|  |  |
| --- | --- |
| **Macintosh HD:Users:Rosalynn:Desktop:C-DEBIlogo4_EEE.eps** | **Center for Dark Energy Biosphere Investigations STC Annual Report 2018** |

[**I. GENERAL INFORMATION**](#_I._GENERAL_INFORMATION_4) **3**

1. Center General Information
2. Changes in Faculty
3. Primary Contact
4. Context Statement

[**II. RESEARCH**](#_II._RESEARCH_4) **6**

1. Overall Research Goals and Objectives
2. Research Thrust Areas
   1. Theme 1: Fluxes, Connectivity, and Energy
   2. Theme 2: Activities, Communities, and Ecosystems
   3. Theme 3: Metabolism, Survival, and Adaptation
   4. Field Projects
   5. Projects from our Grants and Fellowships Program
   6. C-DEBI Workshops
3. Performance with Respect to the Strategic Implementation Plan
4. Plans for the Next Reporting Period

[**III. EDUCATION**](#_III._EDUCATION_5) **22**

1. Overall Education Goals and Objectives
2. Undergraduate Students
3. Graduate Students and Postdoctoral Scholars
4. K-12 and the General Public
5. Performance with Respect to the Strategic Implementation Plan
6. Plans for the Next Reporting Period

[**IV. DATA MANAGEMENT AND KNOWLEDGE TRANSFER**](#_IV._DATA_MANAGEMENT_4) **28**

1. Overall Data Management and Knowledge Transfer Goals and Objectives
2. Knowledge Transfer Activities and Organizations
3. Data Management and Integration Activities and Organizations
   1. Making Data Publically Available
   2. Providing Computational Resources to C-DEBI Researchers
   3. Expanding the Impact of C-DEBI Data through External Partnerships and Collaborations
4. Performance with Respect to the Strategic Implementation Plan
5. Plans for the Next Reporting Period

[**V. EXTERNAL PARTNERSHIPS**](#_V._EXTERNAL_PARTNERSHIPS_7) **33**

1. Overall External Partnerships Goals and Objectives
2. Activities Conducted as Part of Partnerships
3. Performance with Respect to the Strategic Implementation Plan
4. Plans for the Next Reporting Period

[**VI. DIVERSITY**](#_VI._DIVERSITY_3) **37**

1. Overall Diversity Goals and Objectives
2. Programs and Activities Which Enhance Diversity at the Center
3. Performance with Respect to the Strategic Implementation Plan
4. Plans for the Next Reporting Period

[**VII. MANAGEMENT**](#_VII._MANAGEMENT_2) **43**

1. Overall Organizational Strategy
2. Management and Communications Systems
3. Performance with Respect to the Strategic Implementation Plan
4. Plans for the Next Reporting Period

[**VIII. CENTER-WIDE OUTPUTS AND ISSUES**](#_VIII._CENTER-WIDE_OUTPUTS_2) **49**

1. Center Publications
2. Conference Presentations
3. Honors, Awards and Grants
4. Placement of Graduated Students and Postdoctorals
5. Outputs of Knowledge Transfer Activities
6. All Participants
7. Institutional Partners
8. Summary Table for Internal NSF Reporting Purposes
9. Media Publicity
10. Distributable Media

[**IX. INDIRECT/OTHER IMPACTS**](#_IX._INDIRECT/OTHER_IMPACTS_1) **51**

1. International Activities and Other Outputs, Impacts, or Influences

[**X. BUDGET**](#_X._BUDGET) **51**

1. Current Award Year and Unobligated Funds
2. Requested Award Year
3. Center Support from All Sources
4. Additional Investigator Support From All Sources

**APPENDICES**

[Appendix A – References Cited](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-A-References-Cited-2.pdf)

[Appendix B – Active Grants and Fellowships](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-B-Active-Grants-and-Fellowships-2.pdf)

[[Appendix C – CC-RISE and C4 Student Evaluation](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-C-CC-RISE-and-C4-Student-Evaluation-2.pdf)](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-C-CC-RISE-and-C4-Student-Evaluation.pdf)

[Appendix D – GGURE Academic Student Evaluation](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-D-GGURE-Academic-Student-Evaluation.pdf)

[Appendix E – GGURE Summer Student Evaluation](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-E-GGURE-Summer-Student-Evaluation.pdf)

[Appendix F – GEM Student Evaluation](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-F-GEM-Student-Evaluation-1.pdf)

[Appendix G – PD Workshop Evaluation](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-G-PD-Workshop-Evaluation.pdf)

[Appendix H – Center-wide Outputs](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-H-Center-wide-Outputs.xlsx)

[Appendix I – Current Award Year Budget](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-I-Current-Award-Year-Budget.pdf)

[Appendix J – USC Account Status](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-J-USC-Account-Status.pdf)

[Appendix K – Requested Award Year Budget](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-K-Requested-Award-Year-Budget.pdf)

[Appendix L – Institutional Commitment](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-L-Institutional-Commitment.pdf)

# I. GENERAL INFORMATION

## 1. Center General Information

|  |  |
| --- | --- |
| **Date Submitted** | 12/31/2018 |
| **Reporting Period** | 1/1/2018 - 12/31/2018 |
| **Center** | Center for Dark Energy Biosphere Investigations |
| **Center Director** | Jan P. Amend |
| **Lead University** | University of Southern California |
| **Co-Principal Investigator** | Steven L. D’Hondt, University of Rhode Island |
| **Co-Principal Investigator** | Andrew T. Fisher, University of California Santa Cruz |
| **Co-Principal Investigator** | Julie A. Huber, Woods Hole Oceanographic Institution |
| **Co-Principal Investigator** | C. Geoffrey Wheat, University of Alaska Fairbanks |

## 2. Changes in Faculty

None.

## 3. Primary Contact

|  |  |
| --- | --- |
| **Name of Individual** | Jan P. Amend |
| **Center Role** | Director |
| **Address** | 3616 Trousdale Pkwy, Los Angeles, CA 90089-0371 |
| **Phone Number** | 213-740-0652 |
| **Fax Number** | 213-740-8801 |
| **Email Address** | janamend@usc.edu |

## 4. Context Statement

C-DEBI’s stated mission is to explore life beneath the seafloor and make transformative discoveries that advance science, benefit society, and inspire people of all ages and origins. Specifically, we seek to better understand the microorganisms that inhabit the sediment, rock, and fluid in the marine subsurface. Our scientific goals are organized into three broad research themes: (1) *Fluxes, Connectivity, and Energy*—centering on subseafloor environmental conditions; (2) *Activities, Communities, and Ecosystems*—emphasizing resident microbial communities; and (3) *Metabolism, Survival, and Adaptation*—concentrating on the actions and traits of individual microbial species. These goals are pursued with a combination of approaches, including field investigations, laboratory experimentation, chemical analyses, nucleic acid sequencing, and modeling studies. We note that C-DEBI has committed and continues to commit major resources to the scientific investigations at ‘major’ field sites. These include the Juan de Fuca Ridge flank (JdF), South Pacific Gyre (SPG), North Pond (NP), Dorado Outcrop (DO), and the Atlantis Massif (AM). However, we also financially support smaller or burgeoning field investigations, such as those at the Mariana forearc and trench, the sediments of the North Atlantic, the Baltic Sea Basin, Guaymas Basin, and others. C-DEBI scientists visited several of these field sites in 2018, retrieving valuable samples and data for our investigations. In addition to the research themes, C-DEBI also facilitates and encourages the synthesis and broad understanding of submarine microbiological processes within a geochemical, geophysical, and hydrogeologic context. This is largely accomplished by funding scientific and technical activities, coordinating and hosting meetings and workshops, and supporting researchers and graduate students. These research endeavors generate a vast array of diverse datasets that need to be managed and integrated, as well as a vast array of new knowledge that needs to be disseminated. C-DEBI has established and now operates state-of-the-art programs in these arenas. Furthermore, in our education, outreach, and diversity programs, we seek to entrain, educate, inspire, and mentor an interdisciplinary community. Specifically, we create and operate activities aimed at three target groups: (1) undergraduate students, especially community college students; (2) graduate students and postdoctoral scholars; and (3) K-12 and the general public. The aforementioned activities in research, data integration, knowledge transfer, education, outreach, and diversity are managed by a talented and skilled team in each of these disciplines, with critical indicators and a strategic implementation plan in place to quantitatively evaluate the Center’s performance.

In 2018, significant accomplishments were recorded in our three research themes; a few examples are highlighted here. Within Theme 1, *Fluxes, Connectivity, and Energy*, new studies reported on energy usage in biomass generation and maintenance in a model organism, microbial growth and dormancy models in energy-limited sedimentary environments, carbon availability to microbes in ocean crust ecosystems, and 3-dimensional fluid-heat hydrothermal circulation models at a fast spreading ridge flank. Within Theme 2, *Activities, Communities, and Ecosystems*, C-DEBI scientists authored a number of papers that focused on the effects of extracellular DNA in sequencing surveys, the response of sediment microbial communities to large-scale geologic disturbance events and changing geochemistry, the dominance of phylogenetically novel uncultivated taxa in the marine subsurface, deep biosphere samples characterized by very low biomass, *in situ* and *in vivo* microbial activity measurements, and subseafloor microbe-virus interactions. Investigations within Theme 3, *Metabolism, Survival, and Adaptation*, generated new knowledge pertaining to individual microbes. 2018 saw experimental studies of extracellular electron transport in the model organism *Shewanella oneidensis* and in several recent isolates from marine sediments, growth experiments and ‘omics’ approaches applied to a sulfur-reducing deep-sea vent isolate, investigations of genetic plasticity in several dozen *Halomonas* strains, new insight into ribosome stability and chromosome replication in *Dehalococcoides* under low energy fluxes, and bioinformatics studies of numerous near-complete and high quality genomes.

During this reporting period, C-DEBI’s education, outreach, and diversity (EOD) programs again focused predominantly on research opportunities for community college students, and training and mentoring of graduate and postdoctoral researchers. It should be stated that C-DEBI’s approach to improving access and support for members of underrepresented and marginalized groups involves purposeful integration with the fundamental research and education missions. Two of our EOD flagship programs are the Community College Research Internship for Scientific Engagement (CC-RISE) and the Community College Cultivation Cohort (C4). CC-RISE is a non-residential REU-style program at two of our partner institutions, the University of California at Santa Cruz (UCSC) and the Woods Hole Oceanographic Institution in Massachusetts. Eight students spent 8 weeks during the summer in state-of-the-art research labs, carrying out experiments and analyses, and participating in professional development seminars. 2018 was the final year of our residential C4 REU program. As in the previous two years, 8 students spent 9 weeks during the summer characterizing the physiology and phylogeny of a novel marine microbial species. This year, the students learned and applied culturing, microscopy, analytical chemistry, and bioinformatics to an iron-oxidizing Zetaproteobacterium. As noted above, C-DEBI annually supports many (~70) graduate students and postdoctoral scholars. Some of them are members of the research personnel in the Co-I labs, and others are awardees in our fellowship program. All of them received a wide range of professional training in 2018 that intertwined their research with education and outreach.

The main objective of C-DEBI’s data management and knowledge transfer programs is to disseminate freely and rapidly the most important scientific discoveries and technical advances to the scientific community and the broader population. The data management and integration team seeks to ensure that the variety of data types and products are archived, shared, and accessible for the long term. C-DEBI knowledge transfer occurs via numerous mechanisms, the most effective of which for transfer to the scientific community remains to be through peer-reviewed journal publications. Additional avenues include worldwide access to data and new technologies, exchanges of personnel, lectures and presentations, professional development activities, conferences and workshops, and targeted courses for students and educators. The dissemination of C-DEBI products relies on our ability to reach the target audiences. In this regard, we note that C-DEBI’s mailing list counts over 1000 individuals in 40 countries. Of these, over 250 are 'active' participants, defined as those who presented or participated at one of our workshops or conference sessions, received funding from C-DEBI, served on one of our committees or panels, or otherwise engaged directly in C-DEBI science or education activities.

In this Context Statement, we also address some of the key comments made by the external review panel in last year’s site visit report.  The panel encouraged C-DEBI to continue its active participation in improving diversity at higher levels of the center and at the home institutions of the Co-I’s.  We must reiterate, however, that C-DEBI does not hire faculty and does not sit on hiring committees.  Our greatest influence in building and expanding a diverse community is linked to our graduate student and postdoctoral fellowship program.  In the natural sciences, women are still underrepresented, and C-DEBI has a strong record of engaging and funding women at all levels, and in selecting women to leadership positions.  As just a couple of examples, 3 of the 6 new Co-I’s appointed when Amend took over as Director are women (Julie Huber as Associate Director and Beth Orcutt and Victoria Orphan as Senior Scientists), and 14 of the 21 invited lecturers in our Network Speaker Series are early career women.  We also deliberately seek diverse participation at higher levels when positions are available and when we are in a position to influence these decisions.  Lastly, we continue to train a diverse next generation of leaders in our research, education, and outreach programs to strengthen the pipeline. The panel also requested information on the work of the External Advisory Board (EAB). A report from our EAB was not available to include here, but we will inform on their activities at the 2019 site visit. Note that this year, the EAB was specifically tasked with assessing C-DEBI’s successes with regards to our graduate students, postdoctoral scholars, and young investigators. The panel further suggested that the budget presentations (in the annual report and at the site visit) be better aligned with the three research themes; we have included such budgetary partitioning here. The panel’s report also recommended that C-DEBI generate robust predictive and synthetic models of subseafloor ecosystems in the sunsetting years of the STC; while efforts are certainly underway in this direction, the magnitude of this task is beyond our remaining resources. However, this is a clear target for legacy planning. Lastly, the panel called on C-DEBI to have its social media activities be more “outward facing” and less targeted towards internal consumption. We are ever increasing our social media presence and other communication channels with the general public. We note, for example, Co-I Victoria Orphan’s starring role in the full-length documentary ‘The Most Unknown’ (available on Netflix) and Co-I Julie Huber’s interview with Neil deGrasse Tyson on National Geographic’s ‘Star Talk’ (to be televised in spring 2019), along with the many associated (social) media bursts.

# II. RESEARCH

## 1. Overall Research Goals and Objectives

The Center’s overall research goals have not changed from the previous year. We seek to investigate the marine deep subsurface biosphere, including the physiology, phylogeny, distribution, limits, and activity in the sediments, rocks, and fluids that make up this very large biome. Our approaches combine field-based research with laboratory studies of microbial survival and propagation, and modeling studies of physico-chemical properties in the subsurface. Another way to describe our research framework is as a balance of discovery science, hypothesis testing, data integration, laboratory experimentation, and ecosystem modeling. C-DEBI continues to generate knowledge in these areas by addressing fundamental questions, which include: How metabolically active is the subseafloor biosphere? What are the physico-chemical limits of life in the subseafloor? What are the nature and extent of life in the subseafloor? What are dominant metabolic processes in the subseafloor? The central research objectives require multidisciplinary and interdisciplinary approaches, with the greatest emphasis on microbial ecology. To achieve these objectives, we directed a large portion of the research funds to the Co-Investigators (Jan Amend, USC; Julie Huber, WHOI; Steven D’Hondt, URI; Andrew Fisher, UCSC; Geoff Wheat, UAF) and Senior Scientists (Steven Finkel and John Heidelberg, USC; Beth Orcutt, Bigelow; Victoria Orphan, Caltech; Alfred Spormann, Stanford); substantial resources also went to competitively awarded research grants, and graduate student and postdoctoral fellowships. *In this report, the Principal Investigator, Co-Investigators, and Senior Scientists who have equal scientific standing in C-DEBI will all be referred to as “Co-I’s”.* The research themes are:

***Theme 1: Fluxes, Connectivity, and Energy***—centering on subseafloor environmental conditions.

(1.1) Constrain the extent, variability, and controls on fluxes and connectivity within subseafloor biomes and between the subseafloor and the overlying ocean.

(1.2) Map the geochemical energy sources in subseafloor ecosystems at a range of spatial scales.

(1.3) Develop and test the next generation of coupled geochemical-hydrological-microbial models for subseafloor ecosystems.

***Theme 2: Activities, Communities, and Ecosystems***—emphasizing resident microbial communities.

(2.1) Determine community composition, functional potential, and patterns of natural selection in subseafloor ecosystems.

(2.2) Determine metabolic activity of subseafloor microbial communities.

(2.3) Advance understanding of subseafloor microbe-virus interactions.

***Theme 3: Metabolism, Survival, and Adaptation***—concentrating on the actions and traits of individual

microbial species.

(3.1) Isolate and characterize novel bacteria and archaea from diverse subseafloor habitats.

(3.2) Examine fundamental physiology of subseafloor microbes under conditions of low growth rates and low energy flux.

(3.3) Perform adaptive evolution and long-term survival experiments with subseafloor microbes to characterize molecular genetic signatures associated with particular phenotypes.

**2. Research Thrust Areas**

Here, we summarize the most important research accomplishments in 2018; we encountered no noteworthy problems. The first three subsections focus on the primary research themes, as described in the last section. This is followed by summaries of field programs that were active in 2018, several of which completed work that cuts across the research themes. For each of these programs, we provide background/context and describe the key operational, scientific, and technical accomplishments. The last two subsections briefly highlight projects funded through our grants and fellowships program (2.e) and workshops supported by C-DEBI (2.f).

**a. Theme 1: Fluxes, Connectivity, and Energy**

# Research associated with Theme 1 addressed topics of microbial energy use and generation, mainly in sedimentary systems, and coupled fluid-heat transport in hard rock systems. In this section, we highlight only a few selected results, and discuss how this work will be advanced beyond the current reporting period.

# Robador et al. (2018) conducted nanocalorimetry experiments with colonies of the model organism *Shewanella oneidensis* in conjunction with cell counts and measurements of oxygen consumption and protein content to quantify how much energy goes towards generation and maintenance of biomass, and how much is released into the environment. These experiments reveal distinct phases of biomass accumulation and energy release as part of a transient response to experiment initiation with non-coincident periods of rapid growth and energy release.

# Bradley et al. (2018a) reviewed use of models of slow microbial growth under energy-limited sedimentary environments and proposed a new model that incorporates a wide array of factors that can influence subseafloor ecology. Earlier microbial models tended to view growth in terms of incorporation of organic carbon into biomass; these models became more sophisticated by partitioning some organic carbon (OC) use in terms of maintenance energy or the exchange of energy between active and dead pools of OC. Our new model combined these functionalities, allowing OC fate to be better understood in terms of partitioning between pathways and storage. Testing and refining this approach required careful laboratory and/or field measurements of factors such as the microbial growth rate, environmental conditions (temperature, pressure, pH, DOC availability and forms), cellular metabolic activity, and rates of cell death or transition of the carbon pool between active and stagnant components.

