Appendix A

COLORADO ENERGY RESEARCH AUTHORITY

BOARD OF DIRECTORS

Philip DiStefano, Ph.D., Chancellor
University of Colorado Boulder
(Chair)

Dan Arvizu, Ph.D., Director
National Renewable Energy Laboratory
(Vice-Chair)

Jeffrey Ackermann, M.N.M., Director
Colorado Energy Office

Anthony Frank, Ph.D., President
Colorado State University

Kimberly Jordan, CEO
New Belgium Brewing Company

Michelle Hadwiger, Director, Corporate Business Development,
and Director, Colorado Innovation Network
Colorado Office of Economic Development & International Trade

M.W. Scoggins, Ph.D., President
Colorado School of Mines

Appendix B

PRIVATE AND FEDERAL FUNDING FOR COLLABORATORY RESEARCH [1] 2007 - 2013

Shared Research [2]

- C2B2, CRSP and CREW industry member contributions for the centers' shared research projects **$4.72 M**
  (Matched by $4.28 Million in State funds)

Sponsored Research [3]

- Industry and other private (e.g. foundation) funding 11.04M
- Federal funding 40.40M
  (Matched by $1.972 M in State funds)

SUB- TOTAL SPONSORED RESEARCH 51.44M

TOTAL SHARED AND SPONSORED RESEARCH FUNDING FROM PRIVATE AND FEDERAL SOURCES 56.16M

Total Matching Funds Expended or Committed Through 2013 $6.25 M

THE COLLABORATORY HAS EMPLOYED $6.25 MILLION IN STATE FUNDS TO ATTRACT $56.16 MILLION IN PRIVATE AND FEDERAL ENERGY RESEARCH FUNDING TO COLORADO SINCE 2007.

Leverage on State Funding 9:1

Notes:

1. The Collaboratory research centers include:
   - Colorado Center for Biofuels and Biorefining – C2B2
   - Center for Revolutionary Solar Photoconversion – CRSP
   - Center for Research and Education in Wind – CREW
   - Carbon Management Center – CMC

2. Shared research is conducted through the Collaboratory research centers and is funded with a combination of industry membership fees and state matching funds. Topical areas for shared research proposals are identified by industry members, and proposals are then submitted by university and NREL researchers. Proposals are selected for funding by industry members and center leaders. If patents result from shared research projects, all industry members of the center are able to benefit from a paid up, non-exclusive license.

3. Sponsored research may be federally or industry funded and may be conducted by one or more Collaboratory institutions directly or under the umbrella of a Collaboratory research center. Federally funded sponsored research generally requires matching funds, provided by the Collaboratory and other public and private partners. Industry sponsored research generally receives no matching fund support. If patents result from privately sponsored research, the private sponsor generally has the right to negotiate for an exclusive license, consistent with federal law.

Appendix C

RESEARCH PROJECTS RECEIVING STATE MATCHING FUNDS IN 2013

1. **Title: Evaluation of Cellulosic Biomass-Derived Oxygenates as Drop-In Fuel Blend Components (DE-FOA-0000239)**

   a. Authority Matching Funds: $240k
   b. DOE Funding: $1.5 Million
   c. Participating Institutions: National Renewable Energy Laboratory, Colorado State University
   d. Principal Investigators: Robert McCormick, Ph.D., NREL; Anthony Marchese, Ph.D., CSU
   e. Investigators: Matthew Ratcliff (NREL), Earl Christensen (NREL), Lisa Fouts (NREL), Dan Olsen (CSU), Timothy Vaughn (CSU Graduate Student), Arunachalam Lakshminarayanan (CSU Graduate Student)
   f. Project Duration: 2012 - 2015
   g. Project Description:

   This project will determine if and at what levels biomass-derived oxygenates are scientifically and commercially feasible as drop-in fuels – for both diesel and gasoline applications. Many of the most promising biomass-to-advanced-biofuels pathways produce oxygenates as a natural part of the conversion process, but current methods for reducing or eliminating oxygen drastically increase the difficulty and cost of conversion. As has been shown in published reports, use of oxygenate blend components, or the tolerance of up to 2% residual oxygen in upgraded biomass-derived fuels, will reduce the cost and complexity of biomass processing.

