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September 11, 2015

Fiona Arnold, Executive Director
Michelle Hadwiger, Deputy Director & Director of Global Business Development
Colorado Office of Economic Development and International Trade
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Re: Annual Report from the Colorado Energy Research Authority

On behalf of the Board of Directors of the Colorado Energy Research Authority ("the Authority"), in accordance with Section 24-47.5-102(3), Colorado Revised Statutes, I respectfully submit this report regarding the activities of the Authority during calendar year 2014.

The principal statutory purpose of the Authority is to direct the allocation of State matching funds to support research proposals of the Colorado Energy Research Collaboratory, a research consortium consisting of the Colorado School of Mines, Colorado State University, the University of Colorado Boulder, and the National Renewable Energy Laboratory ("the Collaboratory"). I am pleased to report that 2014 was a very successful year for the Authority, for the Collaboratory, and for the advancement of clean and renewable energy in Colorado.

A Record of Successful Investment of State Funding

In 2006, the General Assembly appropriated $2 Million per year for three fiscal years, ending in June, 2009. H.B. 06-1322. These State matching funds were appropriated to the Authority for allocation to the Collaboratory. The Collaboratory would then use these matching funds to attract and supplement funding from federal and private sources.

Under Section 24-47.5-103, as originally enacted in 2006, the Authority was required to demonstrate by June, 2012 that at least $6 Million in federal grants or contracts for renewable energy research in Colorado had been secured through the Collaboratory programs. In 2012, we reported that the General Assembly's 2006 commitment of $6 Million had attracted federal and industry funding in excess of $37 Million, far beyond the $6 Million baseline requirement. And we were pleased to report in 2014 that, from the Collaboratory's launch in 2007 through 2013, the Collaboratory had received federal and industry funding in the amount of $56.2 Million, a return of 9:1 on the State's investment.

Today, I am proud to report on behalf of the Authority and the Collaboratory that, from 2007 through calendar year 2014, the Authority released $6.59 Million in state funds to the Collaboratory, and the Collaboratory employed these funds to attract federal, foundation and industry funding in the amount of $82.77 Million, a return of more than 12.6:1. This represents

the actual amount of new funding attracted to Colorado on Collaboratory research projects supported by State cost share. This total includes no multiplier, so the actual economic impact of this research funding is much higher. Nor does this figure include the economic impact from the clean energy companies that have been created by the Collaboratory institutions or have been attracted to Colorado by the opportunity to work with the Collaboratory institutions.

In short, $82.8 Million is a conservative estimate of the positive economic impact of the Collaboratory over the past eight years, and 12.6:1 is a conservative estimate of the effective leveraging of the State funds made available to the Authority and the Collaboratory, through OEDIT.

The measurement of the Collaboratory's effective leveraging of State matching funds is a dynamic process. Many research projects that received State funds through the Collaboratory have spawned second, third, and now fourth generations of research, funded by federal, industry, and foundation sources. However, these subsequent generations of research generally receive no additional matching funds. To ensure an accurate accounting, these later generations of research have been included in the $82.8 Million total of Collaboratory research only if the Principal Investigators personally confirm that the later research flowed directly from initial research supported by State matching funds.

Through this "follow-on research," Colorado enjoys additional returns on the original investments of state matching funds, and the state will continue to see even more economic benefits generated by the original $6 Million appropriation. There are several examples of $50,000 and $100,000 "seed grants" for early stage research that have led to federal or industry grants of hundreds of thousands and even millions of dollars in subsequent years, sometimes for three or four generations of research projects. We have every reason to believe the investment of more recently approved State matching funds will also lead to multiple generations of research and significant economic impact.

Subsequent to the General Assembly's 2006 appropriation of $6 Million, former Governor Ritter directed $2 Million to the Authority in 2010 (earned by and distributed to the Authority in 2011). Governor Ritter required that these funds be used for the same purposes and be accounted for in the same manner as defined by the General Assembly in 2006. Consistent with Governor Ritter's direction, the use of these funds has been and will continue to be reported in accordance with the General Assembly's requirements in Section 24-47.5-103.