# Bradley et al. (2018b) and Bradley et al. (2018c) used analytical models to explore how sediment-hosted microbes can remain dormant for long time periods and the potential use of microbiological necromass as an energy supply, respectively, with both studies using observations and samples from the South Pacific Gyre (SPG), a region of numerous C-DEBI field and laboratory investigations. The first study shows how low carbon availability in SPG sediments may help to trigger mortality and dormancy, and sets the ability of an organism to simply maintain biomass (and potential for future viability) and the primary criterion that determines success. The model applied in this study does a good job matching observations of biomass and particulate organic carbon over 75 M.y. of sedimentary deposition and reaction (Figure 1A). The second study shows that, although biomass from dead cells is not sufficient in itself to maintain active populations, necromass can contribute to maintenance of a viable and long-lived ecosystem (along with residual particulate organic matter and hydrogen). These and other studies have implications well beyond the deep subseafloor, including other regions of the Earth where there are severe carbon limitations, and potentially extraterrestrial analogs, including ocean worlds such as Europa and Enceladus (Jones et al. 2018). There are numerous other factors that can determine "habitability", including temperature, presence of solvents, and availability of nutrients, but access to electron donors and acceptors is essential for developing and sustaining microbial habitat and ecology.

# Walter et al. (2018) showed analyses of dissolved organic carbon (DOC) analyzed in fluids extracted from crustal observatories in the volcanic rocks below North Pond, a C-DEBI field site on an ~8 M.y.-old ridge-flank west of the Mid-Atlantic Ridge. This area is also relatively limited in terms of carbon availability, and as a consequence, it was possible to identify two distinct "end member" DOC pools that may be accessible to crustal microbes: modern, "labile" carbon that is processed relatively quickly after cool ocean bottom water is recharged into the seafloor, and older, "recalcitrant" carbon that remains accessible for decades to millennia (Figure 1B). Extrapolation of these results to a global scale suggests that as much as 5% of the global DOC loss in the ocean may occur within cool, ridge-flank hydrothermal circulation systems like that below North Pond. This work also points to the importance of resolving the hydrologic nature of water rock interactions in these systems, as the movement of a larger fraction of crustal pore fluids through a small fraction of rock may help to explain how much of the crustal carbon pool can be isolated so that loss is dominated by diffusion, despite rapid fluid flow. This was inferred on the eastern flank of the Juan de Fuca Ridge from a tracer injection experiment (Neira et al. 2016). These findings have important implications for potential to sequester large quantities of CO2 in the upper ocean crust, as isolation of most flow to restricted channels could help to spread injectate across a wide region. However, this might limit rates of reaction that could help ensure stability over long times (Goldberg et al. 2018). Adding CO2 to the volcanic upper crust might also change the nature of the microbiological habitat by shifting the pH, temperature, and other environmental conditions, and potentially introducing labile carbon as well.

# The Mid-Atlantic and Juan de Fuca Ridges generate volcanic upper crust at slow and intermediate spreading rates, respectively, but Lauer et al. (2018) presented the first three-dimensional, coupled (fluid-heat) hydrothermal circulation models of a fast spreading ridge flank, in the area surrounding Dorado Outcrop in the eastern equatorial Pacific Ocean. This region was the focus of multiple C-DEBI expeditions, and resulted in the discovery of the first focused site of massive, low-temperature hydrothermal discharge (Wheat et al. 2017). Simulations used seafloor heat flux as a primary observational constraint to calibrate the permeability of the volcanic crust in this setting, finding that values of 10-10 to 10-9 m2 (100-1000 Darcies) are required. This permeability at the Dorado Outcrop site is 10-1000× higher than that inferred for the Juan de Fuca Ridge flank, based on both modeling and direct testing in boreholes. This suggests that fundamentally different processes may determine the nature of fluid flow pathways, and thus the nature of water-rock-microbiological interactions, for crust produced at a fast spreading rate (Figure 1C). Interestingly, preliminary analytical calculations (Walter et al. 2018) and numerical simulations (A. Price, presented at the 2018 Fall AGU meeting) of conditions under North Pond also suggest that permeability may be elevated relative to that seen on the Juan de Fuca Flank.

# These and other studies help to illustrate the "grand challenge" faced by the C-DEBI community in advancing an integrated understanding of subseafloor microbiological processes through coupled modeling. The middle ground of observations, experiments, theory, and modeling requires that the community (a) extend the representation of biological processes across environmental conditions and timescales appropriate for long-term circulation of fluids through the volcanic crust, including diffusive exchange with overlying sediment, and (b) delineate the nature of fluid pathways at length scales of microns to kilometers, so that associated habitats and biological processes can be accurately described. We continue to move towards this interdisciplinary region of discovery and understanding.

# FigX_EnergyConnectionsFigure.jpg

# *Figure 1. Modeling results from three field sites: South Pacific Gyre (SPG), North Pond (NP), and Dorado Outcrop (DO). A. Comparison of observed and simulated patterns of microbial biomass, showing observations from sediment cores (dots, D'Hondt et al. 2011; 2015) and simulations (green line, Bradley et al. 2018). B. Conceptual model of hydrothermal circulation patterns and processing of dissolved organic carbon in two phases, one occurring relatively rapidly and the other involving more recalcitrant carbon over thousands of years (Walter et al. 2018). C. Particle paths within a cool, hydrothermal flow system on the flank of the fast-spreading East Pacific Rise (Lauer et al. 2018). In the cartoon to the left, the sediment and upper crustal (aquifer) layer have been removed for visualization purposes, and water parcels are tracked in a trajectory from recharge to discharge. Complex flow patterns results in extraction of most of the lithospheric heat by cool crustal fluids (as shown with the black-red heat map to right).*

► See References Cited in [[Appendix A](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-A-References-Cited-2.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-A-References-Cited.pdf)

► See related C-DEBI Contributed Publications in [[Appendix H](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-H-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)

**b. Theme 2: Activities, Communities, and Ecosystems**

Theme 2 focuses on resident microbial communities in the marine deep biosphere. We aim to illuminate the composition of subseafloor microbial communities and the functional potential of these communities, based on the diversity of metabolic activities and interactions with the physicochemical aspects of the system. The specific objectives of this theme are (1) Determine community composition, functional potential, and patterns of natural selection in subseafloor ecosystems; (2) Determine metabolic activity of subseafloor microbial communities; and (3) Advance understanding of subseafloor microbe-virus interactions. In 2018, C-DEBI scientists made several major contributions to these objectives.

|  |  |
| --- | --- |
|  |  |
|  | ***Figure 2****. Patterns of various microbial taxa in turbidite-influenced sediment in comparison to pattern drivers. Some taxa display patterns reflecting displacement influence, others enrichment at interfaces, and others a selection drive in abundance patterns. From Harrison et al. 2018.* |

Addressing the first objective (community composition, functional potential, and patterns of selection in the subseafloor), there were several key papers published, many led by C-DEBI supported postdocs and students. C-DEBI postdoctoral fellow Gustavo Ramírez and his collaborators demonstrated that extracellular DNA has little or no effect on sequencing surveys of prokaryotic communities in subseafloor sediment (Ramírez et al. 2018a). C-DEBI postdoctoral fellow Ben Harrison led a study identifying how sediment microbial communities and taxa respond to physical impacts like turbidite flow events (Harrison et al. 2018). Notably, although the overall community structure does not reveal striking pattern differences above and below turbidite flow layers, key taxa do display distribution patterns that reflect drivers such as displacement, enrichment at interfaces, and selection (Figure 2). A similar C-DEBI-supported study of organic-rich South China Sea sediments containing turbidite and volcanic ash layers also found that overall community structure does not show noticeable influence from the type of sediment inhabited, whereas electron acceptor availability was a stronger driver of community structure (Graw et al. 2018). C-DEBI graduate student Laura Zinke’s 2018 paper also documented the influence of sediment geochemistry on microbial community structure in sediment overlying a basaltic outcrop, where key microbial taxa correlated to nitrogen and manganese geochemistry influenced by fluid flow from the outcrop into the sediment (Zinke et al. 2018). Similar structuring of sediment microbial community patterns based on sediment geochemistry were also observed in the oligotrophic sediment overlying the North Pond C-DEBI Major Program site (Reese et al. 2018). Results of a multi-year observatory project at deep-sea hydrothermal vents revealed the importance of spatial variation in microbial community structuring following disturbance events (Fortunato et al. 2018). C-DEBI researcher Elizabeth Trembath-Reichert used stable isotope probing (SIP) experiments to demonstrate that subseafloor coal-associated microbes are capable of slow growth (doubling times of several months to over 100 years), despite very low cell concentrations and burial to 2 km below seafloor (Trembath-Reichert et al. 2017). At a broader level, a recent C-DEBI supported survey of microbial diversity across Earth environments, including the subsurface, revealed that the vast majority of microbial life on Earth is from phylogenetically novel uncultivated microbial groups (Lloyd et al. 2018), emphasizing the need for efforts to reveal the physiology of these unknown taxa. Finally, two recent studies from the C-DEBI community highlighted improvements and key considerations for working with low-biomass deep-biosphere samples to study microbial community composition based on nucleic acid sequencing (Sheik et al. 2018, Ramírez et al. 2018b).

There were also several key publications concerning the topic of determining metabolic activity in the subsurface in pursuit of objective 2 of this theme. Recent work published in *Nature Geoscience* from C-DEBI Major Program site North Pond revealed patterns of organic carbon cycling in subseafloor basement, emphasizing the importance of this processing on the structure of organic carbon in the global ocean (Walter et al. 2018). Laboratory studies with model culture systems documented how microbial activity during growth phase transitions relates to energy metabolism, providing key lessons for interpreting energy limitation and survival strategies in the deep subsurface (Robador et al. 2018). This kind of work informs modeling efforts by C-DEBI supported postdoc James Bradley, who examined importance of necromass as an energy source in organic-poor marine sediment (Bradley et al. 2018c).

Major field sampling efforts occurred in late 2017 as part of the third objective of this theme to identify subseafloor microbe-virus interactions, and initial analysis of these samples from the North Pond major program site are revealing both similarities (in terms of virus-cell ratios) and differences (types of viral particles) in microbe-virus interactions at the North Pond site as compared to the Juan de Fuca site (Nigro et al. unpublished data).

► See References Cited in [[Appendix A](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-A-References-Cited-2.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-A-References-Cited.pdf)

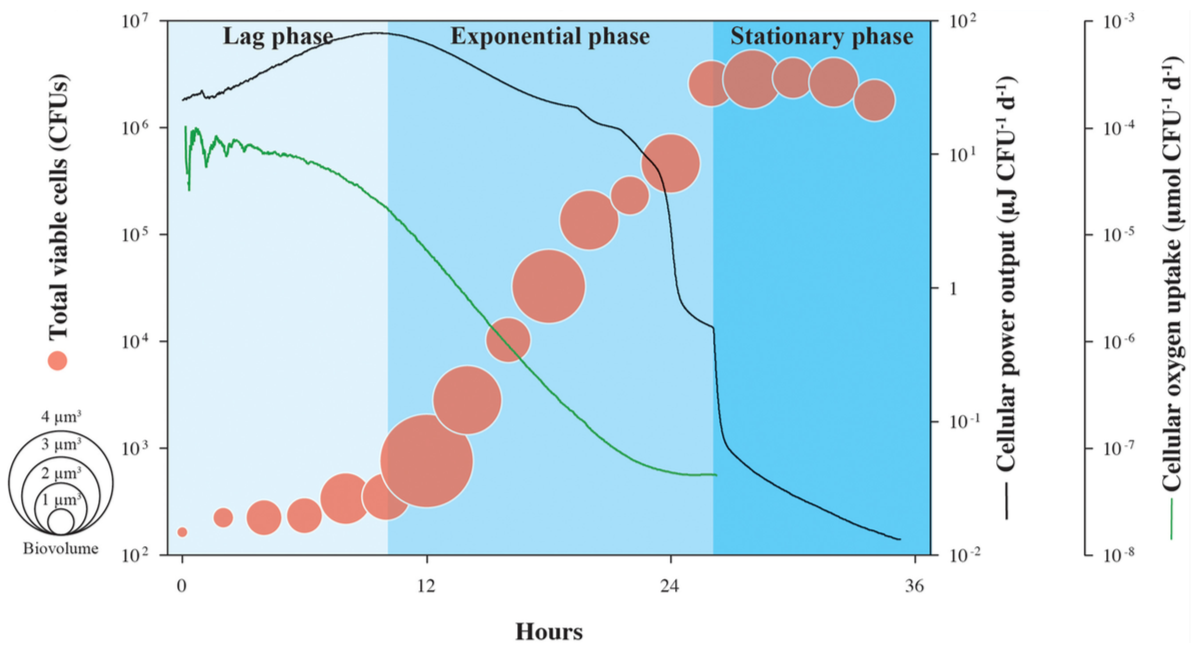
► See related C-DEBI Contributed Publications in [[Appendix H](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-H-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)

**c. Theme 3: Metabolism, Survival, and Adaptation**

Theme 3 concentrates on the actions and traits of individual microbes, including the isolation and characterization of novel bacteria and archaea from diverse subseafloor habitats; examining fundamental physiology of subseafloor microbes under conditions of low growth rates and low energy flux; and carrying out adaptive evolution and long-term survival experiments with subseafloor microbes to characterize molecular genetic signatures associated with particular phenotypes. Traditionally, our understanding of the physiology of microorganisms has been historically derived from fast growing, terrestrial microorganisms. In Theme 3 (*Metabolism, Survival, and Adaptation*), C-DEBI seeks to investigate relevant subseafloor organisms under laboratory conditions and to study their metabolisms in controlled environments that allow for scientific hypotheses testing. Here, we discuss several such ongoing experiments and recently published results.

Isolates from marine sediment, crustal fluids, and hydrothermal vents are being used in several projects. Led by graduate students and postdoctoral scholars from USC, a number of experiments examining extracellular electron transport were carried out using isolates enriched from marine sediments at Catalina Harbor off of Southern California (e.g., Lam et al. 2018). They found both known isolates that were capable of extracellular electron transfer (EET), as well as novel groups (e.g., Campylobacterales) that could also carry out this process, suggesting that insoluble substrate oxidation merits more study in marine sediment microbial communities. In addition, a new isolate capable of both electrode and sulfur-oxidation was characterized from Catalina Harbor sediments and named *Thiocalva* *electrotropha* (Chang et al. 2018).

The model organism *Shewanella oneidensis* MR-1, originally isolated from aquatic sediments, was examined in 2018 by former C-DEBI postdoc Annie Rowe and colleagues. They investigated the mechanism of EET in this organism and discovered that cathode oxidation is linked to cellular energy acquisition, which may be important in low energy environments. Additional laboratory studies with this same organism were carried out by C-DEBI researcher Alberto Robador in Co-I Finkel’s lab to determine how microbial activity during growth phase transitions relates to energy metabolism (Robador et al. 2018, Figure 3). Such data provide important insights into interpreting energy limitation and survival strategies in the deep subsurface for modeling efforts.

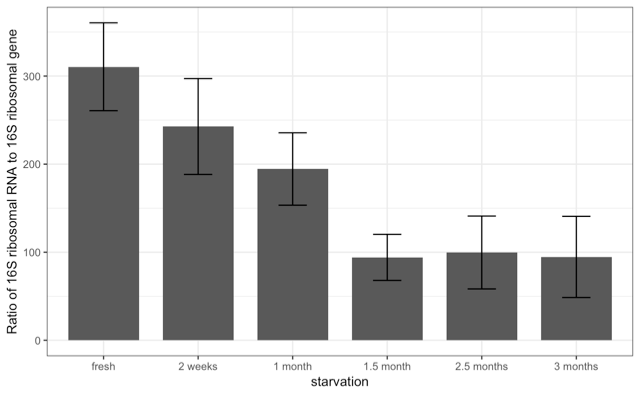


***Figure 3.*** *Changes in microbial cellular power output, metabolic activity from Robador et al. (2018).*

C-DEBI researcher Donato Giovannelli and colleagues examined sulfur reduction in a deep-sea bacterial vent isolate, *Thermovibrio ammonificans* (Jelen et al. 2018). They combined growth experiments with comparative transcriptomic and proteomic approaches to show that the sulfur metabolism in this organism requires an abiotic transition from elemental sulfur to polysulfide to nanoparticulate sulfur for sulfur respiration, highlighting the close coupling between environmental conditions and energy availability to microbes in these habitats. Finally, two additional isolates that were used in the REU Community College Cultivation Cohort (C4) program had their genomes sequenced, analyzed, and published as genome announcements (Neely et al. 2018; Smith et al. 2018).

Additional work has been carried out with novel isolates from the crustal aquifer. Crustal fluids from the deep and shallow horizons of CORK observatory U1383C at North Pond were used to isolate 46 *Halomonas* strains on autotrophic minimal media in Co-I Huber’s lab. Co-I Finkel’s group is now characterizing the suitability of these isolates with respect to their utility as model organisms for laboratory experiments, currently focusing on the genetic plasticity of these organisms and their ability to grow under extremely oligotrophic conditions. These 46 strains fall into 8 phenotypic classes with respect to their laboratory growth characteristics, and a subset of 8 clones were chosen for further study. Each of these strains displays the ability for significant growth in laboratory culture without the addition of nutrients as sources of carbon and energy, growing to densities 10- to 100-fold greater than laboratory strains of *E. coli* under similar conditions. Genetic analyses are now underway to identify genes responsible for the ability of these cells to grow under such extreme conditions of nutrient deprivation.

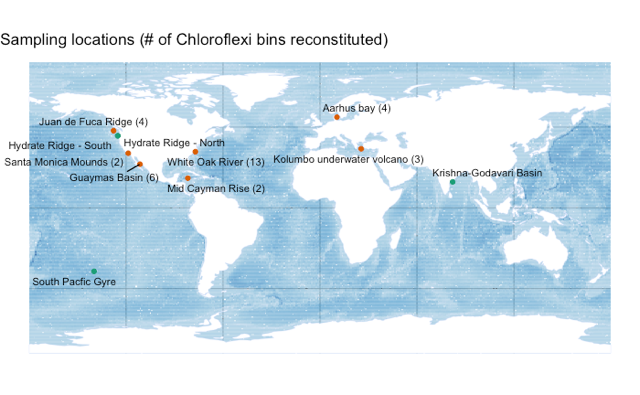
Research into fundamental aspects of microorganisms under slow growth conditions provided some interesting insights into ribosome stability and chromosome replication. Low energy fluxes is the norm and not the exception in deep-sea sediment environments. Yet our knowledge of bacterial metabolism stems from experiments in laboratory conditions with high nutrient availability. We followed the shift in ribosomal content and proteome stability during long-term starvation (up to 3 months) of a slow-growing *Dehalococcoides mccartyi* mixed community to gain insights into bacterial metabolism under limited energy flux. Using qPCR to follow the degradation pattern of ribosomes, we observed the loss of 2/3 of the original ribosomal content per cell after 1.5 months of starvation, after which point degradation seemed to stop and the ribosomal content per cell stabilized around 100 (Figure 4). In addition to qPCR samples, N14/N15 quantitative proteomics samples were also collected. Their analysis will indicate how stable *D. mccartyi* proteins are during long-term starvation and will yield insights into adaption to low or zero nutrient availability.