   The specific goals of this project are to ensure compatibility with existing liquid fuel infrastructure, validate storage and handling properties, measure ASTM performance properties, assess impact on pollutant emissions, demonstrate engine durability and evaluate engineering economics of liquid fuels containing residual levels of these oxygenated components. The work at CSU has focused on diesel pollutant emissions and engine durability.

   h. The manner in which the funding has been applied in connection with the project:

   At Colorado State, funds for this project have been used for graduate student stipend, graduate student tuition, materials and supplies needed to support engine emissions/durability testing, fuel blending components and engine emissions test fees. At NREL the DOE funds have almost entirely gone to support NREL staff, with a fraction going to purchase materials and supplies. [Note: approximately $30K of the DOE funding to NREL were paid to an out of state fuel property testing lab.]

   i. The results achieved by the project, including intellectual property, licensing and commercialization activities:

   At NREL, the research to date supports the overall thesis of the project that many biomass oxygenates can function as drop-in fuels. In the final months of the project, NREL will try to quantify the economic benefit of this for biomass conversion processes. CSU's research is still at an early stage.

Publications

Talmadge, M.S., Baldwin, R.M., Biddy, M.J., McCormick, R.L., Beckham, G.T., Ferguson, G.A., Czernik, S., Magrini-Bair, K.A., Foust, T.D., Metelski, P.D., Hetrick, C., Nimlos, M.R. "A Perspective on Oxygenated Species in the Refinery Integration of Pyrolysis Oil" Green Chemistry 16 407-453 (2014).

Additional publications are in preparation.

2. Title: Effects of Size Quantization of Femtosecond Carrier Dynamics in Individual Colloidal Quantum Dots (Related to the Center for Advanced Solar Photoconversion, a DOE–funded Energy Frontier Research)

a. Authority Matching Funds: $50k for this project (part of the Center for Advanced Solar Photo-conversion)
b. DOE Funding: $10 Million overall for NREL, Colorado School of Mines and CU Boulder
c. Participating Institutions: National Renewable Energy Laboratory, Colorado School of Mines, University of Colorado Boulder
d. Principal Investigator: David Jonas, CU Boulder, Department of Chemistry and Biochemistry
e. Project Duration: 2013 - 2014
f. Project Description:

This project supports graduate student research on the effect of different sized quantum dots in solar photovoltaic arrays. This basic science will inform efforts to develop experimental and, ultimately, commercial solar PV technologies with quantum dots, nano-sized crystal materials. The goal is to use nanotechnology to make solar PV arrays with environmentally benign materials which are much more efficient and, therefore, produce electric power at lower costs.

g. The manner in which the funding has been applied in connection with the project:

The bulk of the funds supported stipends for graduate student research assistants working on the project. A smaller amount was spent on graduate student research assistant tuition and on chemicals and supplies for the project.

h. The results achieved by the project, including intellectual property, licensing and commercialization activities:

To date, the project has generated two-dimensional femtosecond spectra of isolated colloidal core-shell PbSe-CdSe quantum dots (synthesized by EFRC collaborators at Los Alamos and partially characterized by EFRC collaborator Justin Johnson at NREL). We are in the process of simulating and analyzing the 2D data for publication.

Publications

"Lightweight hollow rooftop mirrors for stabilized interferometry" Robert J. Hill, Trevor L. Courtney, Samuel D. Park, and David M. Jonas, Optical Engineering 52, 105103 (2013). (5 pages) DOI: 10.1117/1.OE.52.10.105103

Appendix D

Cumulative Collaboratory Research Metrics
2007 – 2013

Industry Members	52
Colorado Companies as Members	15
Non-member Companies Participating in Collaboratory Activities	88
Shared Research Projects	144
Industry Sponsored Research Projects	41
Federally Sponsored Research Projects	61
Other Sponsored Research Projects (foundation, institute, university etc.)	18
Researchers engaged – Shared Research	174
Researchers engaged – Industry Sponsored Research	34*
Researchers engaged – Federal and Foundation Sponsored Research	185*
Undergraduate Students Engaged	89
Publications	37*
Patent Filings	9*

Note: Metrics with an asterisk do not include researchers, publications or patented filings related to follow-on sponsored research projects flowing from shared research projects.

Appendix E

COLORADO ENERGY RESEARCH COLLABORATORY
CENTERS' SUMMARY 2013

Colorado Center for Biorefining and Biofuels

The Colorado Center for Biorefining and Biofuels, known as C2B2, was the first research center launched by the Collaboratory. C2B2 conducts world class research to develop new biofuels and biorefining technologies with the goal of transferring these advances as rapidly as possible to the private sector. C2B2 also trains new researchers for the clean energy industry in Colorado, and sponsors have the opportunity to recruit future employees. C2B2 offers important value to the State and to the sponsors, by providing educational and work opportunities for undergraduate, graduate and post-doctoral students. The University of Colorado Boulder is the lead institution for C2B2, but all four Collaboratory institutions play prominent roles in the activities of the Center.