There is a wealth of detail regarding the operations of the Authority and the Collaboratory in the following pages and the appendices. Here, in summary, is a brief overview of the Collaboratory's performance from its launch in 2007 through 2014:

- **The Collaboratory centers' private industry members have contributed more than $4.97 Million to support the centers' shared (non-exclusive) research.**

- **Private industry has funded or committed to fund more than $16.63 Million in sponsored research by the Collaboratory centers and individual Collaboratory institutions.**

- **The federal government has funded or committed to fund more than $61.17 Million in sponsored research by the Collaboratory institutions.**
- **To attract these private and federal funding commitments of more than $82.8 Million, the Collaboratory expended $6.59 Million in State matching funds.**
- **The Collaboratory has generated 12.6 dollars in private and federal funding for every dollar of State matching funds.**
- **The Collaboratory is helping to attract large and small employers to Colorado and to create home-grown businesses with strong roots in Colorado and growing employment rolls.**

The initial award of funds by the General Assembly and Governor Owens in 2006, Governor Ritter's 2010 commitment and the General Assembly's 2014 appropriation, with Governor Hickenlopper's support, have been essential to the shared goal of establishing Colorado as a clean energy research leader. The commitment of state funds allows the Collaboratory to successfully attract private support for the Collaboratory's centers and to successfully compete for federal research funding.

In the appendices to this report, I summarize the new grants awarded by the Authority and the Collaboratory in support of groundbreaking research through 2014. In most of the past eight annual reports from the Authority, the activities of the Collaboratory centers have dominated the discussion, because the centers received most of the state funds and conducted most of the Collaboratory-supported research activities. Each of these centers has been managed by a leadership team that includes representatives from all four of the Collaboratory institutions, with one institution serving as the lead. In short, these centers – and their great success to date – exemplify true collaboration.

In fact, the Collaboratory's success has earned special praise from the Brookings Institution.

> *[As] Denver has grown increasingly important for global renewable energy firms, NREL has needed to refocus its technology transfer efforts closer to home. One such successful effort is the Colorado Energy Research Collaboratory, a regional research consortium between NREL and three other Colorado research institutions that provides the region's energy industry a direct avenue to work with leading scientists and engineers.*
>
> *Source: "Going Local: Connecting the National Labs to their Regions for Innovation and Growth,"* p. 4, BROOKINGS/ITIF/CCEI, ADVANCED INDUSTRIES SERIES, September 2014

As we reported last year, the Collaboratory's model of collaborative research has evolved and thrived. The membership and dues structure of the first three Collaboratory centers is yielding to new models and to more emphasis on DOE-funded research. But the level of collaboration among the four institutions has never been stronger, and the close connection to

industry remains a key to our success. For example, the Collaboratory's Carbon Management Center, led by the Colorado School of Mines, has organized and led a team with CSU, NREL, NOAA, and NCAR researchers, funded by DOE, the Research Partnership to Secure Energy for America, and 24 natural gas industry partners – American and multinational. The mission of this powerful team is to reconcile the results of multiple methods of assessing methane emissions to achieve more reliable estimates of emissions from natural gas operations. This Collaboratory-led and Authority-supported research is being watched by industry players, government regulators, and researchers around the world.

The Collaboratory leadership, the Collaboratory centers' management teams, the world class researchers, and the many administrative personnel who support research at the four Collaboratory institutions are responsible for the success of the Collaboratory. They are responsible for the scientific, technological, and economic benefits flowing to the State of Colorado. On behalf of all seven of the Directors of the Colorado Energy Research Collaboratory, I offer our thanks and admiration to these many outstanding individuals.

Shifting Emphasis from Center-Based Research to DOE Funded Research

The General Assembly's original, $6 Million appropriation was expended by the end of 2012, with very successful results, as documented above. When the recession of 2008 hit, many energy companies – including many Global 100 companies – reduced their research budgets, and all of the Collaboratory centers lost industry members. In the following years, renewable energy industries took more targeted hits due to other factors.

The majority of the Collaboratory's solar energy company members were focused on solar photovoltaic technologies. These companies took a severe blow when Chinese companies began to flood the market with low cost (government subsidized) PV panels in 2009 and 2010.