***Figure 4****. Ribosome stability in Dehalococcoides mccartyi as a function of starvation time.*

In addition to working with cultured isolates, C-DEBI scientists are using a variety of genomic tools at the single-cell or population level to understand traits of individual microbes. For example, marine sediments are widely inhabited by members of the phylum *Chloroflexi*. In the lab of Co-I Spormann, Ph.D. student Holly Sewell and collaborators examined the genomes of single cells obtained from deep-sea sediments of the Peru Margin to determine the metabolism and evolutionary relationships of the ubiquitous *Chloroflexi*. The presence of genes encoding for enzymes of a complete Wood-Ljungdahl pathway and other genes implicate a homoacetogenic lifestyle of these marine *Chlorflexi* (Sewell et al. 2017). They also found the first complete pathway for anaerobic benzoate oxidation to acetyl-CoA in this phylum. Of remarkable evolutionary significance, a gene encoding a formate dehydrogenase (FdnI) was discovered with reciprocal closest identity to the formate dehydrogenase-like protein of terrestrial *Dehalococcoides*/*Dehalogenimonas* spp. This finding of a close functional homolog provides an important missing link for understanding the origin and the metabolic core of terrestrial *Dehalococcoides*/*Dehalogenimonas* spp. and of reductive dehalogenation, as well as the biology of abundant deep-sea *Chloroflexi*.

Members of the *Chloroflexi* phylum are commonly found in deep-sea sediments but little is known about their phylogenetic distribution across sediments and depth, or their metabolic characteristics. We used metagenomics and functional genomics analysis to gain insights into the functional potential of this phylum, and we looked at its distribution in deep-sea habitats from 8 locations around the world (Figure 5). After quality cleaning, the reads for each location were assembled using MegaHit and the resulting contigs binned into Metagenome-Assembly Genomes (MAGs), yielding 34 MAGs with 75%+ completeness and less than 5% contamination from 6 different locations. Phylogenetic placement of these MAGs using Phylophlan confirmed them to belong to the *Chloroflexi* phylum. 17 MAGs were siblings of *Dehalococcoidia* and 5 of *Anaerolineae* (with 3 deep branching). 4 MAGs could be placed in the *Thermoflexia* clade, 5 in the *Ardenticatenia* and the last 2 in the *Caldilineae* clade. Further functional genomic analysis using KEGG and custom protein databases targeting genes of interest will yield insight into their metabolic potential.



***Figure 5****. Map of sites with Chloroflexi genomes under investigation.*

Other work with metagenome-assembled genomes (MAGs) to examine microbial populations in the subseafloor includes work from Co-I Huber’s lab that examined microbial populations mediating biogeochemical cycling beneath the seafloor at Axial Seamount (Fortunato et al. 2018). Genomic binning identified key populations of active subseafloor vent-endemic high temperature anaerobic microbes, including *Aquificales* and methanogenic archaea, with groups that appear unique to the subseafloor of individual sites. And a study led by C-DEBI Bioinformatics Specialist Tully utilized the large metagenomic dataset generated from 234 samples collected during the Tara Oceans circumnavigation expedition to reconstruct 2,631 draft genomes with an estimated completion of ≥50% (1,491 draft genomes >70% complete; 603 genomes >90% complete; Tully et al. 2018). Expanding the microbial tree of life with genomes representing novel clades and organisms helps to constrain the evolutionary space which subsurface organisms can occupy. Increasing novelty in genomic databases allows for more accurate identification of all microbes, including those most intriguing to the C-DEBI community.

► See References Cited in [[Appendix A](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-A-References-Cited-2.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-A-References-Cited.pdf)

► See related C-DEBI Contributed Publications in [[Appendix H](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-H-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)

**d. Field Projects**

The Center continues to pursue expedition-based research. Here, we briefly describe activities that took place in 2018 at five sites, identifying key C-DEBI personnel involved.

***Eastern Flank of the Juan de Fuca Ridge.*** The Juan de Fuca Ridge (JdFR) has been a major field site since the start of the Center. Major installation of observatory infrastructure and field cross-hole experiments has been completed, but numerous samples and datasets are still being analyzed, and additional numerical modeling studies are in progress; several papers are currently in review (Ramírez et al. and Carr et al., both at *ISME J*). Co-I Orcutt will be leading an NSF-funded ROV Jason expedition in May 2019 to revisit the observatory network at this site to conduct *in situ* incubation experiments for examining microbial physiology and activity in this low energy system. Numerous C-DEBI-supported scientists, postdoctoral scholars and graduate students will participate in the cruise, along with collaborators from other NSF- and NASA-funded projects.

***North Pond basaltic crust.*** As noted in the last annual report, we returned to the borehole observatory network at North Pond on the Mid-Atlantic Ridge in late 2017. Several C-DEBI supported laboratories are in the midst of analyzing the deep biosphere samples collected on that cruise, with reports of recent findings planned for the 2018 Fall AGU meeting. C-DEBI supported postdocs Nigro (now an Assistant Professor) and Trembath-Reichert are spearheading efforts to organize a synthesis workshop focused on North Pond and potential future drilling targets.

***Dorado Outcrop.***  Major at-sea activities as part of the Dorado Outcrop major program are complete, with several papers published (Wheat et al. 2017; Zinke et al. 2018) or in review. These include geological, geochemical, and microbial analyses, as well as a numerical study of extremely rapid outcrop-to-outcrop hydrothermal circulation. A proposal is also being developed for IODP to drill into the volcanic crust in this area, collect samples, and conduct a tracer experiment using natural spring systems for long-term sampling.

***Atlantis Massif/Lost City.*** C-DEBI community members Susan Lang and Billy Brazelton led an NSF-funded ROV Jason cruise to the Lost City hydrothermal vents on the Atlantis Massif in September 2018. The Atlantis Massif was introduced as a C-DEBI major field program in 2015, and drilled during IODP Expedition 357 to examine microbial life in a deep-sea serpentinizing ecosystem. The 2018 cruise focused on collecting pristine, high pH hydrothermal fluids from an actively serpentinizing deep biosphere system to examine microbial processes supported by biological and abiotic carbon sources. Co-I Orcutt’s laboratory participated in this cruise to collect samples to test new methods for detecting microbial activity at the single cell level; these are currently being analyzed.

***Loihi Seamount.*** C-DEBI Co-I Huber co-led an expedition to Lō`ihi Seamount in August 2018 as part of the Systematic Underwater Biogeochemical Science and Exploration Analog (SUBSEA) research program. SUBSEA is funded by the NASA Planetary Science and Technology from Analog Research (PSTAR) program, with significant infrastructure and in-kind support from the National Oceanographic and Atmospheric Administration (NOAA) Office of Ocean Exploration and Research (OER). There were many goals on this cruise, but Huber was mainly involved in a collaboration with geochemists to model subseafloor fluid flow and energetics, as well as geochemical and microbial analysis of vent fluid samples. Specifically, the objectives were to 1) characterize the geochemical products in venting fluids under a range of pressure and temperature conditions and 2) quantify the standing stock of microbial biomass, the metabolic capabilities of microbial communities as a whole, and potential activity for targeted metabolic groups in venting fluids. Postdocs Elizabeth Trembath-Reichert and Amy Smith sailed on the cruise, while Huber ran dives from the Inner Space Center at URI. Samples from the cruise are currently being analyzed in the Huber lab.

***Mariana serpentinite mud volcanoes.*** IODP Expedition 366 (December 8, 2016 - February 8, 2017) had two primary science objectives: 1) to core a series of sites at the summit and flanks of three large (up to 50 km diameter and 2 km high) serpentinite mud volcanoes in the Mariana forearc (within 100 km west of the Mariana Trench), and 2) to establish a long-term seafloor observatory by emplacing cased boreholes with screened sections at the summit where discharge of subduction channel materials is ongoing. As part of the first objective, the science party, led by Co-I Wheat, examined mass transport within the subduction channel of a non-accretionary convergent margin and the metabolic activity and microbial function of communities that survive in alkaline (pH up to 12.5) waters rich in dissolved methane and hydrogen. This project includes several U.S.-based laboratories that have previously received C-DEBI funding. A post cruise meeting was held in September 2018 to discuss shore-based analyses, progress in interpretation, and manuscript goals. As part of the second objective, a cased borehole is located in each of three serpentinite mud volcanoes, setting the foundation for future deployments of CORK-Lite structures. Such structures present a foundation for *in situ* experimentation and “taking the pulse of subduction”.

***Future expeditions.*** C-DEBI Co-Is are also involved in other upcoming drilling/coring/sampling expeditions and in numerous deep biosphere proposals (submitted and in-development) to the IODP for future drilling. For example, Co-I Orcutt will be co-chief scientist on IODP Expedition 385T scheduled for Aug-Sept 2019, which will re-visit observatories in ODP Holes 504B and 896A to collect crustal fluid samples for deep biosphere research and to prepare these observatories for future upgrades. Co-I Wheat is a co-proponent of these efforts and will lead fluid sampling with a newly designed autonomous fluid sampler being built with support from NSF. Co-Is Orcutt and Wheat are also co-proponents of IODP full proposal 937 for additional drilling on the Atlantis Massif. A south Atlantic transect has been scheduled for drilling in (IODP Exp. 390 and 393). This two-part expedition will drill crust on the western flank of the Mid-Atlantic Ridge at crustal ages of 13 to 54 Ma, complementing the transect of boreholes (ODP Exp. 168) on the eastern flank of the Juan de Fuca that served as the foundation for one of the three primary C-DEBI sites. Co-I Huber’s lab will help lead a field expedition to the Gorda Ridge, with a focus on stable isotope probing experiments to examine carbon cycling in the subseafloor. Co-I D’Hondt is the lead proponent of IODP full proposal 929 (Blake Nose, North Atlantic) to test the extent of vertical migration by subseafloor sedimentary microbes and the influence of past major oceanic events on extant communities. D’Hondt is also the lead proponent of an NSF proposal to core sediment at multiple water depths (100-8400 meters below sea level, Puerto Rico Trench) to determine the impact of *in situ* pressure on subseafloor communities. In support of the latter project, D’Hondt’s lab built an autonomous ocean profiling and water sampling system for the full range of ocean depth (0-11,000 mbsl) and tested it in the North Atlantic and Puerto Rico Trench (RV Endeavor cruises EN610 and EN622). A number of C-DEBI scientists, including several students and post-docs, will be sailing on IODP Expedition 385 to explore the tectonics and subsurface biosphere of the Guaymas Basin, led by co-chief scientist Andreas Teske. Lastly, C-DEBI scientists, led by Co-I Orphan will be involved in a series of short cruises to Monterey Canyon as part of a long term time series seafloor incubations using BONCAT and stable isotope probing to track *in situ* growth rates of microorganisms.

► See more at the [Field Sites webpage](https://www.darkenergybiosphere.org/research-activities/field-sites/)

► See related C-DEBI Contributed Publications in [[Appendix H](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-H-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)

# e. Projects from our Grants and Fellowships Program

C-DEBI has an extensive grants and fellowships program that supports small research projects, research and travel exchanges, education and outreach, and graduate student and postdoctoral fellowships. The funded projects cut across all three Research Themes. A list of the 26 funded projects that were active in 2018 is provided in [[Appendix B](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-B-Active-Grants-and-Fellowships-2.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-B-Active-Grants-and-Fellowships.pdf). The breakdown of active grants and fellowships is as follows: 6 small research projects (up to $80k), 4 graduate student fellowships (1-2 years), 11 postdoctoral fellowships (1-2 years), 2 education and outreach grants (up to $50k), and 3 research exchange grants that require matching funds. Forty-five different individuals, comprised of 18 graduate students and postdocs representing 25 institutions, received financial support for these projects.

The small research grants and fellowships support a wide variety of field projects, experimental and analytical investigations, and modeling efforts relevant to C-DEBI. These include analyses of samples and data from deep subseafloor sites, laboratory studies of microbial activity, and investigations of analog environments. Here, we call out only the 5 *new* research awards and fellowships made in 2018. A small research grant was made to Annette Rowe (Assistant Professor at the University at Cincinnati) to uncover novel mechanisms of extracellular electron uptake in subsurface-relevant marine bacterial isolates. Fellowships were awarded to: Taylor Royalty (graduate student at the University of Tennessee, Knoxville) to characterize subsurface extracellular enzymes and the organisms that produce them using metatranscriptomics and bottom-up metaproteomics; Clarisse Sullivan (graduate student at the University of Hawaii) to investigate population genomics of *Nitrospirae* bacteria inhabiting deep subseafloor fluids of the Juan de Fuca Ridge flank; Claire McKinley (postdoc at the University of Washington) to evaluate the extent of microbial Fe-reduction and its role in the global methane cycle; and Sarah Hu (postdoc at the Woods Hole Oceanographic Institution) to probe subseafloor microbial interactions via hydrothermal vent fluids focusing on protists.

► See more at the [Funded Projects webpage](https://www.darkenergybiosphere.org/?s=&type=award)

► See related C-DEBI Contributed Publications in [[Appendix H](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-H-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)

# f. C-DEBI Workshops

In 2018, C-DEBI funded and organized three workshops focused on the microbiology of the deep subsurface. The first, *Microorganisms and Organic Carbon in the Marine Subsurface*, was held March 11-13 in Knoxville, TN and led by Doug LaRowe (USC) and Andrew Steen (University of Tennessee, Knoxville). Eighteen scientists representing a gender-balanced (10 women, 8 men), international assemblage of investigators that included both early career and established scientists participated in this meeting to address fundamental questions about how microbial ecology, organic geochemistry and soil organic biogeochemistry can be combined to better determine the factors that govern interactions between subsurface organic matter and heterotrophic microorganisms. Because this problem requires novel interdisciplinary approaches, experts in microbiology, proteomics, soil science, genomics, reaction transport modeling, dissolved and particulate organic geochemistry and systems science were brought together in breakout sessions to share the strengths and limitations of their tools and techniques, to stimulate discussion of the current state of knowledge, and to inform on opportunities for new field and laboratory studies. A review paper, tentatively titled “The fate of organic carbon in marine sediments", is in preparation for submission; it will also point out what tools/techniques should be used to better quantify the factors/forces that influence the transformation of organic carbon in marine sediment.

The second workshop, the *C-DEBI/CCB (Center for Computational Biology) Evolution Workshop*, was held March 22-23 in New York, NY at the Simons Foundation Flatiron Institute and led by Rika Anderson (Carleton College) and Cara Magnabosco (Simons Flatiron Institute) with advisement by Co-I Steve Finkel. The 20 workshop participants were gender-balanced and distributed across career stages. Their work focuses on a variety of different habitats, from deep sediments to hydrothermal vents, and on a variety of themes within those habitats, from experimental work, to phylogenetic analyses, to ecological ‘omics-based studies. The goal of the workshop was to identify the greatest unknowns with regards to evolution in the deep subsurface, to identify areas with the greatest opportunity for new advances, and to identify areas of possible collaboration between researchers. A synthesis of the evolution-focused workshop discussions is included in the book chapter “The biogeography, ecology, and evolution of deep life” in the Deep Carbon Observatory book *Whole Earth Carbon: Past to Present* slated for public release in by Cambridge University Press in 2019.

The third workshop, *Deep Sea Mining Impacts on Microbial Ecosystem Services*, was held April 18-19 at the Bigelow Laboratory for Ocean Sciences (East Boothbay, Maine) and led by Co-I Beth Orcutt. The workshop was co-sponsored by the Deep Carbon Observatory and supported 16 core workshop participants; more than half of these were early career researchers (one graduate student, six postdocs, and two assistant professors), and two additional early career scientists participating remotely. The first morning was spent reviewing the current state of knowledge concerning deep-sea mining activities, with key input from an IUCN observer to the International Seabed Authority. The remainder of the workshop was spent collectively identifying the ecosystem services that microbes provide in the deep sea and the potential threats that mining activities could cause to these services. The discussions were focused on four main deep-sea habitat types: active vents, inactive vent fields, cobalt crusts found on seamounts, and ferromanganese nodules in the abyssal plains. A white paper identifying the possible impacts of deep-sea mining to microbial ecosystem services in these various habitats was submitted to a special issue of *Frontiers in Marine Science* on ecosystem management.

► See more at the [Workshops webpage](https://www.darkenergybiosphere.org/outputs-resources/meetings-and-workshops/)

## 3. Performance With Respect to the Strategic Implementation Plan

## Our primary research goal is to enable, produce, and communicate transformative, synergistic research through an inclusive and collaborative culture that crosses disciplinary and institutional boundaries and is embedded throughout the Center’s activities. In Phase 1 (2010-2015), C-DEBI focused primarily on the exploration and discovery of subseafloor ecosystems, with most studies concentrated at four major sites: Juan de Fuca Ridge flank, South Pacific Gyre, North Pond, and the Dorado Outcrop. In Phase 2 (2015-2020), C-DEBI is developing an integrated understanding of microbial subseafloor life, covering and connecting the molecular, cellular, and ecosystem scales. Maintaining highly multidisciplinary and interdisciplinary approaches, C-DEBI is emphasizing microbial ecology while ensuring that essential context is provided through studies and advances in geochemistry, hydrology, oceanography, and related disciplines. The three overarching research themes are (1) fluxes, connectivity, and energy; (2) activities, communities, and ecosystems; and (3) metabolism, survival, and adaptation. C-DEBI research projects target two distinct subseafloor biosphere environments—the igneous ocean crust and overlying sediments—that have historically been studied independently; field investigations of these environments are complemented by coordinated laboratory studies and modeling. C-DEBI is led by five Co-PIs and five senior scientists from eight U.S. universities and research labs, but seeks to build and leverage scientific, educational, and technological partnerships with numerous other U.S. and international institutions (educational, research, outreach, engineering, not-for-profit). In addition, C-DEBI seeks to develop a diverse community of multidisciplinary collaborators, to identify promising topics, and to develop new projects that will help to advance the Center's objectives.