C2B2's researchers have been enormously successful in attracting industry and federal research support. The sponsors' funding and State matching funds have supported 66 research seed grant, postdoctoral, and graduate fellowship research projects. In addition, C2B2 supports additional educational opportunities: a summer "Research Experience for Undergraduates" program, helping to develop the scientists and engineers of the next generation, with support from State matching funds, and professional "short course" seminars on topics related to biorefining and biofuel production.

The Authority has provided a total of $2.132 Million in State matching funds to C2B2. With this State support:

- C2B2 has attracted $2.6 Million in membership commitments for shared research programs.
- C2B2 members Chevron and EcoPetrol contributed an additional $376,000 in fellowships for graduate students and post-doctoral researchers.
- The National Science Foundation awarded $336,000 to support C2B2's Research Experiences for Undergraduates program from 2010 to 2012, and extended funding for this outstanding program for another three years, through 2015.

ConocoPhillips funded more than $3.4 Million in sponsored research, and the four Collaboratory institutions have generated additional research funding from private and federal sources as a result of C2B2 relationships.

In addition to these C2B2 programs, the Authority has also supported Collaboratory institutions in pursuing federal funding for biofuels research programs:

- In 2010, the Authority committed $1.275M in matching funds to support successful proposals from research teams including NREL and the Colorado School of Mines, bringing $11.3 Million in federal funding to these two institutions.
- In 2011, the Collaboratory committed $240,000 in matching funds to support a successful biofuels proposal that will bring an additional $1.5 Million to NREL and CSU.

In total, then, State matching funds of $3.647 Million are directly responsible for attracting more than $19 Million in federal and private funding for biofuels research and educational programming in Colorado.

But that is only the first level of C2B2's and the Collaboratory's contribution to economic growth in Colorado. This "first generation" of federal and privately sponsored research is just the beginning, because many of C2B2's shared research projects have attracted far greater funding for second, third and fourth generations of research founded upon the basic discoveries of the first generation. These later generations of research generally require no additional matching funds from the Authority, so the leverage of the State's initial contribution grows and grows. **At present, we calculate that later generations of research based upon C2B2 shared research have, to date, brought an <u>additional</u> $25.9 Million in federal and private research funding to Colorado.**

In total, then, the investment of $3.647 Million in State matching funds to C2B2 and Collaboratory institutions working on biofuels, biorefining and related bioscience projects has attracted $44.9 Million in both federal and private research, as well as educational funding to Colorado.

Even this estimate does not include the substantial economic benefit to Colorado from biofuels companies which have spun out of, or which have moved here to work with our powerful research community, including Gevo; Genesis Biofuel; OPX Biotechnologies (recipient of the Governor's Excellence in Renewable Energy Award for 2010); Solix Biofuels; Sundrop Fuels; and Cool Planet Energy Systems. Each of these successful companies is now based in Colorado, and employing Colorado residents. C2B2 is a key driver of this economic development, but we have not included any of this economic benefit in the calculations presented in this report.

But there is yet one more important measure of C2B2's success. C2B2 researchers have:

- Filed six patents developed through shared and sponsored research,
- Published more than 29 journal articles, and,
- Provided over 70 technical presentations at professional scientific conferences.

The creation of valuable intellectual property and peer reviewed, published literature confirms the merit of the Collaboratory public/private model and the success of C2B2.

Despite this success, though, C2B2 now faces significant challenges. C2B2 is competing directly with large private and federally funded research cooperatives. The relatively small "matching" investments made by the Authority in the Collaboratory centers, as compared to centers in other states, has reduced sponsor retention, research and development, and technology transfer through business creation. Unfortunately, the Authority does not have sufficient funds available to continue to match both industry and federal funding at the same rate as most of the competing centers.

In conclusion, biofuels and biorefining research (and related employment opportunities) are of greater and greater interest to undergraduate students, graduate students, and postdoctoral researchers. C2B2, however, without proper funding, is unable to meet the educational needs of all interested students at CU, CSU, Mines, and NREL. The more scientists and engineers we are able to train and graduate, the more successful we will be in building an advanced biofuels industry in Colorado, an industry that has and will continue to create jobs and tax revenues for our state.

<u>Center for Revolutionary Solar Photoconversion</u>

The Collaboratory's Center for Revolutionary Solar Photoconversion, or CRSP, conducts research with the objective of developing technologies that can produce clean solar fuels and electricity at costs comparable to traditional fuels and electrical power. The Colorado School of Mines is the lead

administrative institution for CRSP, and the Scientific Director of CRSP is a Research Fellow at NREL, one of only nine researchers presently given this honor. All four Collaboratory institutions participate in CRSP's research programs and are equally represented in its management structure.