The Collaboratory's wind energy industry partners were also hit hard in 2012 and 2013, when Congress signaled that it may not renew the production tax credit for new wind farms. Under the existing tax law, wind farms had to be in operation before yearend 2012 to receive the tax credit, so utilities and other wind farm developers stopped ordering new turbines in mid-2012, fearing they would not be able to complete construction by year end. Collaboratory members such as Vestas, RES Americas, and Mitsubishi saw orders for their products and services vanish during the second half of 2012, and most of these companies reduced their external commitments. Although Congress did renew the PTC at the very end of 2012, the wind industry did not recover until mid-2013.

In response to these events and impacts on Collaboratory centers, the Collaboratory leadership restructured the model for distribution of matching funds to prepare for slow growth of the Collaboratory in future years, as compared to the early, explosive growth. The initial $6 Million appropriation, expected to last three years, was carefully managed to last five years. Governor Ritter offered a one-time opportunity for the Authority and the Collaboratory to earn $2 Million in State Fiscal Stabilization Funds under the American Recovery and Reinvestment Act of 2009, and the Collaboratory was able to meet the terms of this grant. With these new funds, the Authority

and the Collaboratory began to refocus the research targets and improve the return on the use of state funding.

First, the Authority and Collaboratory leadership began in 2011 to gradually reduce the amount of matching funds available to the Collaboratory's established research centers (bioproducts [C2B2], solar [CRSP], and wind [CREW]). Next, the Collaboratory leadership began to increase the amount of funds to support collaborative proposals for federal research grants. The Collaboratory's researchers adapted quickly to the new emphasis on federal grants by identifying attractive grant opportunities, building multi-institutional teams and developing very strong research proposals. These proposals were then reviewed by the Collaboratory leadership before state funds were committed to help the research team meet DOE's cost share requirements.

Over the past seven years, federal grants have provided the best short term leverage of Collaboratory matching funds, with each grant providing at least $4 for every $1 of matching funds, and sometimes as much as $9 for every $1 of state funds. These early stage research projects often lay the foundation for significant advancement in emerging technologies. As a result, Collaboratory support for these DOE-sponsored early stage research projects often leads to later generations of more applied research, which could be funded by DOE, foundations, or industry.

Collaboratory Success in the Competition for Federal Research Funding

It took several years for the shift in funding strategy from center-based research to DOE-funded research to bear fruit, but it has proven to be extremely successful. Paradoxically, the transition away from funding the centers was successful precisely because of the success of the Collaboratory centers in building strong, multi-institutional networks of researchers. These networks became the foundation of numerous teams of Collaboratory researchers who submitted successful proposals for DOE funding in 2013 and 2014.

In 2013, as Collaboratory-supported researchers began to shift from center-focused activities to federally funded research, the Collaboratory disbursed only $239,000 in matching funds, the lowest annual total since inception. In 2013, however, Collaboratory researchers received more than $1.5 Million in federal funding. Continuing this success in 2014, the Authority disbursed only $240,000 in state funds, and attracted $1.67 M in federal funding.

As we look ahead, the future is very bright. As of December 31, 2014, the Collaboratory had outstanding commitments of $1.34 Million on four Collaboratory proposals officially selected for funding by DOE. These commitments of $1.34 Million will bring over $21 Million to the Collaboratory institutions and the Colorado economy in 2015 and succeeding years. This anticipated funding is not included in the $82.8 Million in funding received through 2014, and will be officially tallied in the Authority's 2016 report. (Disbursements of Authority funds and receipt of federal funding are reported as of the calendar year in which the Authority disbursement of funds actually occurs, often in the year following the date of the commitment.)

These new DOE grants provide further evidence of the successful strategic pivot away from the center-based model, a pivot initiated by the Authority and Collaboratory leaders,.but effectuated by the Collaboratory's outstanding researchers. Though highly successful in many ways, the centers generated 1:1 leverage in the first generation of research. In 2014 and, we already know, in 2015, the Collaboratory is successfully competing for DOE funded, early stage research, with 1:4 or 1:9 leverage. And, as we've learned in prior years, this early stage research will attract later generations of research to all four Collaboratory institutions and continue to build Colorado's clean energy research and business sectors.

