

GRANT REQUEST FORM (GRF)

CEC-270 (Revised 10/2015)

CALIFORNIA ENERGY COMMISSION

New Agreement EPC-16-042 (To be completed by CGL Office)

Division	Agreement Manager:	MS-	Phone
ERDD	Mike Kane	43	916-327-1530

Recipient's Legal Name	Federal ID Number
DOE- Lawrence Berkeley National Laboratory	94-2951741

Title of Project
Low-Cost High-Reliability Thermoelectrics for Waste Heat Conversion

Term and Amount	Start Date	End Date	Amount
	5/15/2017	12/31/2019	\$ 2,000,000

Business Meeting Information
 ARFVTP agreements under \$75K delegated to Executive Director.

Proposed Business Meeting Date	4/12/2017	<input type="checkbox"/> Consent	<input checked="" type="checkbox"/> Discussion
Business Meeting Presenter	Prab Sethi	Time Needed:	5 minutes

Please select one list serve. EPIC (Electric Program Investment Charge)

Agenda Item Subject and Description

LAWRENCE BERKELEY NATIONAL LABORATORY. Proposed resolution approving Agreement EPC-16-042 with the Department of Energy's Lawrence Berkeley National Laboratory for a \$2,000,000 grant to develop a cost-effective process for creating advanced thermoelectric materials constructed from silicon nanowire arrays. If successful, the project will create a cost-effective system that will recover waste heat to generate supplemental electricity and help reduce energy use in the industrial sector.

California Environmental Quality Act (CEQA) Compliance

- Is Agreement considered a "Project" under CEQA?
 - Yes (skip to question 2) No (complete the following (PRC 21065 and 14 CCR 15378)):

Explain why Agreement is not considered a "Project":
Agreement will not cause direct physical change in the environment or a reasonably foreseeable indirect physical change in the environment because
- If Agreement is considered a "Project" under CEQA:
 - a) Agreement **IS** exempt. (Attach draft NOE)
 - Statutory Exemption. List PRC and/or CCR section number: _____
 - Categorical Exemption. List CCR section number: Cal. Code Regs., tit 14, § 15301
 - Common Sense Exemption. 14 CCR 15061 (b) (3)

Explain reason why Agreement is exempt under the above section:
This project qualifies for Class 1 exemption for existing facilities. LBNL will direct Alphabet Energy to prepare small samples of prototype silicon-based thermoelectric materials at its existing 8,000 square foot manufacturing facility in Hayward, CA. Alphabet will be adding several small pieces of equipment consistent with its business as a thermoelectric manufacturer. These added items range from a bench top microscope for profiling nanowires to a doping furnace having a footprint of approximately 36 square feet. Except for a doping furnace, all the equipment being added by Alphabet is purchased via match funds and is typical for a cutting-edge manufacturing and research facility. LBNL will receive the prototype samples at its Berkeley laboratory where their properties and thermoelectric effectiveness will be evaluated at bench-scale. Small equipment additions to the Berkeley labs will include a high temperature cryostat for precise temperature control which would typically occupy approximately 2-3 cubic feet. Other purpose built tools and fixtures will be made as needed for testing sample thermoelectric materials. These tools and fixtures will be scaled for bench top use and will generally have a footprint less than 2 square feet. Based on test results, LBNL will prepare computer models and write reports, which will be submitted to the California Energy Commission upon completion.
 - b) Agreement **IS NOT** exempt. (Consult with the legal office to determine next steps.)