**Target 1:** Transfers of fluid, heat, solutes, carbon, and microbes are quantified within and between subseafloor biomes, and between the subseafloor and the overlying ocean; the nature of energy sources available to microbes in these ecosystems is determined; and the next generation of coupled fluid-energy-biochemical-microbial models is developed.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Quantify transfers of fluid, heat, solutes, carbon, and microbes within and between subseafloor biomes, and between the subseafloor and the overlying ocean   1. Continue time-series observations and sampling at selected sites and analyze data and samples from earlier studies to resolve the extent of natural variability (within and between biomes), determine environmental controls on crustal microbial community composition, and assess how this variability impacts flows and connections 2. Develop studies, including some at new field sites, as needed to test and extend understanding of coupled fluid-rock-geochemical-microbial systems | Pending |
| Determine the nature of energy sources available to microbes in subseafloor ecosystems   1. Map the distributions of electron acceptors and electron donors regionally and globally as a function of depth at a range of spatial scales. 2. Quantify metabolic reaction energetics as well as fluxes of electron acceptors and donors by combining internally consistent thermodynamic data, available kinetic parameters, and reactive transport modeling | Pending |
| Develop the next generation of coupled fluid-energy-biochemical-microbial models   1. Combine existing physical and thermal models with rate constants for primary reactions and transport (advection and diffusion) that involve solutes in basement fluids; then attempt to couple these with microbial processes to increase the model complexity 2. Test, calibrate, and apply coupled geochemical-microbiological models to a variety of seafloor and subseafloor environments | Pending |
| Publish 25 (in aggregate) papers in this research theme | Pending |
| Publish 5 (in aggregate) method/instrument papers demonstrating new techniques and tools developed and/or applied in this research theme | Pending |

**Target 2:** The composition of subseafloor microbial communities and the functional potential of these communities are illuminated, based on the diversity of metabolic activities and interactions with the physicochemical aspects of the system.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Determine community composition, functional potential, and patterns of natural selection in subseafloor ecosystems   1. Quantify the number, diversity, and relative abundances of microbes at multiple taxonomic levels—from domain to “species-level” operational taxonomic units (OTUs), ecotypes, and oligotypes 2. Determine the functional potential embodied in these communities 3. Integrate data on community composition and microbial activities to identify how sources of energy and microbial interactions drive natural selection in subseafloor ecosystems | Pending |
| Determine metabolic activity of subseafloor microbial communities   1. Document actual rates of *in situ* activities using gene expression in sediment and rock samples 2. Identify potential activities in laboratory experiments using subseafloor samples incubated with isotope-labeled substrates 3. Closely examine microbe-mineral interactions in conjunction with activity measurements in *in situ* incubations and laboratory microcosms | Pending |
| Advance understanding of subseafloor microbe-virus interactions   1. Integrate correlation network techniques using subseafloor archaeal, bacterial, microeukaryote, and viral diversity datasets combined with microbial activity measurements 2. Incorporate the isotopic and diversity datasets collected as part of 2.a. and 2.b. to develop a food web model in combination with statistical diversity-based networks | Pending |
| Publish 25 (in aggregate) papers in this research theme | Pending |
| Publish 5 (in aggregate) method/instrument papers demonstrating new techniques and tools developed and/or applied in this research theme | Pending |

**Target 3:** A ‘portfolio’ of selected model subseafloor organisms is established, and their physiological and genetic traits are characterized; in addition, these microorganisms are used to investigate energy and carbon use for growth and maintenance under kinetically limiting conditions and to determine rates of metabolism under specific conditions.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Isolate and characterize novel bacteria and archaea from diverse subseafloor habitats   1. Enrich subseafloor bacteria and archaea from sediment, crustal fluids, and rock samples, using, among others, plugged flow, chemostat, and hanging sponge reactors 2. Fully characterize novel organisms, including their genomes 3. Interrogate their abundance and activity in the original sample to help infer their ecological roles | Pending |
| Examine fundamental physiology of subseafloor microbes under conditions of low growth rates and low energy flux   1. Use long-term chemostat-like culturing systems to study the coupling of catabolism and growth in the *Chloroflexi* 2. Use down-flow hanging sponge bioreactors to explore the molecular and physiological underpinnings of the hypothesis that archaea may be low-energy specialists and well adapted to the energetic extremes that define many subseafloor environments | Pending |
| Perform adaptive evolution and long-term survival experiments with subseafloor microbes to characterize molecular genetic signatures associated with particular phenotypes   1. Use subseafloor isolates to determine the genotypic, phenotypic, and biochemical and physiological bases for metabolic traits 2. Develop genetic markers for model organisms to be used in competition experiments | Pending |
| Publish 25 (in aggregate) papers in this research theme | Pending |
| Publish 5 (in aggregate) method/instrument papers demonstrating new techniques and tools developed and/or applied in this research theme | Pending |

**Target 4:** Field investigations at the four ‘major sites’ identified in C-DEBI Phase 1 are largely completed (i.e. at Juan de Fuca, South Pacific Gyre, North Pond, and Dorado Outcrop with the latter two potentially continuing beyond C-DEBI Phase 2). Environmental data and samples from these sites are compiled and analyzed along with laboratory experiments and modeling to address questions across the three Phase 2 research themes.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| C-DEBI researchers lead and participate in expeditions to these and other sites of interest   1. Collect samples for laboratory analyses and experiments 2. Collect environmental data for use in experiments and ecosystem modeling | Met |
| Convene workshops and conference sessions   1. Develop approaches to integrate results from field, lab, and modeling studies 2. Synthesize results and methods from multiple sites | Met |

**Target 5:** The new C-DEBI senior scientists are integrated in all aspects of the Center, and cross-disciplinary and cross-institutional research training is thriving through our grants programs, thereby expanding the community of deep biosphere researchers, technologists, and educators.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Provide substantial research funds to the 5 Co-Investigator labs as well as to the 5 new senior scientist labs | Met |
| Award $1M in research grants/fellowships annually (for the first 3.5 years) to predominantly graduate students, postdoctoral scholars, and other junior researchers through annual RFPs | Met |

**4. Plans for the Next Reporting Period**

The research plans for 2019 remain as stated in our Phase 2 proposal, incorporating field, laboratory, and modeling approaches. As outlined in Theme 1, we will constrain the extent, variability, and controls on fluxes and connectivity within subseafloor biomes and between the subseafloor and the overlying ocean; map geochemical energy sources in subseafloor ecosystems at a range of spatial scales; and develop and test the next generation of coupled geochemical-hydrological-microbial models for subseafloor ecosystems. In Theme 2, we will determine community composition, functional potential, and patterns of natural selection in subseafloor ecosystems; determine metabolic activity of subseafloor microbial communities; and advance understanding of subseafloor microbe-virus interactions. In Theme 3, we will isolate and characterize novel bacteria and archaea from diverse subseafloor habitats; examine fundamental physiology of subseafloor microbes under conditions of low growth rates and low energy flux; and perform adaptive evolution and long-term survival experiments with subseafloor microbes to characterize molecular genetic signatures associated with particular phenotypes. However, as we near the sunset date for C-DEBI (September 2020), our focus also shifts towards finishing long-term investigations and generating numerous synthesis products.

Field-based research, and associated analyses, will focus on a number of different C-DEBI sites. Here, we note just a few examples. Co-I Orphan will lead the analysis of samples acquired during the 2018 expeditions to Costa Rica Margin and Pescadero Basin. This will include molecular, mineralogical and geochemical analyses and single cell stable isotope measurements to assess the community composition, metabolic activity, and growth rates of microorganisms in sediments and carbonates impacted by methane seepage (Costa Rica Margin and Monterey Canyon) or hydrothermal activity (Pescadero Basin). In May, Co-I Orcutt, joined by Co-I Wheat, will lead an NSF-funded ROV Jason cruise to return to the Juan de Fuca Ridge flank CORK observatory network to conduct *in situ* incubation labeling and enrichment experiments focused on identifying active microbial populations and quantifying rates of activity. Orcutt will also be co-chief scientist on IODP Expedition 385T in August, focused on subseafloor observatory work at ODP legacy Holes 504B and 896A, analogs to the Juan de Fuca system to examine microbial biogeography hypotheses. For this expedition, Co-I Wheat’s lab will develop a high-temperature borehole fluid sampler that will collect fluids to 180 °C in Hole 504B and to 90 °C in Hole 896A. Analyses of these fluids will help constrain the thermal limits of microbial life in the basaltic crust. Co-I Huber and others will oversee field-based research, associated sample analyses, and laboratory experiments that focus on key sites from North Pond that were visited in 2017.

Laboratory studies will also tackle a number of important questions. For example, members of Co-I D'Hondt's and Finkel's labs will continue to characterize how pore waters from a variety of sediment cores modulate the ability of microbes to grow and survive long-term. In addition, newly obtained isolates from the subseafloor of Loihi Seamount and the Mariana Back-Arc will be studied from both a physiological and genomic perspective in the Huber lab, and members of the D’Hondt lab will continue to use genomic and transcriptomic approaches to characterize the structure and evolutionary context of subseafloor sedimentary communities. Working with crustal fluids and sediments provided by Co-Is Huber and D’Hondt, members of Co-I Finkel’s lab will continue adaptive evolution experiments, including those on *Halomonas* strains isolated from North Pond. Further, Co-Is Amend and Finkel have an ongoing collaboration that applies nanocalorimetry techniques to microbial growth. Their work seeks to identify and quantify small changes in heat production caused by important changes in microbial populations.

In 2019, C-DEBI researchers will also work on numerous synthesis products and modeling efforts. These include, but are not limited to, review articles and state-of-the-science communications on the Juan de Fuca Ridge flank and Dorado outcrop systems, organic matter and microbial metabolisms in marine sediments, subseafloor metabolic activities and their biogeochemical consequences, and the ocean crust ecosystem, among others. For example, Co-I Fisher’s group will combine and synthesize new thermal data and previous work from around Dorado Outcrop. His group is also developing two- and three-dimensional numerical simulations of coupled processes in the volcanic crust around North Pond. Co-I Amend is working with C-DEBI-funded collaborators to finalize some modeling of organic carbon availability and microbial activity in marine sediments on a global scale, and Co-I D’Hondt is finalizing a study on subseafloor metabolic activities and their biogeochemical consequences.

# III. EDUCATION

## 1. Overall Education Goals and Objectives

The main goal of C-DEBI’s education program is to generate distinctive and targeted activities in and around ocean sciences, in general, and the marine subsurface biosphere, specifically. To achieve this goal, we focus our efforts on three target groups: undergraduate students, graduate students and postdoctoral scholars, and the general public. Central to our mission is the integration of our education programs with our expansive and diverse research effort—we do not see these as independent pursuits. To engage and retain young people in STEM fields and to develop the next generation of specialists, C-DEBI provides training, mentoring, and professional development opportunities, but we also leverage numerous educational partnerships nationally to work with K-12 students and the public to ensure engagement at all levels.

**2. Undergraduate Students**

As part of our undergraduate education program, we focus heavily on hands-on research activities for community college students. In 2018, these again included the Community College Research Internship for Scientific Engagement (CC-RISE) and the Community College Cultivation Cohort (C4) Research Experience for Undergraduates (REU). For undergraduate students from underrepresented minority (URM) groups at USC, we again supported the Genomics and Geobiology Undergraduate Research Experience (GGURE), and for undergraduate students across the country who are interested in microbial ecology and biological oceanography, we offered our Global Environmental Microbiology (GEM) course.

CC-RISE is a non-residential REU-style program at two of our partner institutions, the University of California at Santa Cruz (UCSC) and the Woods Hole Oceanographic Institution (WHOI) in Massachusetts. The overall program is led by C-DEBI’s Education, Outreach, & Diversity (EOD) Managing Director Stephanie Schroeder, with local oversight at UCSC by Adina Paytan, and at WHOI by Co-I Julie Huber. Eight academically competitive students (4 at UCSC, 4 at WHOI) spent eight weeks during the summer in state-of-the-art research labs. For 40+ hours a week, they carried out experiments and analyses, and participated in professional development seminars that ranged from how to read/write a scientific paper to how to apply to graduate school. Six of the students transferred to 4-year universities in the fall (Boston College, UCLA, UCSC, Humbolt State University, and the University of Massachusetts).

For the past 3 summers, we have offered the C4 REU program at USC. In 2018, eight students (recruited from across the US) worked in pairs to characterize a novel bacterium isolated from a seafloor environment. The students learned aerobic and anaerobic culturing techniques, fluorescence microscopy, and some analytical chemistry, and they concurrently participated in a bioinformatics course led by C-DEBI Bioinformatics Specialist Ben Tully. The students also participated in weekly professional development activities and networking lunches coordinated by Stephanie Schroeder, they interacted with members of their host labs, and they learned about different pathways into science. C-DEBI Director Jan Amend conceived C4 and also hosted four of the students; the other four students worked in the lab of Ken Nealson. C-DEBI postdoctoral scholar Roman Barco oversaw the day-to-day research activities. Two peer-reviewed papers by the 2017 C4 cohort (Neely et al., 2018, Smith et al., 2018) were published in *Genome Announcements*; another manuscript, which includes everyone from the 2018 cohort as authors, will be submitted in the next several months. Schroeder and Amend (2018) described the program’s effective incorporation of modern technologies to engage community college students in research.

In post-program surveys ([Appendix C](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-C-CC-RISE-and-C4-Student-Evaluation-2.pdf)), the CC-RISE and C4 students provided substantive and predominantly positive feedback, noting that they felt better prepared to succeed at a 4-year university and that their participation in these programs expanded their views of career options. Several students from the 2017 cohorts attended national meetings to present their research, and one student from the 2018 C4 is traveling to next year’s ASLO meeting as part of their dedicated multicultural program.

GGURE, a research internship program that targets URMs, continues a 15-year effort led by Co-I Steven Finkel to recruit and maintain USC undergraduate students in STEM fields. The program is part-time during the academic year and full-time over 10 summer weeks, with students carrying out microbiological research in a wide range of USC labs. Weekly journal clubs provide opportunities for students to delve deeper into research topics while forming a tight research cohort. Weekly meetings also focus on professional development sessions with topics ranging from ‘Demystifying Graduate School’ to ‘Career Paths’. As reported in the external evaluations ([Appendix D](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-D-GGURE-Academic-Student-Evaluation.pdf)/[Appendix E](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-E-GGURE-Summer-Student-Evaluation.pdf)), these experiences made the students more likely to include research in their career goals.

Another flagship component of our undergraduate education program is the GEM course, which targets URMs early in their academic careers. Now in its eighth year, this field-based, hands-on, 3-week course is led by USC faculty Co-I John Heidelberg and Eric Webb, with directional support from Diversity Director Gwen Noda. In 2018, sixteen students participated, many from community colleges across the country. We remain in close contact with all graduates of the course through social media and other means, and we strive to form a community of young researchers with this common experience. More than 90% of the GEM students reported in the external evaluation ([Appendix F](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-F-GEM-Student-Evaluation-1.pdf)) that the course had a significant impact on their educational goals and careers. The hands-on lab experiences and field work were noted as meaningful components of the course, but students also reported how the interpersonal connections were incredibly valuable.

|  |  |
| --- | --- |
| **Activity Summary** | **Undergraduate and Community College Programs** |
| Led by | Dr. Stephanie Schroeder, Co-I Dr. Jan Amend, Co-I Dr. Julie Huber, Dr. Ken Nealson, Co-I Dr. Andrew Fisher, Co-I Dr. Steven Finkel, Co-I Dr. John Heidelberg, Dr. Eric Webb, Dr. Adina Paytan, Dr. Gretta Serres, Dr. Ben Tully, Dr. Roman Barco |
| Intended Audience | Undergraduates |
| Approximate Number of Attendees | 164 |

► See References Cited in [[Appendix A](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-A-References-Cited-2.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-A-References-Cited.pdf)

##### ► See more at the [CC-RISE webpage](https://www.darkenergybiosphere.org/education-diversity/for-undergraduates/cc-rise/)

##### ► See more at the [C4 webpage](https://www.darkenergybiosphere.org/education-diversity/for-undergraduates/nsf-c4/)

##### ► See more at the [GEM webpage](https://www.darkenergybiosphere.org/education-diversity/for-undergraduates/gem-course/)

##### ► See more at the [GGURE webpage](https://www.darkenergybiosphere.org/education-diversity/for-undergraduates/ggure/)

**3. Graduate Students and Postdoctoral Scholars**

The close integration of education and research is particularly evident in the activities of our graduate students and postdoctoral scholars. C-DEBI provides both formal and informal training to these early career scientists. First and foremost, graduate students and postdoctoral scholars make up the bulk of the research personnel in the Co-I labs. In addition, C-DEBI awards numerous 2-year research fellowships, hosts an on-line seminar series, and supports a range of professional development opportunities.

At any time, approximately 30-40 graduate students and postdoctoral scholars are working on C-DEBI research in the 10 Co-I labs. In 2018, these graduate students and postdoctoral scholars received a wide variety of professional training that intertwined research with education and outreach, including participation in research and training cruises, oral and poster presentations at national and international meetings, invitations to focused workshops, opportunities to deliver classroom and public lectures, inclusion in and leadership of grant proposals, and mentoring of undergraduate and graduate student research.

C-DEBI also invests in the next generation of subseafloor researchers via its graduate student and postdoctoral scholar fellowship programs. These fellows have always integrated education and outreach with their research activities, and since 2016 have been required to include a formal broader impacts statement in the proposal process. The cohort of C-DEBI fellows (together with the C-DEBI graduate students and postdoctoral scholars in Co-I labs) constitutes a private forum to discuss research problems, professional development, and future employment opportunities. EOD Managing Director Stephanie Schroeder also sends weekly emails with information on a variety of topics from organizations including, but not limited to, the AGU, National Postdoc Association, Council of Graduate Schools, and National Association of Geoscience Teachers.

The C-DEBI Networked Speaker Series (NSS) is another opportunity for early career scientists to interact with the larger community. Speakers can be nominated by anyone, with selections made by ExCom. The speakers give live, 30-minute web seminars, followed by a Q&A session. The seminars are recorded for those unable to attend, and C-DEBI hosts 3-4/year. In 2018, the speakers were: Alma Parada (postdoctoral scholar, Stanford University), Nagissa Mahmoudi (Assistant Professor, McGill University), Jackie Goordial (postdoctoral scholar, Bigelow Laboratory for Ocean Sciences), and Rosa León Zayas (Assistant Professor, Willamette University).