Over the past five years, fifty percent of Collaboratory proposals for DOE competitive research opportunities have been selected for funding, *a rate of success far greater than the average, and substantially higher than any of the four Collaboratory institutions have achieved individually.* In combination, the four institutions have an extraordinarily talented community of researchers, and they have learned how to work together.

State Funding Remains Essential to the Authority and Collaboratory Missions

The 2014 appropriation of $1 Million for FY 15 and an additional $1 Million for FY 16 provide the Authority and Collaboratory with a level of baseline funding which is likely to carry the Collaboratory through mid-2016. However, if, as expected, DOE continues its recent focus on research topics that align well with Collaboratory strengths, the Collaboratory may exhaust the balance of available funds before mid-2016.

The Authority and Collaboratory leaders are keenly aware of the budget challenges facing the Governor's Office and the General Assembly, and we will continue to search for alternative sources of funding and for cost-saving practices to stretch the remaining matching funds. In the long term, though, State matching funds are essential to attract federal and industry funding for the following reasons:

- Most federally funded energy research grants require some level of matching funds (usually 20% of the total project budget) as a precondition for application;
- Industry partners view State matching funds both as an indicator of State commitment to important research projects and as a way to stretch industries' own research investments; and
- Other states are successfully using state funds to attract industry partnerships to their state research institutions, so Colorado State support is essential to our competitive success.

With full recognition that the State's funding has been critical to the Authority's and the Collaboratory's success, we are grateful for the continuing commitment of Colorado's elected leaders to the missions of the Authority and the Collaboratory.

Helping to Build Colorado's Economy

H.B. 06-1322 recognized that the development and production of clean energy will advance the economic well-being of Colorado. Since the Collaboratory's launch in January, 2007, we have seen a substantial expansion in Colorado's clean energy research, development, production, and manufacturing capabilities. According to the Metro Denver Economic Development Corporation, the Colorado "cleantech cluster" now ranks as the sixth highest concentration of cleantech workers among the 50 largest metropolitan areas in the country, *with a growth rate of 29% since 2009, twice the national growth rate*.

Cleantech Cluster

Metro Denver EDC's report defines the cleantech cluster as follows: "The cleantech sub cluster includes companies that produce and conserve energy using wind, solar, biomass, fuel cells, hydroelectric resources, and green transportation technologies. Companies that manufacture renewable energy equipment, storage, and power transformers, and businesses that provide engineering and other support services are also included. The sub cluster includes energy research companies that provide laboratory testing, scientific and technical consulting services, and institutional research related to the environment, natural resources, and energy. The cleantech sub cluster consists of 29, six-digit North American Industry Classification System (NAICS) codes." Metro Denver Economic Development Corporation | ENERGY: Colorado Industry Cluster Profile | January 29, 2015 | Page 1

- In absolute numbers of cleantech workers, Colorado ranks 10th.
- In addition, the number of companies directly engaged in Colorado's cleantech sector grew from 1,430 in 2013 to 2,020 in 2014, a 41% increase in one year.
- Direct employment grew from 18,880 in 2013 to 23,410 in 2014, a 24% increase.

In short, Colorado's cleantech sector is already a significant aspect of Colorado's economy, and its rate of growth is continuing to accelerate.

Among the reasons cited by Metro Denver EDC for Colorado's strong standing as a national energy leader are the quality of and accessibility to our educational and research centers, including the four Collaboratory institutions. The Collaboratory helps to attract employers to Colorado by building an educational and research cluster that serves industry. By educating undergraduate and graduate students in science, engineering, business and other disciplines, the Collaboratory ensures that clean energy businesses and their suppliers can find the talent that will help them succeed.

The close partnership between NREL and the universities has also helped to attract world class researchers. Without this powerful partnership, many of these nationally recognized researchers would have been hired by our competitors in other states and countries. In short, clean energy R&D and manufacturing companies locate where the R&D community can support their needs, and Colorado's R&D community is recognized as a world leader.

Colorado is a world-class hub for energy research and technology innovation. The state's 30 federal laboratories—one of the highest per-capita concentrations of federal research facilities in the nation—support the state's energy research platform. These laboratories employ over 15,680 direct and indirect workers and generate over $2.3 billion in annual economic impact to Colorado, contributing significantly to the evolution of the state's high-tech industries.

