not necessarily have to be carried by pipeline; they could be transported by truck or rail car. Since compaction results in much denser material, more weight could be carried in a smaller volume, reducing transportation costs. By compacting waste materials as refuse into logs before disposal, not only is the volume of the waste reduced and transportation and handling made easier, but the waste materials also become more impermeable. This reduces the leaching of pollutants into ground water when such waste materials are deposited in landfills. ■ William D. Siuru Jr.

Columbia and Rolla