At our 2018 annual meeting, approximately 20 C-DEBI graduate students and postdoctoral scholars participated in an all-day professional development workshop entitled *Strategic Persuasion for Meetings and Negotiations*. The workshop, led by Nancy Houfek of COACh (Committee on the Advancement of Women Chemists, University of Oregon), focused on negotiation theory, tips, techniques, and strategies one can use when negotiating in both personal and professional settings. In the evaluation ([Appendix G](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-G-PD-Workshop-Evaluation.pdf)), participants commented that they valued the hands-on approach of the workshop and felt better equipped to negotiate using a variety of tactics.

Individual C-DEBI graduate students and postdoctoral scholars also participated in a range of other professional development activities, from mentoring undergraduates to organizing workshops. For example, many C-DEBI postdocs mentored C-DEBI graduate students; others (e.g., Jackie Goordial (Bigelow), Blair Paul (UCSB) and Alma Parada (Stanford)) gave seminars about microbes to various administrators, and undergraduate and high school students; and yet others (e.g., James Bradley (USC) and Claire McKinley (University of Washington)) participated in outreach activities at tabling events. Lastly, C-DEBI Bioinformatics Specialist and postdoctoral scholar Ben Tully organized and ran two bioinformatics workshops that were geared towards graduate students and researchers.

|  |  |
| --- | --- |
| **Activity Summary** | **Professional Development** |
| Led by | Dr. Stephanie Schroeder, Co-I Dr. Jan Amend, Co-I Dr. Julie Huber, Co-I Dr. Andrew Fisher, Co-I Dr. Geoff Wheat, Co-I Dr. Steven Finkel, Co-I Dr. Victoria Orphan, Co-I Dr. Beth Orcutt, Co-I Dr. Alfred Spormann, Co-I Dr. Steven D’Hondt, Co-I Dr. John Heidelberg, Dr. Stephanie Schroeder, Dr. Benjamin Tully, Dr. Jacqueline Goordial, Dr. Alma Parada, Dr. Blair Paul, Dr. Jesse Colangelo, Dr. Abhiney Jain, Dr. Jeanine Ash, Tucker Ely, Dr. James Bradley, Dr. Claire McKinley |
| Intended Audience | Graduate students, postdoctoral researchers |
| Approximate Number of Attendees | 1000+ |

► See more at the [Networked Speaker Seminar Series webpage](https://www.darkenergybiosphere.org/outputs-resources/networked-speaker-series/)

► See more at the [Professional Development Webinar Series webpage](https://www.darkenergybiosphere.org/outputs-resources/professional-development-webinar-series/)

**4. K-12 and the General Public**

C-DEBI, in partnership with institutions across the country, engaged K-12 students in a variety of activities to increase their knowledge about ocean science and subseafloor biosphere research. For example, in collaboration with the USC Wrigley Institute and USC Sea Grant, we sponsored the High School Marine Science Camp for a seventh year. This 1-week camp is a hands-on, inquiry-based program for 20 diverse high school students recruited nationally. C-DEBI also again supported the USC Young Researchers Program, a 6-week internship for 15 local high school students to carry out research with graduate student mentors, culminating with a poster presentation. Co-I Geoff Wheat again ran the Seafloor Science and ROV Summer Camp for 6th-8th graders, which emphasizes crucial technology to conduct subseafloor research; community college students were recruited to serve as interns in the camp.

C-DEBI’s general outreach activities range from interactive programs that involve a wide audience to promoting C-DEBI through popular media, all with broad and regular social media publicity. This ranges from presentations to middle and high school students, general audience research seminars, cruise blogs, and interviews with the media. Here, we highlight just a few of these activities for 2018: Co-I Victoria Orphan and Luke McKay (former C-DEBI graduate fellow) starred in ‘The Most Unknown’, a full-length documentary revealing unexpected answers to some of humanity’s biggest questions (in theaters and available on Netflix); Christopher Petrone of the Delaware Sea Grant, funded through a C-DEBI E&O Small Grant, produced 11 *Dive Deeper* videos focused on topics such as *Measuring gases at the seafloor* and a VR 360-degree tour of a geoscience laboratory and equipment with Peter Girguis; Associate Director Co-I Julie Huber and Co-I Beth Orcutt highlighted C-DEBI research during the NSF twitter takeover; Sharon Cooper helped develop an interactive video game that is part of a touring exhibit *Stories from the Cores*; and Julie Huber was interviewed by Neil deGrasse Tyson for National Geographic’s ‘Start Talk’ (to air in spring 2019). Additional stories in media outlets including the Boston Globe, LA Times, Motherboard, Newsweek, and The Scientist are listed in [Center-wide Outputs and Issues Section VIII](#_VIII._CENTER-WIDE_OUTPUTS_3) and [[Appendix H](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-H-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx).

|  |  |
| --- | --- |
| **Activity Summary** | **K-12 Programs and General Outreach** |
| Led by | Dr. Stephanie Schroeder, Co-I Dr. Julie Huber, Co-I Dr. Geoff Wheat, Co-I Dr. Beth Orcutt, Co-I Dr. Victoria Orphan, Linda Chilton, Christopher Petrone, Emily Burt, Dr. Anne Dekas, Dr. Margrethe Serres, Lynn Whitley, Sharon Cooper, Dr. Annette Rowe, Dr. Dionysis Foustoukos, Dr. Luke McKay, Dr. Peter Girguis |
| Intended Audience | K-12 students, general audience |
| Approximate Number of Attendees | 1000+ |

# ► See more at the [High School Marine Science Camp webpage](http://dornsife.usc.edu/uscseagrant/summer-science-programs/)

# ► See more at the [Young Researchers Program webpage](http://youngresearchers.usc.edu/)

# ► See more at the [Seafloor Science and ROV Summer Camp webpage](http://www.ssrovcamp.org/)

**5. Performance with Respect to the Strategic Implementation Plan**

Our strategic implementation plan seeks to bring C-DEBI research and the role of subseafloor microbes to the forefront by increasing microbiology literacy in the general public, engaging and retaining students in STEM fields, and training the next generation of subseafloor researchers. As noted above, we focus our efforts on undergraduate students (especially community college students and students from marginalized groups), graduate students and postdoctoral scholars, and the general public. To engage these groups and retain young people in STEM fields, C-DEBI provides training, mentoring, and professional development opportunities, but we also leverage numerous educational partnerships nationally to work with K-12 students to ensure engagement at all levels. Here, we give just a very few examples of how members of the C-DEBI community met our SIP goals. Major media outlets interviewed C-DEBI scientists, including Newsweek (Karen Lloyd, University of Tennessee-Knoxville) and New Scientist (James Bradley, USC). In addition, we keep in contact with our program participants and have had 80% of our community college interns transfer to a four-year institution (with 9% in graduate school).

**Target 1:** The general public is engaged in discovery science through public seminars, outreach activities, and social media.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Present at 5 informal science events or national education conferences | Met |
| Communicate the deep biosphere in 3 general audience, non-scientific publications | Met |
| Communicate C-DEBI and related science content to a science-interested public audience through 2-3 weekly social media posts | Met |

**Target 2:** Hands-on science opportunities are provided to engage K-12 students in microbiology and oceanography.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Conduct 3 informal activities and programs for K-12 classrooms | Met |

**Target 3:** Cutting-edge university research opportunities are provided to undergraduates, especially for community college students and members of underrepresented minorities, attracting early and potentially undecided undergraduate students into STEM majors and strengthening their interest and passion for science and research.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Incorporate deep biosphere content into 5 C-DEBI and partner post-secondary programs | Met |
| Assess program effectiveness using formative and summative evaluations with 70% of respondents rating programs as “very good” or “excellent” (4 or 5 out of 5) | Met |
| Follow the pathway of former program participants using long-term tracking with 50% of former community college participants successfully transitioning to 4-year institutions in STEM majors, and 25% of all former undergraduate participants earning a degree in a STEM major and continuing on to graduate school and/or STEM careers | Met |
| Sustain long-term engagement of C-DEBI and STEM opportunities with >75% of former program participants | Met |

**Target 4:** The next generation of subseafloor researchers (graduate students and postdoctorals) are trained in state-of-the-art laboratories across the country and nurtured through professional development opportunities provided to expand their transferable skills.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Support 30-40 individuals from varied institutions through C-DEBI awards (fellowships, exchanges, research and education grants) and in C-DEBI leadership laboratories | Met |
| Develop and conduct 5-8 regular and varied professional development activities for graduate students and postdoctoral researchers | Met |
| Assess professional development workshop effectiveness using formative and summative evaluations with 70% of respondents rating workshops as “very good” or “excellent” (4 or 5 out of 5) | Met |
| Follow the pathway of former program participants using long-term tracking with 50% of former graduate student and postdoctoral participants successfully transitioning to postdocs or STEM careers | Met |

**6. Plans for the Next Reporting Period** C-DEBI is committed to the continued development of broad-based, targeted education programs that train and foster the next generation of deep subseafloor biosphere researchers and on a broader scale, engage and retain STEM researchers.  Our future objectives are to:

1. Create ongoing outreach programs that include standards-based lesson plans and activities delivered to teachers, while providing outreach opportunities for graduate students and postdoctoral researchers.

2. Strengthen partnerships with community colleges by providing cutting edge research to faculty, promoting undergraduate courses and expanding summer research internship programs.

3. Expand the web site to include downloadable lesson plans and activities for teachers using existing partnerships and evolving new ways to enhance existing curriculum.

4. Use networking, existing organizations, social networking tools and local contacts to increase the scope of C-DEBI’s impact.

5. Promote calls for graduate student fellowships, travel grants, and postdoctoral researchers to attract the next generation of innovative scientists.

# IV. DATA MANAGEMENT AND KNOWLEDGE TRANSFER

## 1. Overall Data Management and Knowledge Transfer Goals and Objectives

C-DEBI facilitates the exchange of knowledge, expertise, intellectual and physical resources, experimental methods, and application of new technologies within its diverse community and between the STC and the community at large. This commitment is demonstrated through open access of all new discoveries, sensors, samplers, data, methods, and platforms. This access has many avenues including, but not limited to, the distribution of information through teleconferences, our website, workshops, meetings, newsletters, presentations, technical documents, peer-reviewed publications, educational activities, and outreach events. C-DEBI is also committed to mentoring students and scientists of all ages, including the exchange of personnel among laboratories and professional development.

The overarching objective of Data Management and Integration (DMI) and Knowledge Transfer (KT) is to disseminate C-DEBI scientific discoveries and technical advances both to the scientific community and broader population. This objective has not changed during the transitions from growth in Phase 1 to nurturing in Phase 2. As such, our DMI and KT goals include (1) implementing effective mechanisms to facilitate intellectual exchanges between institutions of various types, (2) maintaining worldwide access to C-DEBI data and information, (3) nurturing a new generation of C-DEBI researchers, (4) developing and making available targeted education, public outreach, and community interactions, and (5) promoting economic growth through technology development. Significant accomplishments and focused objectives of Center activities during the period of performance have been the implementation of an effective data portal, a concentrated effort that continues to archive C-DEBI produced data within the construct of BCO-DMO (Biological and Chemical Oceanography Data Management Office), the development of an internet-based system for distributing laboratory and analytical protocols, and continued development and implementation of a center-wide bioinformatics program.

There were no concerns raised during the 2018 annual NSF site visit for data management or knowledge transfer. Recommendations included a focus on synthesis of results that will have the highest impact for future studies and to highlight the success and state of the subsurface community. This recommendation has been a major focus of management discussions.

## 2. Knowledge Transfer Activities and Organizations

KT at C-DEBI occurs on a near-constant basis with numerous organizations, most significantly with those highlighted in [External Partnerships Section V](#_V._EXTERNAL_PARTNERSHIPS_8). Here, we specifically call out KT activities that occurred during the reporting period and focused on overall Goals 1, 2, and 5 above (implementing effective mechanisms to facilitate intellectual exchanges, maintaining worldwide access to C-DEBI data and information, and economic growth and technical development). Other forms of KT (e.g., those involving Goals 3 and 4) are covered in other sections of this report, such as classroom lectures, public presentations, the Networked Speaker Series, fellowship and travel grants, professional development (online and in person), workshops, conferences, field trips, GEM, CC-RISE, C4, GGURE and teachers-at-sea.

One of the most effective tools for transferring knowledge to the scientific community is the publication of peer-reviewed papers. During the reporting period, the C-DEBI community published 41 peer-reviewed journal articles, an IODP proceeding, and two book chapters. Of the 41 articles, 25 included graduate students, postdoctoral fellows, or both, and 19 (46%) of the first authors were either graduate students or postdoctoral fellows. Each of these contributions is posted on our web page and introduced to the community in a monthly newsletter that reaches over 1000 individuals globally. In addition, during the performance period, 95 reported presentations/posters were given at numerous special sessions and workshops of large national and international meetings hosted by scientific organizations and partners (e.g., AGU, ISME, ASM, ISSM). Other, smaller C-DEBI leadership-hosted workshops and meetings also contributed to knowledge transfer. These meetings included the C-DEBI Annual Meeting (~65 people) that provides opportunities for experienced and new C-DEBI members to report and discuss recent results, and plan for ongoing and future work. Also, C-DEBI research and researchers were highlighted in approximately 30 media bursts. Some of these bursts reached millions of individuals through a network of national and international news agencies and social media feeds.

Several new technological advances were made during the reporting period. These advances, which can take multiple years for development and implementation, fall within the categories of platform, software, and laboratory developments. New developments include: (1) recent funding from NSF to design and fabricate a high-temperature, borehole fluid sampler with a trigger that uses shape memory alloys; (2) a large agar plate to maintain anoxic conditions to conduct experiments to assess microbial adaptations; (3) an interactive video game that is suitable for a variety of venues including stand-alone kiosks in libraries and museums; (4) a biogeochemical model for marine sediment; (5) a software package that calculates the amount of sequencing effort that is required to sequence microbial genomes in a complex community; (6) a number of python computer scripts designed to expand existing thermodynamic software (e.g., EQ3/6, supcrt92, and DBCreate); and (7) a protocol for cell separation, enumeration, and sorting of low biomass samples for SIP-NanoSIMS preparations. Most of these developments will certainly expand beyond the C-DEBI community.

## 3. Data Management and Integration Activities and Organizations

# The DMI team ensures that C-DEBI data and products are archived, shared, and accessible for the long term. The data types and products covered by C-DEBI include a wide variety of geophysical, geological, geochemical, and biological information, in addition to education and outreach materials, technical documents, and samples. The overall DMI goal is to make sure that all data and information generated by C-DEBI-supported researchers as part of their C-DEBI projects are made publically available either following publication or within two years of data generation (see details in our [Data Management Plan](http://www.darkenergybiosphere.org/wp-content/uploads/docs/C-DEBIDataManagementPlan_2015.pdf)). A second goal is to make certain that no C-DEBI researcher is limited by computational resources (e.g., computers or tools). As part of Phase 2, the DMI team also takes the responsibility to make sure the C-DEBI data are integrated in ways to allow larger, more comprehensive analysis. Finally, we now mandate that all small grant awardees make their protocols available on the protocols.io site. We have further suggested that previous awardees also deposit protocols at that site and have made C-DEBI staff available to help researchers in depositing their protocols.

**a. Making Data Publically Available**

Many C-DEBI products require long term archiving. These include diverse data sets (biological, chemical, physical, and geological), samples, peer-reviewed publications, technological advances with associated engineering drawings and software, educational/outreach materials (such as K-12 and community college lesson plans relating to subseafloor science), and model parameters (e.g., inputs, grids, reaction rates). Biological products include, but are not limited to, molecular data, activity data (isotope abundance, community enzymatic, etc.), frozen samples, living microbial strains, and post-processed molecular data (e.g., 16S rDNA and 16S rRNA sequences, single-cell genome, metagenome and metatranscriptome sequences). Non-biological data include multi-beam maps, seismic reflection profiles, and thermal, chemical, and physical data from recovered samples of fluids, sediment, rocks, and experiments. *In situ* measurements include those at borehole observatories, drilling platforms, cabled observatories, and coring facilities.

In 2018, we continued our efforts to ensure that all post-embargo data were deposited in appropriate internationally accessible data repositories, with BCO-DMO serving as the main one. The C-DEBI DMI team has worked with BCO-DMO to make this location either the primary host of C-DEBI data or to have them provide stable links to data housed in other repositories (e.g., NCBI, IODPdb, PRIDE, etc.). Products for which a suitable national repository does not exist, such as educational materials, outreach materials, and technical advances, have been posted directly on the C-DEBI main page under the headers 'For Teachers', 'For Everyone', etc. To the extent possible, all such products have also been described in the peer-reviewed literature to ensure public dissemination and long-term accessibility beyond C-DEBI. All C-DEBI intellectual products (publications, technical advances, software, education and outreach materials) are directly linkable by searching the main C-DEBI page. This provides direct electronic access to the data repository, publication, and protocols.

We have made major progress in our mandate to deposit C-DEBI data in public repositories. There are currently 67 “Projects” currently on the C-DEBI BCO-DMO webpage (<https://www.bco-dmo.org/program/554979>). Additionally, several others are queued in the BCO-DMO quality check phase. The majority of the Small Grants programs that ended more than two years ago have deposited their required data in public repositories.

We have also made progress in depositing protocols into public databases, specifically into protocols.io (<https://www.protocols.io/groups/center-for-dark-energy-biosphere-investigations>). As of 2018, this is also now mandatory for our grant/fellowship recipients. The DMI team will work with the awardees to ensure deposition of their protocols.

We have also been working to ensure that data generated from C-DEBI projects remain available to future researchers after the Center sunsets in 2020. Toward that end, we have begun to work with Dr. Hurwitz and her “Planet Microbe” EarthCube Building Block program (see below). This program will facilitate easy access to both the data and a suite of analysis tools long-term.

**b. Providing Computational Resources to C-DEBI Researchers**

C-DEBI continues to provide computing resources to accommodate data analysis on scales too large for laboratory computational resources, but too small (or poorly designed) for high powered computing centers. Currently, there are 20 C-DEBI researchers with access, provided on a rotating basis. The current computational capacity hosts over 30 terabytes of user data and supporting infrastructure. The users are all part of the larger C-DEBI community, and include graduate students, postdoctoral researchers and faculty from multiple labs and grants, not just the Co-I’s. The need for this service continues to grow, and we expect continued use in future years.

Beyond basic access to a maintained computer resource, several initiatives have been implemented to make sure C-DEBI researchers are not limited by any step in the bioinformatics process. One important aspect of this is the training of researchers on available tools. To this end, we have successfully hosted/co-led 5 beginner bioinformatics workshops. This workshop has reached over 100 participants from within C-DEBI, the marine geosciences, and other NSF-funded STC programs. We are in the planning stages for hosting additional bioinformatic-centric workshops to work with researchers who have data and domain expertise.