Source: Metro Denver EDC Energy Cluster Report 2014

The Collaboratory is playing a key role in creating and supporting homegrown companies and in attracting existing clean energy companies that are looking to relocate. These employers already representover 23,000 jobs in Colorado. We are grateful that the Collaboratory's role in bringing businesses and jobs to Colorado has been acknowledged by State officials, by the Metro Denver Economic Development Corporation, and by other Colorado economic development agencies.

Protecting Colorado's Role as a Leader in Clean Energy Innovation

The Collaboratory is a uniquely successful model of true collaboration. Our first generation of research has led to second, third and fourth generations, leveraging **$6.59 Million** in state funding to attract more than $**82.8 Million** in additional federal and industry funding for advanced energy research in Colorado. However, the continued success of the Collaboratory is not guaranteed. To survive, an R&D community needs a constant stream of new research ideas, supported by a combination of public and private funding.

From 2007 to 2012, the biofuels, solar, and wind sectors helped to build and broaden Colorado's economy, and these sectors will continue to play a significant role in Colorado's economic growth. Looking forward, the Authority and Collaboratory leaders also see four other areas of energy innovation which will play increasingly large roles in federal funding and in Colorado research and economic growth: carbon management; energy management systems; subsurface scientific exploration leading to geothermal energy development; and the complex interconnections of water, energy, and food.

The interface of water, energy, and food takes us back to Colorado's cultural and economic roots. Our people and our industry cope with these interconnections every day:

- Water and energy are needed to produce food;
- Energy is needed to move and use water, whether for pumping underground aquifers, trans-basin diversion or purifying water for municipal or industrial use;
- Most thermal energy power plants need water for power generation or cooling, or both;
- Increasingly, crops and woodlands are sources of fuel to produce energy.

This complex of issues is attracting major attention from the National Science Foundation and the Department of Energy. Colorado can and should play a leading role as the nation works to understand these Water/Energy/Food interconnections and to maximize the benefits and minimize the costs of these interdependencies, especially as we prepare to face of the possibility of water shortages.

These emerging research issues, along with bio-refining, solar and wind, and the traditional energy sectors of oil and gas, will drive the creation of new technologies, new companies, and new jobs. The Collaboratory's reputation for research excellence has been and will continue to be a central factor in creating and supporting Colorado-born businesses and helping to attract top companies to our state.

The Collaboratory's success and the impact of clean energy R&D as an economic driver have not been ignored by other states. Today, it's widely recognized that the states that succeed in establishing leadership in the still emerging clean energy sector will attract major national and international companies and investment. This success will bring research, manufacturing, construction, and financial jobs to those states for the next 25 years and beyond.

The Directors of the Colorado Energy Research Authority are grateful for the past support of Colorado's Governors and the Colorado General Assembly, and we are proud that we have exceeded your and our expectations in the effective investment of these State funds. We look forward to continuing this productive relationship, and we will be pleased to respond to any questions you may have at this time or in the future.

Sincerely,

Anthony Frank, Ph.D.
President and Chancellor, Colorado State University
Chair, Colorado Energy Research Authority

Copies:

Governor Hickenlooper
Directors of the Colorado Energy Research Authority

Appendix A

2015

COLORADO ENERGY RESEARCH AUTHORITY

BOARD OF DIRECTORS

Anthony Frank, Ph.D., President and Interim Chancellor
Colorado State University
(Chair)

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

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

Philip DiStefano, Ph.D., Chancellor
University of Colorado Boulder

Michelle Hadwiger, Deputy Director
Colorado Office of Economic Development & International Trade

Paul Johnson, Ph.D., President
Colorado School of Mines

Kimberly Jordan, CEO
New Belgium Brewing Company (*Second and final term ended August 1, 2015)*

Appendix B

PRIVATE AND FEDERAL FUNDING FOR COLLABORATORY RESEARCH [1]
2007 - 2014

Shared Research [2]

- C2B2, CRSP and CREW industry member contributions for the centers' shared research projects **$4.97 M**
  (Matched by $4.57 Million in State funds)

Sponsored Research [3]