Check all that apply

<input type="checkbox"/> Initial Study	<input type="checkbox"/> Environmental Impact Report
<input type="checkbox"/> Negative Declaration	<input type="checkbox"/> Statement of Overriding Considerations
<input type="checkbox"/> Mitigated Negative Declaration	

GRANT REQUEST FORM (GRF)



List all subcontractors (major and minor) and equipment vendors: (attach additional sheets as necessary)	
Legal Company Name:	Budget
Alphabet Energy, Inc.	\$ 1,333,333
	\$
	\$
	\$
	\$
	\$
	\$
	\$
	\$

List all key partners: (attach additional sheets as necessary)
Legal Company Name:

Budget Information			
Funding Source	Funding Year of Appropriation	Budget List No.	Amount
EPIC	15-16	301.001C	\$2,000,000
			\$
			\$
			\$
			\$
			\$
R&D Program Area:	EGRO: Renewables	TOTAL:	\$2,000,000
Explanation for "Other" selection			
Reimbursement Contract #:		Federal Agreement #:	

Recipient's Administrator/ Officer				Recipient's Project Manager			
Name:	Betsy Quayle			Name:	Ravi Prasher		
Address:	1 Cyclotron Rd MS 56A-0120			Address:	1 Cyclotron Rd. MS 56A-0120		
City, State, Zip:	Berkeley, CA 94720			City, State, Zip:	Berkeley, CA 94720		
Phone:	510-486-7391	Fax:		Phone:	510-486-7291	Fax:	510-486-4260
E-Mail:	BEQuayle@lbl.gov			E-Mail:	rsprasher@lbl.gov		

Selection Process Used	
<input checked="" type="checkbox"/> Competitive Solicitation	Solicitation #: GFO-16-302
<input type="checkbox"/> First Come First Served Solicitation	

The following items should be attached to this GRF			
1. Exhibit A, Scope of Work		<input checked="" type="checkbox"/>	Attached
2. Exhibit B, Budget Detail		<input checked="" type="checkbox"/>	Attached
3. CEC 105, Questionnaire for Identifying Conflicts		<input checked="" type="checkbox"/>	Attached
4. Recipient Resolution		<input checked="" type="checkbox"/> N/A	<input type="checkbox"/> Attached
5. CEQA Documentation		<input type="checkbox"/> N/A	<input checked="" type="checkbox"/> Attached

Agreement Manager _____ Date _____ Office Manager _____ Date _____ Deputy Director _____ Date _____

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

I. TASK ACRONYM/TERM LISTS

A. Task List

Task #	CPR ¹	Task Name
1		General Project Tasks
2		Procure, Commission, and Validate Experimental Equipment
3	X	Micro Fabrication of Single Wire Measurement Platform
4		Silicon Nanowire Template, Etch, and Doping Optimization
5	X	Individual Silicon Nanowire Thermoelectric Property Characterization
6		Free-standing Silicon Nanowire Array Development
7		Silicon Nanowire Array Property Characterization
8		Silicon Nanowire Based Device Optimization and Fabrication
9		Techno-economic Model
10		Evaluation of Project Benefits
11		Technology/Knowledge Transfer Activities

B. Acronym/Term List

Acronym/Term	Meaning
CAM	Commission Agreement Manager
CAO	Commission Agreement Officer
CPR	Critical Project Review
Recipient	Lawrence Berkeley National Laboratory, or "LBNL"
Si	Silicon
Si-nw	Silicon Nanowire
TAC	Technical Advisory Committee
TE	Thermoelectric
TE-WHR	Thermoelectric Waste Heat Recovery

II. PURPOSE OF AGREEMENT, PROBLEM/SOLUTION STATEMENT, AND GOALS AND OBJECTIVES

A. Purpose of Agreement

The purpose of this Agreement is to fund the development of a high-performance, silicon nanowire array-based, thermoelectric (TE), p-type material and device.

¹ Please see subtask 1.3 in Part III of the Scope of Work (General Project Tasks) for a description of Critical Project Review (CPR) Meetings.

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

B. Problem/ Solution Statement

Problem

There is a significant environmental benefit and market for TE devices to convert mid- to high-grade waste heat into electrical power. Unfortunately, the problem with current commercially-available TE materials is that they can only operate reliably up to 250°C in temperature. Although there are a few materials that have been evaluated for higher temperature; some of them use lead or they suffer from oxidation and sublimation problems, leading to reliability issues. While an n-type material, magnesium silicide stannide, performs fairly well in the mid-grade waste recovery temperature range, there is a significant void for p-type materials. Silicon nanowires represent a new, highly scalable technology that overcomes the limitations of previous efforts.