**c. Expanding the Impact of C-DEBI Data through External Partnerships and Collaborations**

C-DEBI believes the best way to ensure continued access to both the data and analysis tools is by collaboration with the ongoing EarthCube programs. Therefore, we continue to collaborate with Drs. DeLong, Hurwitz, and Wood-Charlson to integrate C-DEBI data into their EarthCube Building Block, “Planet Microbe.” C-DEBI believes such collaborations are the soundest way to meet our goals for data discovery, integration, synthesis, and open sharing, and we strive to leverage available infrastructure and to partner with excellent groups like “Planet Microbe.” We are excited to collaborate at all stages of Planet Microbe, from development and validation to implementation and sustainability. C-DEBI Co-I and DMI manager Heidelberg, together with Dr. Benjamin Tully, C-DEBI Bioinformatics Specialist, have committed their expertise and support needed to validate current C-DEBI data. In addition, they continue to develop standardized workflows to ensure that future C-DEBI data will also be contributed to and validated in Planet Microbe. While Planet Microbe (<http://www.hurwitzlab.org/projects/planet-microbe/>) has been focused until now on the BATS and HOTS data sets, they are now beginning the C-DEBI data phase of their program; we will continue to work with them to develop meaningful intermigration sites for C-DEBI data.

## 4. Performance with Respect to the Strategic Implementation Plan

Our DMI and KT goals are to implement effective mechanisms and pathways to facilitate the exchange and application of knowledge, expertise, physical resources, and novel methods and technologies within C-DEBI and between the Center and the broader community. The overall data management plan is in place to 1) ensure that all data generated from the STC are deposited in publically accessible data repositories, 2) allow STC researchers tools and computational resources that allow them to efficiently perform data analysis, and 3) develop and maintain a data portal for visualization and hypothesis generation from the STC data.

**Target 1:** Innovations are imported/exported/shared and partnerships are developed with other fields, research institutions, industry and government.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Publish and promote scholarly activity via 10 publications | Met |
| Continue to develop research collaborations through networking at 2-3 interdisciplinary meetings and talks/posters/exhibition at 2-3 conferences | Met |
| Lead 3 C-DEBI-focused meetings or special sessions at national or international meetings | Met |
| Enhance, develop, or commercialize 2 tools, analytical capabilities, software products, sensors and platforms | Met |

**Target 2:** New innovation in the field is communicated through web tools, publications, media, presentations, and educating the next generation of researchers and ocean stewards.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Continue to ensure all data generated through the STC are in stable public data repositories within 2 years of generation (or for graduate students upon defense of the dissertation or thesis) | Met |
| Continue transition of C-DEBI data into "Planet Microbe" to preserve continued access to the data and analysis tools for discovery, integration, synthesis, and open sharing | Met |
| Train researchers in new tools for data analysis by producing 3 webinars on data analysis tools and 2 small workshops for data analysis | Met |
| Engage 20 new undergraduates to the fields of microbiology and oceanography and mentor 10 graduate students in C-DEBI fields | Met |
| Communicate with the public through non-scientific journals via social and journalistic media (5 significant contributions) | Met |

## 5. Plans for the Next Reporting Period

C-DEBI is continuing with its vision for long-term data management and knowledge transfer activities for the next reporting period, consistent with the current practices and those outlined in the renewal proposal and in response to feedback from previous NSF Site Review committee members and NSF personnel. During the final 1.5 years of C-DEBI, the management team has and will continue to focus on synthesis products from high level contributions to regional-, theme-, and program-based summaries. Such products will focus on a range of media outlets from scientific and educational journals to more broad-based community resources (e.g., newspapers, magazines, and social media).

# V. EXTERNAL PARTNERSHIPS

## 1. Overall External Partnerships Goals and Objectives

C-DEBI supports cross-disciplinary and cross-institutional partnerships that facilitate, augment, and expand the education, training, and research opportunities of Center participants.

## 2. Activities Conducted as Part of Partnerships

C-DEBI continues to strongly support long-standing relationships with high-profile external partnerships and to look for new partnering opportunities. These efforts cover research and education. Of particular note on the research side are partnerships with the International Ocean Discovery Program (IODP), University-National Oceanographic Laboratory System (UNOLS), National Deep Submergence Facility (NDSF), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), the Sloan Foundation-funded Deep Carbon Observatory (DCO), International Continental Drilling Program (ICDP), Schmidt Ocean Institute (SOI), NASA, Los Alamos National Laboratory (LANL), and the new International Center for Deep Life Investigation (ICDLI). On the education side, we again partnered with the International GeoBiology course to train graduate students and postdoctoral scholars (Co-I Victoria Orphan is one of the directors of the course), and we continue to leverage our partnerships with the USC Wrigley Institute for Environmental Studies and USC SeaGrant programs on our undergraduate and high school experiences. In 2018, we again offered our CC-RISE program at UCSC and WHOI, and we partnered with an NSF REU site (C4) to train community college students in microbial cultivation.

**IODP**

Since its inception, C-DEBI science has been firmly connected to IODP's focus on exploring and documenting the deep biosphere. During Phase 1, C-DEBI scientists led several expeditions (327, 329, 336) and were integral science party members of many others (323, 330, 331, 337, 339, 347, 353). Research continues from those expeditions in Phase 2 and in the current reporting year. In the current reporting year, C-DEBI scientists participated in Expedition 376 (Brothers Arc Flux) to collect crustal samples from an active volcanic system with high temperatures and low pH. Co-I Orcutt was invited to participate in the IODP Science Evaluation Panel and the newly formed subcommittee of the US Science Support Program for IODP, which are focused on devising a plan for scientific ocean drilling after the current phase ends in 2023 (SOD23+). C-DEBI early career scientist Jessica Labonté serves as the deep biosphere representative on the current US Science Advisory Committee (USAC) for the ocean drilling program.

**UNOLS and NDSF**

C-DEBI relies heavily on the UNOLS fleet of research vessels for expeditions, including the NDSF fleet of remotely operated vehicles (e.g., *Jason*), autonomous underwater vehicles (e.g., *Sentry*), and the human occupied vehicle *Alvin*, particularly for CORK servicing activities and coring expeditions. C-DEBI early career scientists Susan Lang and Billy Brazelton were co-chief scientists of an ROV Jason cruise in September 2018 to sample pristine hydrothermal vent fluids from the Lost City site hosted on the Atlantis Massif, collecting thousands of co-registered samples for examining the deep biosphere in actively serpentinizing systems. A number of C-DEBI affiliated early career scientists, including postdoc Elizabeth Trembath-Reichert and former postdoc Rika Anderson (now at Carleton College), are also currently taking part in the UNOLS-supported HOV Alvin Early Career Training cruise to the East Pacific Rise. Co-I Orcutt will be leading an ROV Jason cruise to return to the Juan de Fuca CORK observatory network in May 2019; this cruise includes several students and junior C-DEBI researchers from multiple labs.

**JAMSTEC**

C-DEBI collaborates closely with the Geomicrobiology Group (led by Fumio Inagaki) at the JAMSTEC-Kochi Institute for Core Sample Research. Members of C-DEBI and JAMSTEC have also partnered on international expeditions, as well as proposals for new expeditions.

**DCO**

The Sloan Foundation-funded DCO is organized into four science ‘communities’, including one called Deep Life, co-chaired by Mitch Sogin and Kai-Uwe Hinrichs. The DCO funds scientific networking opportunities (e.g., workshops), instrumentation, infrastructure, and focused research initiatives. Several members of the DCO Executive Committee that are major contributors to C-DEBI activities include John Baross (former Chair of C-DEBI’s External Advisory Board, EAB), Karen Lloyd (C-DEBI research grant recipient and member of our Ethics Board), and Rob Pockalny (member of the C-DEBI Data Management and Integration team). Several DCO Deep Life Steering Committee members are also involved in C-DEBI activities; these include Doug Bartlett (Chair of C-DEBI’s EAB), Steve D’Hondt and Beth Orcutt (C-DEBI Co-I’s), Rick Colwell and Matt Schrenk (C-DEBI research grant recipients), and Mitch Sogin (former Chair of C-DEBI’s EAB). Further, Co-I Orcutt is also lead editor of a book (Cambridge University Press) that highlights deep biosphere science, including chapters led by C-DEBI scientists Susan Lang, Doug LaRowe, Karen Lloyd, and Cara Magnabosco.

**ICDP**

The ICDP is supporting several deep life projects, including recent drilling of the Oman ophiolite and coring into an active fault zone at the Moab Khotsong gold mine in South Africa. Alexis Templeton, PI on the NAI *Rock-Powered Life* team, is directly involved in the Oman drilling activities, and she hosted C-DEBI PI Amend during his 2018 sabbatical at CU Boulder. Tullis Onstott is involved in the aforementioned coring activities in South Africa and collaborating closely with C-DEBI Co-I Orcutt on the deployment and subsequent extraction of a kinetically-activated subsurface microbiology sampler (KASMS).

**SOI**

SOI is a private foundation that serves as an oceanographic operator for the seagoing community by providing ship and vehicle time via community solicited, peer-reviewed proposals. A number of Co-I’s and other C-DEBI scientists have participated in cruises aboard the SOI research vessel *Falkor*. For example, Co-I Orphan and several members of her lab sailed to the Pescadero Basin in the Gulf of California and Costa Rica Margin in 2018. Several C-DEBI members have submitted proposals to SOI for expeditionary proposal selections.

**NAI**

The *Life Underground* node, led by PI Amend at USC, is one of the NASA Astrobiology Institute (NAI) CAN-6 teams (funded through 2018). The cross-disciplinary team, which includes Co-I’s Victoria Orphan and Beth Orcutt, used field, laboratory, and modeling approaches to detect and characterize microbial life in the subsurface—predominantly, but not exclusively, in the continental subsurface. C-DEBI and NAI also shared other key personnel, jointly developed down-hole biomass detection capabilities using deep UV microscopy, modeled microbial metabolic potential in marine sediments globally, used electrode cultivation techniques to enrich for microbes from North Pond, and coordinated several education and outreach efforts. A few examples of C-DEBI/NAI partnerships include: Elizabeth Trembath-Reichert, a former C-DEBI-funded graduate student in Co-I Orphan’s lab, spent 2018 as an NAI Postdoctoral Fellow working with Julie Huber and Jan Amend on microbial activity in North Pond crustal fluids; former C-DEBI postdoctoral scholar Annie Rowe (with Ken Nealson) finished up an NAI *Life Underground*-funded postdoctoral project at USC (with Amend and Moh El-Naggar in Physics), and assumed a tenure track faculty job in early 2018 at the University of Cincinnati; Eric Boyd, a C-DEBI small grant recipient (with John Dore), continued to serve as Deputy PI of the *Rock-Powered Life* node of the NAI that focuses on subsurface water-rock interactions and the links to a corresponding microbial biosphere; and Fabai Wu continued a shared postdoc between the Amend and Orphan labs, funded equally by C-DEBI and the NAI. In addition, Co-I Huber is part of a NASA PSTAR grant termed Systematic Underwater Biogeochemical Science and Exploration Analog (SUBSEA). The team conducted a successful real (non-simulated) telerobotic expedition to Loihi Seamount to understand the habitability potential of Ocean Worlds in our Solar System. This project also included access to infrastructure enabled through in-kind support from the NOAA Office of Ocean Exploration and Research and the Ocean Exploration Trust.

**LANL**

C-DEBI (through the UCSC Hydrogeology group) continues to collaborate with researchers in the Earth and Environmental Sciences Group at LANL, to develop complex simulations of seafloor hydrothermal circulation. Co-I Fisher and members of his group (Weathers and Price) visited with LANL colleagues in June 2018, to collaborate on modeling projects. Weathers is developing solute transport simulations in an effort to replicate tracer transport results, and Price is simulating hydrothermal processes in the volcanic crust beneath the North Pond study site. Fisher is running simulations of fluid and heat flow through Dorado Outcrop, as part of a study synthesizing thermal data from the region.

**ICDLI**

The new International Center for Deep Life Investigation (ICDLI) held its inaugural symposium in Shanghai, China in October 2018. More than a dozen C-DEBI participants attended the meeting, with several giving invited lectures. ICDLI’s Advisory Board also features a number of C-DEBI scientists, including Co-Is Amend, Orcutt, and D’Hondt.

**Education**

The interdisciplinary nature of C-DEBI research lends itself magnificently to a diverse array of external education partnerships as well. One of our primary education goals is to train the next generation of deep subseafloor biosphere researchers, and to do so, we partner with one of the top training courses for graduate students and postdoctoral scholars, the Agouron Institute-funded International GeoBiology summer course. In 2018, this course was again co-directed by Co-I Victoria Orphan, featured several C-DEBI members as guest lecturers, and also included two C-DEBI-funded graduate student attendees. Just as C-DEBI and the International GeoBiology course share key personnel (administrative and instructional), so do C-DEBI and the USC Wrigley Institute. This facilitates our training of undergraduates through programs such as the Global Environmental Microbiology course (based heavily on the successful GeoBiology program) and a growing ROV education program at the Institute’s marine lab on Catalina Island. The facility is also the site of our high school program, run by the USC SeaGrant program, and held at the Wrigley Institute. Our outreach partners also include the Monterey Bay Aquarium Research Institute, the College of Exploration, and community colleges across the country that enable us to train teachers at the K-16 levels.

## 3. Performance with Respect to the Strategic Implementation Plan

Our overarching goal is to engage and support cross-disciplinary and cross-institutional partnerships that facilitate, augment and expand the education, training and research opportunities of Center participants. Partnerships among individuals, institutes, organizations, and programs are the core of C-DEBI research and educational efforts. One of the strengths of these partnerships is the quality and broad appeal of publications. C-DEBI has a range of cross-disciplinary and cross-institutional collaborations that have transformed our view of subsurface microbial conditions, activity, and mechanisms within the hydrologic and geochemical context of fluid flow within the oceanic crust. Another strength of C-DEBI partnerships is the web of interaction of the C-DEBI community within other organizations and programs and the joint efforts of these organization and programs in collaboration with C-DEBI to promote and facilitate synergetic research objectives. These partners also extend to education and diversity efforts, leading to a community of junior scientists that are engaged in cross-disciplinary and cross-institutional training activities and exchanges.

**Target 1:** Strong cross-disciplinary research projects and strong cross-institutional programs are demonstrated in all aspects of Center activities, including publications, presentations, proposals, educational exchanges, and educational programs.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Publish 5 (in aggregate) cross-disciplinary papers per each of the three research themes with support from calls for small research and travel grants to facilitate the interaction of dispersed Center researchers | Met |
| Submit 2 cross-disciplinary and cross-institutional proposals | Met |
| Support 2 interdisciplinary workshops or meetings in concert with other national programs | Met |
| Fund 10 graduate students, postdoctoral fellows and C-DEBI community scientists in their pursuit of generating data or developing cross-discipline techniques and tools to further Center objectives | Met |
| Provide the funds that allow 3 student/researchers the opportunity to participate in research expeditions or travel to another institution to expand the scope of their education/research in the use of novel techniques and tools | Met |

**Target 2:** Partnerships are developed with other fields, research organizations, industry, government, and foundations.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Build 10 (total) partnerships by networking at interdisciplinary meetings, developing industrial and governmental partners, and targeting partnerships and interactions for new applications of existing or budding technologies | Met |
| Develop documents and materials that highlight significant results through C-DEBI research, education, and diversity programs suited to specific organizations, foundations, and programs to form the basis of a dialogue between C-DEBI and that organization to further fiscal and research needs | Pending |

## 4. Plans for the Next Reporting Period

C-DEBI has had long-standing partnerships with most of these external partners—others have come on board more recently—and the close collaborations are likely to continue at similar levels of commitment for the foreseeable future.

# VI. DIVERSITY

## 1. Overall Diversity Goals and Objectives

C-DEBI seeks totrain a new, diverse generation of K-12, undergraduate, graduate and postdoctoral researchers within an integrated and collaborative multidisciplinary community. We are committed to improving access and support for members of underrepresented and marginalized groups to be able to succeed in STEM fields. It should be noted, however, that the activities intended to enhance diversity do not happen in a vacuum—they are purposefully integrated with C-DEBI’s fundamental research, education, and outreach missions. Through its academic programs, C-DEBI promotes inclusion and retention among underrepresented groups, including women and first-generation college students. With a strong base established to increase STEM diversity at all levels, both academically and nationally, we are developing and exporting distinctive, in-depth education and research experiences that encourage historically underserved students. These initiatives will be targeted toward three primary sectors: 1) pre-college; 2) undergraduate and community college populations; and 3) early-career and established scientists.

Our specific targets are to: a) increase the diversity of C-DEBI participants to reflect the diversity of the United States; b) emphasize diversity awareness with the active C-DEBI community through an in-person diversity and inclusion training workshop at C-DEBI’s annual meeting, and among individual student cohorts of each C-DEBI summer education program; and c) promote C-DEBI research opportunities to diverse audiences through several different partners that primarily serve underrepresented groups.

## 2. Programs and Activities Which Enhance Diversity at the Center

C-DEBI continues to build on program successes of the past years by expanding and evaluating six distinct programs targeting underrepresented minorities, women, and first generation and low-income students: C4 and CC-RISE (see [Education section](#_III._EDUCATION_6)), the Global Environmental Microbiology (GEM) course, the Genomics and Geobiology Undergraduate Research Experience (GGURE), the USC Young Researchers Program (YRP), and the High School Marine Science Camp. These programs enrich the scientific skills of students through a combination of field-based research with professional development activities.

|  |  |  |  |
| --- | --- | --- | --- |
| **Program** | **Number of Participants** | **Diversity Objective** | **Measurement of Outcomes** |
| NSF REU: Community College Cultivation Cohort (C4) | 8  (24 from 2016-2018) | NSF REU for community college students recruited at a national level | External evaluation, Longitudinal tracking |
| Community College Research Internship for Scientific Engagement (CC-RISE) | 8  (52 in 6 years) | Summer research internship for community college students near UCSC and WHOI | External evaluation, Longitudinal tracking |
| Genomics and Geology Undergraduate Research Experience (GGURE) | 24 (192 positions from Fall 2014 to present) | Academic year and summer research internship program for underrepresented undergraduate students at USC | External evaluation, Longitudinal tracking |
| Global Environmental Microbiology (GEM) Summer Course | 16  (126 in 8 years) | Hands-on experience for 2- and 4-year undergraduate students in environmental microbiology | External evaluation,  Retrospective survey,  Longitudinal tracking |
| Young Researchers Program | 12 (54 in 7 years) | Research lab experience for high school students | Summary report |
| Marine Science Camp | 15  (130 in 7 years) | Hands-on exploration of oceanography for high school students | Summary report of survey |

We continue to have success in recruiting a diverse group of participants for each of these six programs. We advertise widely for all except the USC-based GGURE which, through word-of-mouth via participants and mentors/PIs, already receives more interest than we can support. We leverage our existing contact lists (applicants and participants of each of our programs, writers of recommendation letters, etc.) by sending information to them about other C-DEBI programs for which we think they are qualified or would know someone who is qualified. For example, it makes sense for past community college GEM applicants to apply to GEM again or to apply to C4 if they are getting ready to transfer to a four-year school, so we advertise both those programs to that subset of people. We also recruit Ph.D. student mentors for the YRP program by advertising the program to the mentors/PIs of GGURE students.