CRSP's member companies have been hard hit by turmoil in the international market for solar photovoltaic panels, caused by unfair trade practices of Chinese government-supported manufacturers. Cheap Chinese panels have drastically reduced the cost of installing both commercial and residential solar generating equipment, a boon to consumers, but non-Chinese solar manufacturers have been struggling to compete. U.S., Japanese and French manufacturers – who have been the core of CRSP's membership – highly value CRSP's research capabilities, which can help these companies reduce their manufacturing costs. Unfortunately, these same companies are cutting their research budgets in an effort to survive.

Despite these significant short term challenges, the future for solar energy and solar photovoltaics, in particular, is very positive. The falling cost of solar photovoltaic energy is creating greater demand, and solar technologies are gradually playing a larger role in power generation worldwide. CRSP is working with the industry to find ways to reduce the costs of production and achieve profitability.

Since 2008, CRSP has received approximately $1.66 Million from its member companies. CRSP has also received more than $3 Million in federal research funding, part of a larger DOE commitment described below. To date, CRSP has earned $1.8 Million in matching funds from the Authority.

CRSP's federal research funding was earned through the Center's participation in a multi-institutional team, including NREL and Los Alamos National Laboratory. This team was selected by the U.S. Department of Energy for funding as a prestigious Energy Frontier Research Center in advanced photo physics. With the benefit of a commitment of $300,000 in State matching funds, CRSP participating research institutions (including CU-Boulder, CSM, and NREL) has received a total of $6.6 Million over five years from the US DOE. **Later generations of research based upon CRSP shared research have, to date, brought an <u>additional</u> $4.7 Million in federal and private research funding to Colorado.**

In total, then, the investment of $1.8 Million in State matching funds to CRSP and Collaboratory institutions working on solar fuel and electricity projects has attracted $11.3 Million in both federal and private research, as well as educational funding to Colorado.

CRSP also works closely with the National Science Foundation's first – and only – Renewable Energy Materials Research Science and Engineering Center (REMRSEC), housed at the Colorado School of Mines. The REMRSEC is also closely engaged with NREL. The close collaboration between these two research centers and the four institutions magnifies the capabilities of all of these Colorado organizations.

CRSP has filed for three patents developed through CRSP sponsored research, a very significant achievement for CRSP and a sign of CRSP's coming of age. After four full cycles of shared research projects, valuable intellectual property is being developed, defined and protected. This momentum will continue to accelerate in the coming years.

CRSP is also engaged in cooperative research programs with two internationally regarded programs: the Research Corporation for Science Advancement, headquartered in Tucson, Arizona, and the Research Center for Advanced Science and Technology, a program of the University of Tokyo.

Center for Research & Education in Wind

The third Collaboratory center, the Center for Research & Education in Wind, was publicly launched in August, 2009. CREW is the first Collaboratory center to include additional research institutions beyond the four Collaboratory member institutions. In recognition of the wind industry's interest in atmospheric sciences, CREW invited two of the world's leading atmospheric science research institutions to participate: the National Center for Atmospheric Research and the National Oceanic and Atmospheric Administration, both of which operate laboratories in Colorado. The University of Colorado-Boulder is the lead institution for CREW, and the Scientific Director resides at Colorado State University.

Topics of CREW research cover a wide range of topics, including: integration of energy storage to control wind farm output; innovative approach to the design and control of wind farms; modeling system and ensemble data assimilation for wind energy predictions; active coating materials for preventing icing on wind blades; and mitigation devices for generated aero-acoustic noise.

CREW's members have included leaders in the manufacture of wind turbines and the development of wind farms: RES Americas, Vestas and WindLogics. Since CREW's launch in 2009, CREW's corporate members contributed a total of $460,000 in membership fees to support shared research activities, and additional contributions from Vestas as part of its sponsored research. CREW has received a total of $475,000 in State matching funds.

CREW has conducted four rounds of shared research funding competitions, attracting 43 proposals, and funding the top 13 proposals, as identified by CREW's member companies. CREW also conducts sponsored research, generally funded and directed by a single company. Vestas has funded $498,000 of sponsored research with CREW since 2010.

Due to instability in the production tax credit (PTC) and other industry restructuring, many international wind technology companies have reduced and restructured their R&D presence in the USA. This has created significant challenges for CREW, causing traditional membership in the center to drop to zero in the last year. Currently, CREW is pursuing a new strategy: Sponsoring the development of educational products, including workshops and for-credit university classes, of interest to industry. CREW will build upon this engagement with industry to identify research areas of interest to industry, leading to renewed industry sponsorship.