Solution

Silicon (Si) is abundantly available and does not suffer from oxidation and sublimation problems. It is very stable at high temperature and has well-characterized material properties due to its use in the solar PV and microelectronics industries. Although TE devices made from Si hold much promise, bulk Si has low figure-of-merit. One established strategy for increasing figure-of-merit is to employ nanostructuring to decrease thermal conductivity. Previous research by the Recipient indicates that thermal conductivity of rough silicon nanowires can be much lower than the bulk thermal conductivity, which can lead to much higher figure-of-merit. This increased figure-of-merit leads to a waste heat-to-electricity conversion efficiency higher than 10%.

C. Goals and Objectives of the Agreement

Agreement Goals

The goals of this Agreement are to:

- Develop a cost-effective mid- to high-temperature range (400°C-800°C) p-type TE material and waste heat recovery technology;
- Reduce electricity-related carbon emissions;
- Improve remote power generation technology; and
- Advance nanowire-based nanotechnology

Ratepayer Benefits:² This project will create a cost-effective Thermoelectric Waste Heat Recovery (TE-WHR) system that will reduce energy use in the industrial sector, thus benefiting California ratepayers by increasing electrical reliability and lowering electricity costs. The total potential net saving in electricity use per year is about 0.022 quads in California. Assuming a TE-WHR system operates 90% of the year with 10% downtime attributed to industry closures for maintenance, and an average cost of \$0.17/kilowatt-hours for electricity generated renewably, the TE-WHR system could save IOU ratepayers a maximum of about \$1.16 billion/year. The estimated cost for a TE-WHR system is \$1.5/watt (W). The total waste heat potential in California is 763 megawatts (MW) [1].

² California Public Resources Code, Section 25711.5(a) requires projects funded by the Electric Program Investment Charge (EPIC) to result in ratepayer benefits. The California Public Utilities Commission, which established the EPIC in 2011, defines ratepayer benefits as greater reliability, lower costs, and increased safety (See CPUC "Phase 2" Decision 12-05-037 at page 19, May 24, 2012, http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/167664.PDF).

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

Technological Advancement and Breakthroughs:³ This project will lead to technological advancement and breakthroughs that will enable the State of California to overcome barriers to achieving its statutory energy goals. It will do so by providing a low-cost, reliable, affordable and mass-producible technology that can be ubiquitously applied to convert high-temperature heat that is currently wasted at the production and retail levels in California. Today's principal barriers to the widespread application of current TE materials are their expense, accessibility to the supply of their constituent rare-earth elements, ability to scale to mass production, and their limit of 5%, or less, heat to electrical energy conversion efficiency. The development of Si-nw based TE module devices has the potential to enable low-cost devices (produced with very mature and well-characterized silicon manufacturing processes) with energy conversion efficiencies greater than 10% to be produced using abundant low-grade silicon. Standard-sized Si-nw modules could be applied to a wide range of heat sources greater than 400°C to increase the energy efficiency of combustion and thermal generating process at the industrial and retail levels.

Alphabet Energy is the first company to create a 25 kilowatt (kW) electricity generator using TE for waste heat harvesting from a diesel generator set using traditional materials. This technology is already being applied for automotive and oil and gas industries. The system-level knowledge gained from the 25 kW generator will be directly applicable in high-temperature waste heat harvesting. In fact, this demonstration was cited in a waste heat report by Oak Ridge National Laboratory⁴ as a major breakthrough. The advent of high-temperature energy conversion using Si-nw based TE technology would significantly increase the penetration into these markets, as well as the cost-effective application to the retail high-temperature waste heat market.