To recruit participants at higher levels, we advertise graduate student openings and postdoctoral positions through social media, the SACNAS opportunity board, and the Institute for Broadening Participation Pathways to Science, among others.

We continue to work toward increasing underrepresented minorities in C-DEBI by promoting deep subsurface research through Minority Professional Organizations and national networks. This year, we disseminated program and graduate training opportunities with partners such as the Institute for Broadening Participation (IBP), Society for Advancing Chicanos and Native Americans in Science (SACNAS), American Indian Science and Engineering Society (AISES), National Science Teachers Association (NSTA), and the broader STC Education and Diversity network. In addition, we attended SACNAS USC Chapter meetings, Intertribal Education Collaboration (ITEC) meetings, and the Cerritos College Native American Student Resource Fair to share opportunities and resources directly with students. We have also discussed future networking and funding possibilities with Kimberly Freeman, hired in 2018 as the Chief Diversity Officer for the USC Dornsife College.

A number of activities are designed to build and maintain a community and to keep participants active in STEM. To keep in touch with participants and share STEM opportunities, we run an email listserv for undergraduates and one for graduate students and postdoctoral researchers as well as invite everyone to sign up for our email newsletter and engage with us through our social media accounts. To strengthen the C-DEBI network, we create connections between participants in different programs and bring back alumni to engage with current students. For example, Julieta Aguilar, a GGURE alumna, is now a professor at Los Angeles Trade Tech College (LATTC), and she spoke to our current GGURE students about her career path. A few of our current GGURE students have spoken about their research to Dr. Aguilar’s students at LATTC, and three GGURE students spoke about their research to the YRP high school participants. We also recognize the importance of sending our undergraduates to conferences. One C4 student is part of the ASLO Multicultural Program and will attend the ASLO meeting in Puerto Rico in February 2019.

We incorporated a diversity discussion into our GEM and C4 programs (combined session) and both the YRP and High School Marine Science Camp each held their own discussion sessions with students. From the GEM post-survey report, we learned that “Students valued the program’s focus on diversity and inclusion. They felt the program celebrated diversity beyond ethnicity, including culture and region.” At our C-DEBI annual meeting, we hosted an Education, Outreach, and Diversity session that featured Dr. Rina Roy, Dean of Science and Engineering at American River College and a member of our External Advisory Board, who presented the needs of community college students and programs to help support them.

2018 was the last year of the NSF C4 REU, but a renewal proposal (PI Amend) has been submitted. We also resubmitted an NSF:IUSE GEOPATHS-IMPACT proposal (PI Amend), which, if funded, would offer bioinformatics training to cohorts of Los Angeles-based community college students.

Of the 268 participants active in C-DEBI this year, 68 are faculty and research scientists, 69 are postdoctoral researchers and graduate students, and 77 are undergraduate students indicating the breadth of participation across career stage. Participant gender distribution (Table 1) is nearly balanced with women representing ~55% and men ~45%. Ethnicity (Hispanic/Latinx or not) and race (White, Native Hawaiian or other Pacific Islander, Asian, Black or African American, American Indian or Alaska Native, multiracial) were reported by 82% of participants (Table 2). Out of all individuals, about 18% identified as Hispanic/Latinx. Regarding race, ~60% of participants identified as White, ~13% Asian, ~5% Black or African American, just under 1% American Indian or Alaska Native, and 3.4% multiracial. Multiracial individuals identified various combinations of White, Asian, Black or African American, and/or American Indian or Alaska native. Of all participants, 184 (69%) identified as U.S. Citizens, 16 (6%) identified as Permanent Residents, 22 (8%) identified as other non-U.S. Citizens, and 46 (17%) did not provide citizenship information. Five individuals (2%) identified one or more disabilities, 219 individuals (82%) reported none, and 44 individuals (16%) did not provide disability information.

|  |  |  |  |
| --- | --- | --- | --- |
| **Table 1. Gender Distribution of C-DEBI Participants (Total Number)** | **Women (Percent)** | **Men (Percent)** | **Gender Not Provided (Percent)** |
| Faculty (56) | 46 | 54 | 0 |
| Other Research Scientist (12) | 42 | 58 | 0 |
| Postdoctoral (36) | 50 | 47 | 3 |
| Graduate Student (33) | 67 | 33 | 0 |
| Undergraduate (77) | 56 | 44 | 0 |
| Pre-college (27) | 56 | 44 | 0 |
| Teacher / Educator (13) | 85 | 15 | 0 |
| Other Participant (9) | 22 | 78 | 0 |
| Staff (5) | 80 | 20 | 0 |
| **Total (268)** | **54.5** | **45.1** | **0.4** |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Table 2. Racial and Ethnic Distribution of C-DEBI Participants  (Total Number)** | **White (Percent)** | **Native Hawaiian or Other Pacific Islander**  **(Percent)** | **Asian (Percent)** | **Black or African American (Percent)** | **American Indian or Alaska Native (Percent)** | **Multi-racial (Percent)** | **Race Not Provided (Percent)** | **Hispanic/ Latinx\* (Percent)** |
| Faculty (56) | 77\*\* | 0 | 5\*\* | 0 | 0 | 2 | 16 | 0 |
| Research Scientist (12) | 92 | 0 | 0 | 0 | 0 | 0 | 8 | 8 |
| Postdoctoral (36) | 69 | 0 | 17\*\* | 0 | 6\*\* | 3 | 6 | 14 |
| Graduate Student (33) | 61\*\* | 0 | 18\*\* | 3 | 0\*\* | 6 | 12 | 6 |
| Undergraduate (77) | 49\*\* | 0 | 18\*\* | 14\*\* | 0\*\* | 3 | 16 | 26 |
| Pre-college (27) | 41\*\* | 0 | 15 | 7\*\* | 0 | 11 | 26 | 70 |
| Teacher / Educator (13) | 54 | 0 | 0 | 0 | 0 | 0 | 46 | 8 |
| Other Participant (9) | 22 | 0 | 0 | 0 | 0 | 0 | 78 | 0 |
| Staff (5) | 60 | 0 | 40 | 0 | 0 | 0 | 0 | 20 |
| **Total (268)** | **59.7\*\*** | **0** | **13.1\*\*** | **5.2\*\*** | **0.7\*\*** | **3.4** | **17.9** | **18.3** |

*\*Individuals can identify as Hispanic/Latinx, regardless of race*

*\*\*Indicates races identified of multiracial individuals*

Comparing the 2018 C-DEBI community (who reported) to the July 1, 2017 U.S. Census population (figure below; race is separate from the concept of Hispanic origin in the U.S. Census), we have broadly captured the racial/ethnic diversity of society through our active participants, and continue to strive towards that distribution across all career levels of our participants.

**U.S. CENSUS**

18.1% Hispanic/Latinx

**C-DEBI**

18.3% Hispanic/Latinx

Diversity, in the broadest sense and at all levels, is an active goal for C-DEBI—and always has been. We remind the reader that in the natural sciences, women remain vastly underrepresented, and C-DEBI has a strong record of appointing women to leadership positions, selecting women in our grants and fellowship program, and featuring women in numerous public forums. We also note that improving diversity at ‘higher levels’ is only possible when existing positions become vacant or new positions are created. At C-DEBI, diversity was considered in the few vacant and new positions, and of the 13 current leadership positions at C-DEBI (consisting of the Directorship, Co-Investigators, Data Management, Knowledge Transfer, and Senior Scientists) nearly half are filled by women, including the Associate Director (Huber) and Managing Director (Sylvan). Lastly, we want to reiterate that our approach to building ‘diversity in leadership’ has always been to train the next generation of leaders. Note that to date, nearly 60 CDEBI-funded graduate students and postdoctoral scholars, over30 of whom are women and nearly 10 of whom are from underrepresented minorities, have transitioned (or are in the process of transitioning) to permanent career appointments with opportunities for leadership in their chosen professions. Those women and underrepresented minorities include a Nature editor, a number of research scientists, and more than 30 faculty members at universities in the USA and elsewhere.

## 3. Performance with Respect to the Strategic Implementation Plan

**Target 1:** The diversity, especially underrepresented minority representation, of participants in all levels of C-DEBI from undergraduate, graduate students, and postdoctoral scholars to participating researchers and staff, has increased in recent years to more appropriately reflect our diverse society.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Increase the diversity of C-DEBI participants to reflect the diversity of the United States | Met |

|  |  |
| --- | --- |
| Emphasize diversity awareness with the active C-DEBI community through 1 in-person diversity and inclusion training workshop at C-DEBI’s annual meeting, and among individual student cohorts of each C-DEBI summer education program | Met |
| Promote C-DEBI research opportunities to diverse audiences through 4 different partners that primarily serve underrepresented groups | Met |

**Target 2:** Pathways to careers in STEM fields are developed for minority undergraduate students who are interested in STEM majors.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Conduct 3-5 programs attracting underrepresented students into STEM fields | Met |
| Assess program effectiveness using formative and summative evaluations with 70% of respondents rating programs as “very good” or “excellent” (4 or 5 out of 5) | Met |
| Follow the pathway of former program participants using long-term tracking with 50% of former community college participants successfully transitioning to 4-year institutions in STEM majors, and 25% of all former undergraduate participants earning a degree in a STEM major and continuing on to graduate school and/or STEM careers | Met |
| Sustain long-term engagement of undergraduate participants with/in C-DEBI and STEM opportunities with >75% of former program participants | Met |

**Target 3:** Partnerships are initiated with other organizations, institutions, programs, or informal science centers that target underrepresented students and engage them in STEM fields of study.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Introduce C-DEBI science with appropriate resources and training to 10 institutions and/or educators that primarily serve underrepresented groups | Met |

## 4. Plans for the Next Reporting Period

Our future goals are to:1) actively encourage undergraduates to progress to graduate school in areas of deep subsurface research by promoting summer research or intensive programs being led at C-DEBI networked institutions; 2) continue to leverage support services and potential connections, organizations and institutional resources within partnering universities to promote diversity; 3) actively promote all opportunities throughout the Center to underrepresented groups and recruit at all levels of Center activity; 4) inform and encourage the C-DEBI community to participate in conferences and outreach that engages them with underrepresented students to promote recruitment into C-DEBI fields; 5) continue to leverage SACNAS involvement to promote and provide financial support to undergraduate and graduate students from C-DEBI to present research at the annual SACNAS conference; 6) continue to document and codify components of the GGURE program such as ‘Demystifying graduate school’ and ‘Applying to Graduate School’ to create a more robust resource website for students who cannot attend meetings or are not directly in the GGURE program; and 7) continue to reconnect with and track past C-DEBI participants to see how their C-DEBI experiences influenced their career paths.

# VII. MANAGEMENT

**1. Overall Organizational Strategy**

Our management plan facilitates the achievement of the principal scientific, education, and diversity goals of C-DEBI. C-DEBI management is composed of these major leadership groups: Directorship; Executive Committee; Administration; Research; Knowledge Transfer, Data Management and Integration; and Education, Outreach, and Diversity. The major advisory groups for C-DEBI are the External Advisory Board; Ethics Panel; External Evaluator; and the Education & Outreach Steering Committee. We maintain a simple hierarchy in the management structure (rectangles below) with several advisory groups (ovals below) to encourage communication and collaboration, as well as provide transparency in decision-making. Their roles and interactions are described below and further detailed in our [Operations Manual](http://www.darkenergybiosphere.org/wp-content/uploads/C-DEBIOperationsManual_2018b.pdf).

****

**Directorship**

The Center is led by the Director, PI Jan Amend (USC), the Associate Director, Julie Huber (WHOI), and the Managing Director, Rosalynn Sylvan. The Director is responsible for overall C-DEBI coordination and performance. He provides leadership in C-DEBI scientific, education, diversity, outreach, and administrative activities; he represents C-DEBI in interactions with USC administration and funding agencies; and he promotes the Center worldwide.

The Associate Director is the ‘right hand’ of the Director; she assumes all responsibilities and powers of the Director should he, for any reason, be unable to carry out his duties. Together with the Managing Director, she coordinates the grants program and communicates with grant recipients about outcomes, products, and dissemination of results.

The Managing Director manages fiscal matters and grants administration and oversees the administrative staff.

**Executive Committee**

The Executive Committee (ExCom) manages, supports and leads the direction of the Center’s science initiatives. ExCom also provides guidance to integrate research, education, and data across the Center. ExCom coordinates with the Senior Scientists (see Research management section below) on C-DEBI research directions. ExCom generates calls for proposals and serves with the Senior Scientists as the review panel, with mechanisms to avoid conflict-of-interest.

ExCom consists of seven permanent members and two rotating members. The permanent members are Director and PI Jan Amend (USC), Associate Director and co-PI Julie Huber (WHOI), co-PI Steven D’Hondt (URI), co-PI Andrew Fisher (UCSC), co-PI C. Geoffrey Wheat (U Alaska-Fairbanks), Data Management Director and Senior Scientist John Heidelberg (USC), and Education Director Stephanie Schroeder (USC). The rotating members consist of Senior Scientists (see Research management section below) added to complement the research expertise on ExCom and serving 15-month terms. Steve Finkel (USC), Beth Orcutt (Bigelow), and Alfred Spormann (Stanford) served as rotators for part or all of 2018.

ExCom maintains communication via biweekly videoconference meetings, two annual face-to-face meetings, and ad hoc meetings at selected C-DEBI, national and international meetings, with participation by the Managing Director and as needed by members of the Administration; Research; Knowledge Transfer, Data Management and Integration; and Education, Outreach and Diversity Teams.

**Administration**

The administrative staff, led by Managing Director Rosalynn Sylvan, is based at USC, where they manage the Center’s day-to-day activities. They link to C-DEBI activities at the partner institutions and communicate with all participants worldwide. The Managing Director manages fiscal matters and grants administration and with the Education Director, Stephanie Schroeder, oversees the administrative staff. The Managing Director attends the biweekly ExCom videoconference meeting and any other face-to-face ExCom meetings as the administrative liaison. Since 2015, the Managing Director has been operating remotely at Texas A&M University as a Visiting Scholar at the International Ocean Discovery Program (IODP) with regular email and telecommunications in addition to the biweekly administrative and ExCom meetings via videoconferencing. In the fall of 2018, the Education Director began operating remotely at a reduced effort (50%), continuing her oversight of the Education, Outreach, and Diversity programs. To help support the administrative activities of these programs, the effort of the Administrative Assistant, Nerissa Rivera-Laux, has increased (from 50% to full time). Like the Managing Director, the Education Director continues regular email and telecommunications in addition to the biweekly administrative and ExCom meetings via videoconferencing.

The Data Manager, Matthew Janicak, is responsible for supporting the database infrastructure (see Data Management and Integration below) and development and maintenance of the website and other community communications. The Administrative Assistant, Nerissa Rivera-Laux, implements day-to-day activities of the center and is responsible for meeting coordination.

**Research**

C-DEBI research is organized in three cross-cutting themes: *Fluxes, Connectivity, and Energy* (Theme 1); *Activities, Communities, and Ecosystems* (Theme 2); and *Metabolism, Survival, and Adaptation* (Theme 3). They are led by the PI Amend; co-PIs D’Hondt, Fisher, Huber, and Wheat; and Senior Scientists Finkel, Heidelberg, Orphan (California Institute of Technology), Orcutt, and Spormann.

**Knowledge Transfer, Data Management and Integration**

Knowledge Transfer (KT) is central to all of C-DEBI’s research, education, and outreach programs, and hence, it is the responsibility of all our senior personnel. As KT Director, Wheat coordinates and tracks the various knowledge transfer activities, with a special focus on dissemination of scientific and technical knowledge, increasing public awareness of the subseafloor biosphere, and promoting development and application of novel technologies through commercialization and entrepreneurial use of C-DEBI products.

The Data Management and Integration (DMI) team has the primary objective to make C-DEBI data and products accessible to the world. The products include C-DEBI publications, data generated by C-DEBI projects, documentation of technological advances, and products for education and outreach. Heidelberg leads the DMI effort, with support from personnel at USC (Data Manager Matthew Janicak and Bioinformatics Specialist Benjamin Tully) and URI (Data Portal Lead Robert Pockalny). The DMI Director is also responsible for ensuring that C-DEBI participants have access to the Center’s computational resources and/or bioinformatics expertise, as well as making certain C-DEBI generated data are properly deposited in public archives and databases, including future EarthCube initiatives.

**Education, Outreach, and Diversity Administration**

The Education, Outreach, and Diversity (EOD) team is based at USC and develops, implements, and coordinates EOD programs and activities. The Education Director, Dr. Stephanie Schroeder, provides oversight, leadership, and commitment to the integration of C-DEBI research with our EOD efforts at all levels. The Education Director also leads the professional development and mentoring efforts for undergraduate and graduate students, postdoctoral scholars, and K-12 teachers. The Diversity Director, Gwen Noda, reports to the Education Director and leads programs to entrain members of underrepresented groups into STEM fields with a special focus on microbiology, geochemistry, and oceanography. The Diversity Director also expands the reach of C-DEBI through social media communication. The Administrative Assistant, Nerissa Rivera-Laux, also supports the administrative activities of the EOD programs.

**External Advisory Board**

The External Advisory Board (EAB) provides an annual assessment of the science, education, mentoring, management, and functioning of C-DEBI to the Directorship. The current five-member committee includes Chair Doug Bartlett (Scripps), Vicki Ferrini (LDEO), Jon Kaye (Moore Foundation), Rina Roy (American River College), and Judy Wall (University of Missouri). The EAB met with the C-DEBI leadership at the 2018 C-DEBI Annual Meeting to discuss future research and education directions, and reports their recommendations to the directorship confidentially. Their assessment will be presented at the Site Visit.