- Industry and other private (e.g. foundation) funding 16.63 M
- Federal funding 61.17 M
  (Matched by $2.02 Million in State funds)

SUB- TOTAL SPONSORED RESEARCH **77.80 M**

TOTAL SHARED AND SPONSORED RESEARCH FUNDING FROM PRIVATE AND FEDERAL SOURCES **82.77 M**

Total Matching Funds Expended or Committed Through 2014 **$6.59 M**

THE COLLABORATORY HAS EMPLOYED $6.59 MILLION IN STATE FUNDS TO ATTRACT $82.77 MILLION IN PRIVATE AND FEDERAL ENERGY RESEARCH FUNDING TO COLORADO SINCE 2007.

Leverage on State Funding **12.6:1**

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

   The Collaboratory also distributes limited state funds to multi-institutional teams to help meet DOE cost share requirements for federally funded research opportunities.
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.
3. Sponsored research may be federally or industry funded and may be conducted by one or more Collaboratory institutions, either 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.
4. These estimates of initial research funding, follow-on funding and economic impact are not represented to be in compliance with accounting standards, but are based upon actual disbursements of state funds and best estimates of federal and industry funding.

Appendix C

RESEARCH PROJECTS RECEIVING STATE MATCHING FUNDS IN 2014

1. **Update on this project: Title: Evaluation of Cellulosic Biomass-Derived Oxygenates as Drop-In Fuel Blend Components (DE-FOA-0000239): See new publications**

   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 was 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 portion of this research project is still at an early stage.

Publications

Ratcliff, M.A., Burton, J., Sindler, P., Christensen, E., Chupka, G.M., Fouts, L., McCormick, R.L. "Knock Resistance and Fine Particle Emissions for Several Biomass-Derived Oxygenates in a Direct-Injection Spark-Ignition Engine" in preparation.

Baumgardner, M.E., Vaughn, T.L., Lakshminarayanan, A., Olsen, D., Ratcliff, M., McCormick, R.L., Marchese, A.J. "Combustion of Cellulosic Biomass Based Oxygenated Components in a Compression Ignition Engine" Energy Fuels submitted.

McCormick, R.L., Ratcliff, M., Christensen, E., Fouts, L., Luecke, J., Chupka, G.M., Yanowitz, J., Tian, M., Boot, M.D. "Properties of Oxygenates Found in Upgraded Biomass Pyrolysis Oil as Components of Spark and Compression Ignition Engine Fuels" Energy Fuels 29 2453–2461 (2015).

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).

Ratcliff, M., Luecke, J., Williams, A., Christensen, E., Yanowitz, J., McCormick, R.L. "Impact of Higher Alcohols Blended in Gasoline on Light-Duty Vehicle Exhaust Emissions" Environ. Sci. Technol. 47 13865–13872 (2013).

Tao, L., Aden, A., He, X., Tan, E.C.D., Zhang, M., Zigler, B.T., McCormick, R.L. "Techno-economic Analysis and Life-cycle Assessment of Cellulosic Iso-Butanol and Comparison with Cellulosic Ethanol and n-Butanol" Biofuels, Bioproducts, and Biorefining DOI: 10.1002/bbb.1431 (2013).

Hensley, J.E., Lovestead, T.M., Christensen, E., Dutta, A., Bruno, T., McCormick, R.L. "Detailed Compositional Analysis and Distillation Properties of Mixed Alcohols Produced via Syngas on K-CoMoS$_x$" Energy Fuels 27 3246–3260 (2013).

II. **Title: Selective Area Growth of III-V Materials on Si Patterned using Nanoimprint Lithography**

a. Authority Matching Funds: $166k
b. DOE Funding: $1.5 Million
c. Participating Institutions: National Renewable Energy Laboratory, Colorado School of Mines
d. Principal Investigators: NREL: Adele Tamboli, Emily Warren, Daniel Friedman, Bill McMahon, Andrew Norman, Pauls Stradins; CSM. Jeramy D. Zimmerman
e. Investigators: Emily Makoutz (CSM Graduate Student)
f. Project Duration: 2013 – 2017

g. Project Description:

The objective of this project is to develop a cost-competitive growth technique for the direct integration of III-V on Si tandem solar cells, which are a promising technology to meeting the SunShot goals for photovoltaic efficiency and cost metrics. By using nanoscale heteroepitaxy, we plan to decrease the metamorphic relaxation region for lattice-mismatched materials grown on Si while maintaining excellent Si surface passivation.