Agreement Objectives

The objectives of this Agreement are to:

- Demonstrate an etch process on at least four silicon wafers that produces nanowire arrays with diameters less than 400 nm and length greater than 400 μm .
- Demonstrate at least one boron doped silicon nanowire array with doping level greater than $1\text{e}19$ atoms/ cm^3 .
- Demonstrate at least one free standing, filled array of silicon nanowires with areal density greater than 30%.
- Demonstrate at least one metallized silicon nanowire array sample with electrical continuity through the array.
- Demonstrate at least one silicon nanowire device prototype and laboratory measurements of resistivity, Seebeck, and power from room temperature to 600°C.

³ California Public Resources Code, Section 25711.5(a) also requires EPIC-funded projects to lead to technological advancement and breakthroughs to overcome barriers that prevent the achievement of the state's statutory and energy goals.

⁴Oakridge National Laboratory. Waste Heat to Power Market Assessment.
<http://info.ornl.gov/sites/publications/files/Pub52953.pdf> (2015)

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

III. TASK 1 GENERAL PROJECT TASKS

PRODUCTS

Subtask 1.1 Products

The goal of this subtask is to establish the requirements for submitting project products (e.g., reports, summaries, plans, and presentation materials). Unless otherwise specified by the Commission Agreement Manager (CAM), the Recipient must deliver products as required below by the dates listed in the **Project Schedule (Part V)**. Products that require a draft version are indicated by marking “**(draft and final)**” after the product name in the “Products” section of the task/subtask. If “(draft and final)” does not appear after the product name, only a final version of the product is required. With respect to due dates within this Scope of Work, “**days**” means working days.

The Recipient shall:

For products that require a draft version, including the Final Report Outline and Final Report

- Submit all draft products to the CAM for review and comment in accordance with the Project Schedule (Part V). The CAM will provide written comments to the Recipient on the draft product within 15 days of receipt, unless otherwise specified in the task/subtask for which the product is required.
- Consider incorporating all CAM comments into the final product. If the Recipient disagrees with any comment, provide a written response explaining why the comment was not incorporated into the final product.
- Submit the revised product and responses to comments within 10 days of notice by the CAM, unless the CAM specifies a longer time period, or approves a request for additional time.

For products that require a final version only

- Submit the product to the CAM for acceptance. The CAM may request minor revisions or explanations prior to acceptance.

For all products

- Submit all data and documents required as products in accordance with the following:

Instructions for Submitting Electronic Files and Developing Software:

○ **Electronic File Format**

- Submit all data and documents required as products under this Agreement in an electronic file format that is fully editable and compatible with the Energy Commission’s software and Microsoft (MS)-operating computing platforms, or with any other format approved by the CAM. Deliver an electronic copy of the full text of any Agreement data and documents in a format specified by the CAM, such as memory stick or CD-ROM.

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

The following describes the accepted formats for electronic data and documents provided to the Energy Commission as products under this Agreement, and establishes the software versions that will be required to review and approve all software products:

- Data sets will be in MS Access or MS Excel file format (version 2007 or later), or any other format approved by the CAM.
 - Text documents will be in MS Word file format, version 2007 or later.
 - Documents intended for public distribution will be in PDF file format.
 - The Recipient must also provide the native Microsoft file format.
 - Project management documents will be in Microsoft Project file format, version 2007 or later.
- **Software Application Development**
- Use the following standard Application Architecture components in compatible versions for any software application development required by this Agreement (e.g., databases, models, modeling tools), unless the CAM approves other software applications such as open source programs:
- Microsoft ASP.NET framework (version 3.5 and up). Recommend 4.0.
 - Microsoft Internet Information Services (IIS), (version 6 and up) Recommend 7.5.
 - Visual Studio.NET (version 2008 and up). Recommend 2010.
 - C# Programming Language with Presentation (UI), Business Object and Data Layers.
 - SQL (Structured Query Language).
 - Microsoft SQL Server 2008, Stored Procedures. Recommend 2008 R2.
 - Microsoft SQL Reporting Services. Recommend 2008 R2.
 - XML (external interfaces).

Any exceptions to the Electronic File Format requirements above must be approved in writing by the CAM. The CAM will consult with the Energy Commission's Information Technology Services Branch to determine whether the exceptions are allowable.