**Ethics Panel**

The Ethics Panel advises ExCom on any issue pertaining to ethics, including concerns regarding administration, funding, and scientific conduct. This Panel handles all C-DEBI ethics complaints and convenes (electronically or in person) on an ‘as needed’ basis or on request of ExCom. The panel also makes recommendations to ExCom with respect to ethics training programs for C-DEBI members. The Ethics Panel consists of Chair Karen Lloyd (Associate Professor at U Tennessee), Frederick Colwell (Professor at Oregon State), Andrew Fisher (ExCom), Sharon Cooper (Education Officer of the IODP US Science Support Program at Lamont-Doherty Earth Observatory), and William Orsi (Assistant Professor at LMU Munich), representing several groups within C-DEBI. To date, the committee has not received any ethics complaints.

In addition, we continue to emphasize a comprehensive ethics policy for C-DEBI participants based on existing models starting with NSF and integrating with specific IODP and other institution policies. This sets forth a community standard to minimize and resolve conflicts effectively. The online ethics training is mandatory for all C-DEBI participants and completion by deadline is enforced.  See more at our [Ethics Policies webpage](https://www.darkenergybiosphere.org/about-our-center/ethics-policy/).

**External Evaluator**

The External Evaluator, Beth Rabin, assesses and evaluates the effectiveness of C-DEBI management, research, and education, outreach, and diversity programs and provides thorough, rigorous, independent, and results-based assessments to ExCom.

**Education & Outreach Steering Committee**

The Education & Outreach Steering Committee serves in an advisory role to the EOD administration. The committee consists of current or previous STC Education and Diversity Directors Sharnnia Artis (UC Irvine), Vanessa Green (Oregon Health & Science U), and Elisa Maldonado (U San Diego).

**2. Management and Communications Systems**

C-DEBI is a geographically distributed center, with members and participants around the world. Our Center and its participants have ample experience in long-distance collaboration and communication. There are biweekly administrative and ExCom meetings via videoconferencing, a biweekly newsletter (sent to over 1000 e-mail addresses), an active social media presence, and regular updates to our website. C-DEBI’s annual meeting includes leadership and advisory groups, graduate and postdoctoral fellows, and invited guests. We also organize several targeted workshops annually and encourage members (especially postdoctoral scholars and early career scientists) to organize sessions at national and international meetings. Coordination of these communication activities is under the purview of the Administrative team.

##### C-DEBI’s social media platforms include Facebook (cdebi, ccrise, CdebiGlobalEnvironmentalMicrobiologyCourse), Twitter (@deepbiosphere), and LinkedIn. Diversity Director Noda manages the Center’s social media presence amplifying Center news, opportunities, resources, and more to stay engaged with our deep sea scientific community as well as engage members of the science-interested public. Social media also serves as an outlet to share related science news, opportunities, and professional development from organizations such as DCO, IODP, Schmidt Ocean, MBARI, and the NSF/NSF Geosciences as well as articles on diversity in STEM/academia, work/life balance, resume writing, applying for graduate school, and more.

The C-DEBI website plays a number of important roles in Center communications. As the website is often a first point of contact with the Center, numerous cosmetic improvements and performance enhancements have been implemented to improve user experience and first impressions, and this work will be ongoing as expectations for website usability continue to advance. The website also serves as the definitive source for Center goals, policies and programs. We will continue to improve navigational awareness through greater visual differentiation of pages and entities, and promote the discoverability of related content via metadata enrichment. As a principal source of community news and activities, the website lists time-sensitive items on the front page and archives them for search. Lastly, the website is intended to serve as a working resource for active research and education participants, and we have improved the website’s search interface and metadata-driven cross-linking. As such, we have centralized data assets in BCO-DMO, so project data are now first level entities on the website – and future development will integrate BCO-DMO’s ontology-focused metadata system with our website interface and own metadata requirements. To lower technological barriers to data access and synthesis, we will leverage resources like iMicrobe, protocols.io, and other partners in the EarthCube community.

**3. Performance with Respect to the Strategic Implementation Plan**

Our leadership and management goals are to envision and enable the Center’s mission through inclusive and transparent decision-making; inspire Center members; and facilitate collaborative effort and guide all participants in the Center via a cross-disciplinary and multi-institutional ethics program to instruct them on ethical and responsible conduct of scientific research. A fundamental challenge for C-DEBI leadership is to maintain trust and support among a diverse and interdisciplinary community of scientists, educators, and technologists. Maintaining confidence in STC leadership, throughout the existence of the Center, is essential if busy STC participants are to retain a willingness to allocate some of their limited time for advisory, review, and collaborative activities. STC leaders will also need to assure that there are robust opportunities for inter-institutional and cross-disciplinary exchanges and training, and help to secure external resources in support of ongoing and future STC activities. In addition, the Center will maintain a rigorous ethics training system for all C-DEBI participants and an Ethics Panel overseeing policies and procedures. Finally, STC leadership needs to remain focused on the critical goal that motivated formation of C-DEBI in the first place: creating a vibrant, innovative, and focused community, who will work together to achieve what cannot be accomplished by individuals working alone, to transform the nature of deep biosphere research.

**Target 1:** The decision-making process is defined, transparent and effective leading to a high degree of confidence, ownership, and engagement by STC participants in the Center.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Hold biweekly administration meetings as well as biweekly ExCom meetings and an annual ExCom face-to-face retreat to enable clear and effective management of the Center | Met |
| Invite the evaluation of Center research, education, diversity, and knowledge transfer management by the External Advisory Board (typically in conjunction with the C-DEBI annual meeting) for feedback and suggestions to the Director to improve the integration of C-DEBI programs and activities | Met |
| Update the C-DEBI Operations Manual to elucidate the functions of key individuals and groups and main research, education, outreach, and administration activities, programs, operations and procedures and post on the website with the Annual Report and Strategic Implementation Plan | Met |

**Target 2:** Communication is effective in facilitating the exchange of science, education of students, and promotion of other C-DEBI activities and opportunities.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Regularly update the comprehensive website at www.darkenergybiosphere.org with research and education portals and resources | Met |
| Distribute biweekly newsletters to the C-DEBI community to highlight recent and upcoming C-DEBI research and education programs and events and other relevant/partner activities and opportunities | Met |
| Continue to improve the private login site for internal documents and community reporting | Met |
| Solicit 3 nominations for the next season of the videoconferenced Networked Speaker seminar series to present early career scientist research to the C-DEBI community | Pending |
| Maintain protocol/procedure for issuance and usage of C-DEBI contributed publication numbers and of logo and branding information | Met |

**Target 3:** STC participants are engaged in cross-Center training and collaboration.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Organize 5-7 C-DEBI-specific opportunities for collaboration and training and entrain new membership (e.g., Center-wide Annual Meetings, Research Workshops, and Exchange Grants) | Met |
| Support 4-6 research and professional development opportunities specifically for graduate students and postdoctorals (e.g., workshops at Annual Meetings, professional development webinars, and fellowships and networking activities in Research and Education sections above) | Met |

**Target 4:** Community commitment to an environment promoting high ethical standards in the conduct of research is maintained.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Require 100% of participants complete ethics training within these standards | Met |
| Ethics Panel composed of Research, Education, ExCom and Early Career representatives resolves complaints regarding C-DEBI administration, funding and scientific conduct in a timely manner (within 6 months of being presented to C-DEBI) | Met |

**Target 5:** Strategies, tools, and resources are developed for sustainability of C-DEBI activities.

|  |  |
| --- | --- |
| **Metric** | **Status/Problems** |
| Secure $3M in aggregate (beyond initial STC funding) in support of C-DEBI activities | Met |

## 4. Plans for the Next Reporting Period

To further enhance C-DEBI’s culture of collaboration and cross-disciplinary thinking, we will continue to develop cyber-infrastructure for our website enabling public access and data sharing among the C-DEBI research community. The architecture to aid our online communities in collaboration and learning has two principal objectives: 1) to support the connection among scientists and others in the C-DEBI project research community, and 2) to foster the connections between C-DEBI scientists and educators. See also [Data Management and Knowledge Transfer Section IV](#_IV._DATA_MANAGEMENT_5).

# VIII. CENTER-WIDE OUTPUTS AND ISSUES

## 1. Center Publications

In the current reporting period, the C-DEBI community produced 44 publications, including 41 peer-reviewed journal articles ([[Appendix H](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-H-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)). Details in the appendix include graduate and postdoctoral authors, contributing C-DEBI funding, expedition, site, habitat and theme association.

## 2. Conference Presentations

##### Center participants reported 95 oral or poster presentations at venues, including the 2018 Goldschmidt Conference in Boston, Extremophiles 2018 in Italy, and several Gordon Research Conferences ([[Appendix H](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-H-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)).

## 3. Honors, Awards and Grants

##### C-DEBI participants reported receiving 37 (with another 4 pending) honors, awards and grants during the reporting year related to their C-DEBI funding ([[Appendix H](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-H-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)).

## 4. Placement of Graduated Students and Postdoctorals

##### Twenty-three C-DEBI undergraduates, graduate students, postdoctoral scholars, early-career scientists and educators obtained degrees or placement during the current reporting year ([[Appendix H](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-H-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)). C-DEBI funding contributing to the degrees or placement is identified.

## 5. Outputs of Knowledge Transfer Activities

The C-DEBI community developed seven technologies in the current year including laboratory techniques, hardware and software. See also [Education Section III](#_III._EDUCATION_7) and [Data Management & Knowledge Transfer Section IV](#_IV._DATA_MANAGEMENT_6).

## 6. All Participants

Of the 270 individuals reported as being involved with Center activities, 127 are classified as “participants” (per NSF: individuals who have spent over 160 hours on Center activities), while 143 are “affiliates,” reported spending under 160 hours. Affiliates are included where they were reported as personnel on a C-DEBI grant or other budgeted item, attended a C-DEBI event, or have a titular role in the Center. Sources of Center support and known, subseafloor-related, event attendance are included per participant to provide further differentiation of engagement level. See [[Appendix H](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-H-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx) for details.

**7. Institutional Partners**

C-DEBI has identified 108 participating institutions categorized per NSF reporting requirements. Types are determined based on the activities of its participants as follows:

Graduate student: *education, research*

Postdoctoral or researcher: *research*

Outreach or professional development: *education*

Program targets diverse groups: *diversity, education*

Participant worked on new tools, software, methods or products: *knowledge transfer*

Participant plays an advisory or managerial role in the Center: *all types*

Whether the institution has “participated” less or more than 160 hours is likewise determined by its affiliated participants. See [[Appendix H](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-H-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx) for details. See also [External Partnerships Section V](#_V._EXTERNAL_PARTNERSHIPS_9).

## 8. Summary Table for Internal NSF Reporting Purposes

|  |  |
| --- | --- |
| Number of participating institutions (all academic institutions that participate in activities at the Center) | 57 |
| Number of institutional partners (total number of non-academic participants, including industry, states, and other federal agencies, at the Center) | 51 |
| Total leveraged support (funding for the Center from all sources other than NSF-STC) | $276,600 |
| Number of participants excluding affiliates (total number of people who utilize center facilities; not just persons directly supported by NSF) | 127 |

## 9. Media Publicity

##### Thirty media publicity items have been identified, including press releases, news articles, and audio and video programming at a variety of outlets from TED, Discover Magazine, Newsweek, NPR Science Friday, The Scientist, the LA Times, Motherboard, Boston Globe, NSF, Eos, to Caltech, Rice University, and USC ([[Appendix H](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-H-Center-wide-Outputs.xlsx)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-I-Center-wide-Outputs.xlsx)).Additionally, C-DEBI has an active presence on Facebook (799 page likes) and Twitter (1,307 followers), and produces a bi-weekly newsletter (1,029 subscribers).

**10. Distributable Media**

##### Our [current brochure](http://www.darkenergybiosphere.org/wp-content/uploads/C-DEBIbrochure2018.pdf) provides an overview of the deep biosphere, C-DEBI research programs and themes, C-DEBI education and outreach programs, and how to get involved.

# IX. INDIRECT/OTHER IMPACTS

# 1. International Activities and Other Outputs, Impacts, or Influences

C-DEBI regularly and consistently engages the international community in the majority of its activities, with individual and institutional partnerships as described throughout this report. Of particular note are research expeditions, where multi-national participation is common and often mandated, and C-DEBI-led conference sessions and workshops, where scientists from Germany, Japan, China, Great Britain, France, and other countries are commonly invited. All other outputs, impacts, or influences related to the Center’s progress and achievement in 2018 have been captured in other sections of this report.

# X. BUDGET

## 1. Current Award Year and Unobligated Funds

**Macintosh HD:Users:Rosalynn:Dropbox:C-DEBI ADMIN:NSF REPORTING:Year 9_180401-190331:report:budget-R working:current year:2018pie.pdf**

The Center’s current award year budget (4/1/18 – 3/31/19) is $5,000,000 with 34% supporting the research of the lead investigators including the Co-Is (PI, Co-PIs and Senior Scientists; see figure above). Indirect costs at USC consist of 20% of the budget. The remainder of almost half the budget serves the greater C-DEBI community with support for grants and fellowships, education and diversity programs, community meetings and activities, data management, and the general administrative operations based at USC. Our grants program includes support for small seed research grants up to $80,000-100,000 per year. This year we awarded 1 research grant of ~$80,000, 3 research exchange grants, 2 new postdoctoral fellowships of ~$100,000 each and 2 new graduate fellowships of ~$50,000 each (see details in the [Research Section II.2.e](#_e._Projects_from) and [[Appendix B](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-B-Active-Grants-and-Fellowships-2.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-B-Active-Grants-and-Fellowships.pdf)). Our education and diversity programs target all audiences from teachers, K-12, undergraduates/community college students, graduates, postdoctorals, and the general public. Community meetings and activities include the C-DEBI Annual Meeting and C-DEBI Site Review. Administrative support includes salary and fringe benefits for the USC staff, work study students, travel and other operating costs. Education and diversity and data management staff are included in their respective categories.

As requested in last year’s Site Visit report, we present the research budget in alignment with the three C-DEBI research themes below (figure in direct cost dollars). Each of the themes is supported by the research budgets of the lead investigators and grants and fellowships program distributed across themes 1, 2, and 3 at 24%, 42%, and 34%, respectively.

Macintosh HD:Users:Rosalynn:Dropbox:C-DEBI ADMIN:NSF REPORTING:Year 9_180401-190331:report:budget-R working:current year:themebudget.pdf

As of November 30, 2018, we have expensed 62% of the total award of $5,000,000 for the current award year ([[Appendix I](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-I-Current-Award-Year-Budget.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-J-Current-Award-Year-Budget.pdf)). These expenditures of $3,117,446 consist of expenses posted in the USC ledger as of 11/30/18, however do not include liens/obligations (e.g., subcontracts) and known pending expenses (e.g., USC salaries). The bulk of the remaining funds will support operating costs (e.g., the upcoming Site Visit).

The discrepancy between what has been expensed (and reported to NSF by USC Sponsored Projects Accounting) and what is reported in [[Appendix I](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-I-Current-Award-Year-Budget.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-J-Current-Award-Year-Budget.pdf) is the inclusion of our committed expenses. For example, a large portion of our budget is in our small research grants and fellowships which are awarded as 1-2 year subcontracts or satellite accounts, and we report as committed expenses of ~$80K per award. However, the expenses reported by USC's SPA only include the individual invoices paid by USC which are incrementally billed/paid up to the entire award of ~$80K over the 1-2 year award period. What we report above carefully accounts for these types of commitments that may not be completely billed and paid for some period of time. See [[Appendix J](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-J-USC-Account-Status.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2015/12/Appendix-K-Management-Effectiveness-Evaluation.pdf) for a statement of our accounts in the USC Financial Accounting System.

## 2. Requested Award Year

In the final 18 months of C-DEBI beginning with the next award period (4/1/19 – 3/31/20), NSF funding for the STC scales back substantially, and a number of changes at C-DEBI must consequently occur in the phase down (see figure below and [[Appendix K](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-K-Requested-Award-Year-Budget.pdf)](http://www.darkenergybiosphere.org/private/wp-content/uploads/2013/12/Appendix-L-Requested-Award-Year-Budget.pdf)). 2018 represented the last round of the Research Grants and Fellowships programs; we now move towards synthesis activities and continue to support community workshops. We must also eliminate a number of our Education, Outreach, and Diversity programs, but we are developing plans for sustaining some of these with outside support. 2018 also marks the end of CC-RISE at UCSC, Community College Instructor Workshops, Teacher Small Grants, and the USC SeaGrant Summer Marine Science Camp; 2019 will see the final installments of CC-RISE at WHOI, the GEM course, and GGURE. The community college C4 REU has been hugely successful, and we have submitted a renewal proposal to the NSF for 2020. As we approach the end of NSF-funding, we continue to strategize on how to maintain C-DEBI and our community in its next phase.

# Macintosh HD:Users:Rosalynn:Dropbox:C-DEBI ADMIN:NSF REPORTING:Year 9_180401-190331:report:budget-R working:requested year:phasedown.pdf

## 3. Center Support from All Sources

In addition to NSF core funds, the center received $276,600 directly from USC in the form of institutional returns on indirect costs this year, and will receive $276,600 in the requested award year (see table below). In the current award year and the requested award year, the USC Institutional Support funded additional Center activities including GEM Summer Course instructors (an additional 0.5 month of summer salary each), and additional C-DEBI community meetings and activities. Remaining funds are used at the Director’s discretion to support important Center projects and to position C-DEBI closer to renewal success. See details of non-monetary institutional commitment in [Appendix L](http://www.darkenergybiosphere.org/wp-content/uploads/Appendix-L-Institutional-Commitment.pdf).

|  |  |  |
| --- | --- | --- |
| **Center Support** | **Current Award Year** | **Requested Award Year** |
| NSF-STC Core Funds | $5,000,000 | $3,700,000 |
| USC Institutional Support | $276,600 | $276,600 |
| **TOTAL** | **$5,276,600** | **$3,976,600** |

**4. Additional Investigator Support From All Sources**

Additional levels of support not included above have been awarded to Center investigators from federal and state agencies, universities, and private foundations and organizations (see table below).

|  |  |  |
| --- | --- | --- |
| **Additional Support** | **Current Award Year** | **Requested Award Year** |
| NSF | $579,878 | $479,110 |
| Other Federal Agencies  (DOE, NASA, USDA) | $1,120,190 | $596,443 |
| State Government | $304,415 | $153,584 |
| University | $145,552 | $160,553 |
| Private Foundation (DCO/Sloan, Simons, Moore, NOMIS, etc.) | $860,380 + in-kind sequencing | $886,367 |
| **TOTAL** | **$3,010,415 + in-kind** | **$2,256,056** |