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

At Colorado School of Mines, the funds for this project have been used for graduate student stipend, graduate student tuition, PI summer effort, materials and supplies needed to support microstructural analysis. At NREL the DOE funds support NREL staff, purchase materials and supplies, and microstructural analysis.

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

None to date.

Appendix D

Cumulative Collaboratory Research Metrics
2007 – 2014

Industry Members	52
Colorado Companies as Members	15
Non-member Companies Participating in Collaboratory Activities	88
Shared Research Projects	144
Industry Sponsored Research Projects	48
Federally Sponsored Research Projects	69
Other Sponsored Research Projects (foundation, institute, university etc.)	18
Researchers engaged – Shared Research	185
Researchers engaged – Industry Sponsored Research	43
Researchers engaged – Federal and Foundation Sponsored Research	213
Undergraduate Students Engaged	89
Publications	44*
Patent Filings	9*

Note: Metrics with an asterisk do not include researchers, publications or patent 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 Bioproducts

The Colorado Center for Biorefining and Bioproducts, 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 have played 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 $2.147 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 $1.275 Million 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 directed $1.5 Million to NREL and CSU.

In total, then, State matching funds of $3.66 Million are directly responsible for attracting more than $19.5 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. Many of C2B2's shared research projects later 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 and other Collaboratory supported biofuels research have, to date, brought an <u>additional</u> $44.77 Million in federal and private research funding to Colorado.**

In total, then, the investment of $3.66 Million in State matching funds to C2B2 and Collaboratory institutions working on biofuels, biorefining and related bioscience projects has attracted $64.27 Million in both federal and private research, as well as educational funding to Colorado.

The $64 Million defined above 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 nine patents developed through shared and sponsored research,
- Published more than 44 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.

Bioproducts and bio refining research (and related employment opportunities) are of greater and greater interest to undergraduate students, graduate students, and postdoctoral researchers. Without increased funding, however, C2B2 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.

Center for Revolutionary Solar Photoconversion

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 $1.976 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 $2 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 has 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. Through 2014, the University of Colorado-Boulder served the lead institution for CREW, and the Scientific Director resided 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 $444,000 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, reducing industry membership and funding. Currently, CREW is pursuing a new strategy: Sponsoring the development of educational products, including workshops and for-credit university classes, on topics 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.

In 2014, CREW used a combination of state and industry partner funds to support development of a course curriculum entitled "Grid Integration of Wind Energy Conversion Systems," organized by CSU Assoc. Prof. Sid Suryanarayanan, Ph.D., with assistance from Dr. James Cale, NREL, and Dr. Andrew Oliver of RES-Americas. The course is appropriate for upper-class undergraduate students, graduate students and representatives of the wind and electric utility industries. The course was

initially offered at CSU and, in 2015, the course was made available to the public on line. http://www.engr.colostate.edu/ECE566/course_info.shtml

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 $342,000 in State matching funds to qualify for $1.37 Million in federal sponsored research 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 $350,000 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 of $1.2M were contributed by major gas producers. In July, 2014, the CMC team was selected for funding by DOE and awarded a $3.2 Million contract for this important research, but the actual federal contract was not executed until August 2015. This research project will be included in the financial summary of calendar year 2015, to be submitted in 2016.

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 (ESIF), 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 (including liquid fuels for plowing, harvesting and distribution, natural gas for the production of many fertilizers, and natural gas and electricity for the processing of foods). 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. The insecurity of water and food supplies, and the degradation of our air, land, and water through pollution related to energy production and consumption, present growing challenges to our health, our economies, and our lifestyles. Today, these are topics of interest. Soon, these will 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. Building multi-disciplinary and multi-institutional research teams, these expert researchers are identifying local and global issues, and defining areas of research needs. The Collaboratory is also supporting NREL's work with other U.S. Department of Energy Laboratories to work on the issues at the regional and national scales.