MEETINGS

Subtask 1.2 Kick-off Meeting

The goal of this subtask is to establish the lines of communication and procedures for implementing this Agreement.

The Recipient shall:

- Attend a "Kick-off" meeting with the CAM, the Commission Agreement Officer (CAO), and any other Energy Commission staff relevant to the Agreement. The Recipient will bring its Project Manager and any other individuals designated by the CAM to this meeting. The administrative and technical aspects of the Agreement will be discussed at the meeting. Prior to the meeting, the CAM will provide an agenda to all potential meeting participants. The meeting may take place in person or by electronic conferencing (e.g., WebEx), with approval of the CAM.

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

The administrative portion of the meeting will include discussion of the following:

- Terms and conditions of the Agreement;
- Administrative products (subtask 1.1);
- CPR meetings (subtask 1.3);
- Match fund documentation (subtask 1.7);
- Permit documentation (subtask 1.8);
- Subcontracts (subtask 1.9); and
- Any other relevant topics.

The technical portion of the meeting will include discussion of the following:

- The CAM's expectations for accomplishing tasks described in the Scope of Work;
 - An updated Project Schedule;
 - Technical products (subtask 1.1);
 - Progress reports and invoices (subtask 1.5);
 - Final Report (subtask 1.6);
 - Technical Advisory Committee meetings (subtasks 1.10 and 1.11); and
 - Any other relevant topics.
- Provide an *Updated Project Schedule*, *List of Match Funds*, and *List of Permits*, as needed to reflect any changes in the documents.

The CAM shall:

- Designate the date and location of the meeting.
- Send the Recipient a *Kick-off Meeting Agenda*.

Recipient Products:

- Updated Project Schedule (*if applicable*)
- Updated List of Match Funds (*if applicable*)
- Updated List of Permits (*if applicable*)

CAM Product:

- Kick-off Meeting Agenda

Subtask 1.3 Critical Project Review (CPR) Meetings

The goal of this subtask is to determine if the project should continue to receive Energy Commission funding, and if so whether any modifications must be made to the tasks, products, schedule, or budget. CPR meetings provide the opportunity for frank discussions between the Energy Commission and the Recipient. As determined by the CAM, discussions may include project status, challenges, successes, advisory group findings and recommendations, final report preparation, and progress on technical transfer and production readiness activities (if applicable). Participants will include the CAM and the Recipient, and may include the CAO and any other individuals selected by the CAM to provide support to the Energy Commission.

CPR meetings generally take place at key, predetermined points in the Agreement, as determined by the CAM and as shown in the Task List on page 1 of this Exhibit. However, the CAM may schedule additional CPR meetings as necessary. The budget will be reallocated to cover the additional costs borne by the Recipient, but the overall Agreement amount will not increase. CPR meetings generally take place at the Energy Commission, but they may take

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

place at another location, or may be conducted via electronic conferencing (e.g., WebEx) as determined by the CAM.

The Recipient shall:

- Prepare a *CPR Report* for each CPR meeting that: (1) discusses the progress of the Agreement toward achieving its goals and objectives; and (2) includes recommendations and conclusions regarding continued work on the project.
- Submit the CPR Report along with any other *Task Products* that correspond to the technical task for which the CPR meeting is required (i.e., if a CPR meeting is required for Task 2, submit the Task 2 products along with the CPR Report).
- Attend the CPR meeting.
- Present the CPR Report and any other required information at each CPR meeting.

The CAM shall:

- Determine the location, date, and time of each CPR meeting with the Recipient's input.
- Send the Recipient a *CPR Agenda* and a *List of Expected CPR Participants* in advance of the CPR meeting. If applicable, the agenda will include a discussion of match funding and permits.
- Conduct and make a record of each CPR meeting. Provide the Recipient with a *Schedule for Providing a Progress Determination* on continuation of the project.
- Determine whether to continue the project, and if so whether modifications are needed to the tasks, schedule, products, or budget for the remainder of the Agreement. If the CAM concludes that satisfactory progress is not being made, this conclusion will be referred to the Deputy Director of the Energy Research and Development Division.
- Provide the Recipient with a *Progress Determination* on continuation of the project, in accordance with the schedule. The Progress Determination may include a requirement that the Recipient revise one or more products.