The wind industry has already contributed a great deal to Colorado, but the industry's best years are still ahead. CREW will continue to serve as a magnet to attract wind power companies to our state.

Carbon Management Center

The Collaboratory's first three research centers have been focused on renewable energy technologies, but the Carbon Management Center's focus will include research and policy analysis having direct application to the coal, oil, and natural gas industries. This work will have direct application to the electric utility industry as well, which is the largest consumer of coal and natural gas, and the largest emitter of carbon dioxide in the state.

The Carbon Management Center commenced research activities in 2009, with a federal grant to conduct basic research related to geologic sequestration of carbon dioxide. The CMC received $342,744 in State matching funds to qualify for $1.37 Million in federal funding.

In 2013, the CMC anchored a team of Colorado researchers competing for a major DOE grant to reconcile inconsistent results from two different methodologies to measure methane gas emissions from natural gas production operations in the D-J Basin, north of Denver. The Collaboratory committed $250,000 in matching funds to help this team meet DOE's requirement for 20% local cost share. The natural gas industry is supportive of this research, and additional matching funds were contributed by major gas producers. In July, 2014, the CMC team was selected for funding by DOE and awarded a $5.2 Million contract for this important research.

CSU is already working on a separate study to detect methane emissions from natural gas gathering and processing systems. And, the U.S. Department of Energy's Advanced Research Projects Agency – Energy (ARPA-E) recently announced that it will fund additional research to detect and facilitate correction of methane leaks from natural gas equipment, from wellheads to end users. CSU and Mines will be submitting separate proposals for this ARPA-E funding, with very different areas of focus. Although they are submitting competing proposals, the two research teams are in close communication and will be happy to collaborate if either proposal is selected for funding.

Developing Areas of Collaborative Research Focus

Energy Systems

All four of the Collaboratory institutions have significant research programs focused on energy systems. The Collaboratory's coordinated energy systems research activities will emphasize smart grid components, management systems and energy efficiency technologies. Led by Colorado State University, this collaborative effort will work with private and public partners to study and overcome the challenges to building a more efficient, reliable and secure grid that incorporates more clean and renewable energy. Because residential and commercial buildings consume approximately 40% of the electricity in the United States, the Collaboratory's energy systems research will also include technologies to design, build, and operate more efficient buildings.

These research activities will benefit from two world class hard-wired grid simulators: the InteGrid Lab, a CSU laboratory in operation since 2006, and the Energy Systems Integration Facility, an award-winning NREL laboratory and office building. Opened in 2013, ESIF is still adding capabilities and is destined to become the world's most powerful smart grid research, test and demonstration facility.

Energy systems researchers from all four Collaboratory institutions are engaged in an ongoing series of networking meetings to build greater awareness of researchers' current research activities, laboratory capabilities and particular areas of interest in energy systems. These team-building activities lay the groundwork for successful, multi-institutional research proposals.

Batteries and Energy Storage Technologies

Energy storage will play a critical role in the energy systems of the future. Whether the focus is compact batteries for mobile devices or large scale storage technologies for local or regional power grids, the future of our electrical energy systems and devices will be driven by storage technologies. And, as the

use of batteries and other energy storage technologies continues to expand around the world, so too does the need to build these storage devices from environmentally benign, low cost materials.

Again, energy storage systems researchers from all four Collaboratory institutions have been engaged in an ongoing series of networking meetings to lay the groundwork for multi-institutional research proposals.

Water/Energy/Food

In all industrial economies, issues related to water, energy and food are inextricably linked. Water is essential to the production of food and energy (steam turbine power plants, cooling towers and hydroelectric power plants). Energy, in turn, is increasingly required to pump and purify water and to produce food (plowing, harvesting, production and delivery). Water and food are essential to life, of course, and so, therefore, is energy.

Too often, the production of energy depends upon the consumption, heating, evaporation or degradation of water. The reduced availability of safe water reduces agricultural production and raises the cost of food. And the insecurity of water and food supplies and the degradation of our air, land and water through pollution related to energy production and consumption impact our health, our economies and our lifestyles. Today, these are topics of interest. Soon, these may become critical issues.

Colorado's economy and our lifestyle are dependent upon fresh water, reliable energy and healthy food. With a semi-arid climate, numerous rivers, a wide variety of energy alternatives, a large agricultural economy, and outstanding research institutions, Colorado is well-positioned to lead the nation and the world in understanding the powerful and intricate interconnections between these interdependent and competing resources and demands.

The Collaboratory is facilitating a series of meetings and conversations among water, energy, food and social science experts at the four institutions to identify issues, define areas of research needs, and build multi-disciplinary and multi-institutional research teams to begin to address these issues of local and global significance.