Recipient Products:

- CPR Report(s)
- Task Products (draft and/or final as specified in the task)

CAM Products:

- CPR Agenda
- List of Expected CPR Participants
- Schedule for Providing a Progress Determination
- Progress Determination

Subtask 1.4 Final Meeting

The goal of this subtask is to complete the closeout of this Agreement.

The Recipient shall:

- Meet with Energy Commission staff to present project findings, conclusions, and recommendations. The final meeting must be completed during the closeout of this Agreement. This meeting will be attended by the Recipient and CAM, at a minimum. The meeting may occur in person or by electronic conferencing (e.g., WebEx), with approval of the CAM.

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

The technical and administrative aspects of Agreement closeout will be discussed at the meeting, which may be divided into two separate meetings at the CAM's discretion.

- The technical portion of the meeting will involve the presentation of findings, conclusions, and recommended next steps (if any) for the Agreement. The CAM will determine the appropriate meeting participants.
- The administrative portion of the meeting will involve a discussion with the CAM and the CAO of the following Agreement closeout items:
 - Disposition of any state-owned equipment.
 - Need to file a Uniform Commercial Code Financing Statement (Form UCC-1) regarding the Energy Commission's interest in patented technology.
 - The Energy Commission's request for specific "generated" data (not already provided in Agreement products).
 - Need to document the Recipient's disclosure of "subject inventions" developed under the Agreement.
 - "Surviving" Agreement provisions such as repayment provisions and confidential products.
 - Final invoicing and release of retention.
- Prepare a *Final Meeting Agreement Summary* that documents any agreement made between the Recipient and Commission staff during the meeting.
- Prepare a *Schedule for Completing Agreement Closeout Activities*.
- Provide *All Draft and Final Written Products* on a CD-ROM or USB memory stick, organized by the tasks in the Agreement.

Products:

- Final Meeting Agreement Summary (*if applicable*)
- Schedule for Completing Agreement Closeout Activities
- All Draft and Final Written Products

REPORTS AND INVOICES

Subtask 1.5 Progress Reports and Invoices

The goals of this subtask are to: (1) periodically verify that satisfactory and continued progress is made towards achieving the project objectives of this Agreement; and (2) ensure that invoices contain all required information and are submitted in the appropriate format.

The Recipient shall:

- Submit a monthly *Progress Report* to the CAM. Each progress report must:
 - Summarize progress made on all Agreement activities as specified in the scope of work for the preceding month, including accomplishments, problems, milestones, products, schedule, fiscal status, and an assessment of the ability to complete the Agreement within the current budget and any anticipated cost overruns. See the Progress Report Format Attachment for the recommended specifications.
- Submit a monthly or quarterly *Invoice* that follows the instructions in the "Payment of Funds" section of the terms and conditions, including a financial report on Match Fund and in-state expenditures.

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

Products:

- Progress Reports
- Invoices

Subtask 1.6 Final Report

The goal of this subtask is to prepare a comprehensive Final Report that describes the original purpose, approach, results, and conclusions of the work performed under this Agreement. The CAM will review the Final Report, which will be due at least **two months** before the Agreement end date. When creating the Final Report Outline and the Final Report, the Recipient must use the Style Manual provided by the CAM.

Subtask 1.6.1 Final Report Outline

The Recipient shall:

- Prepare a *Final Report Outline* in accordance with the *Style Manual* provided by the CAM. (See Task 1.1 for requirements for draft and final products.)
- Submit a draft of the outline to the CAM for review and comment.
- Once agreement has been reached on the draft, submit the final outline to the CAM. The CAM will provide written approval of the final outline within 10 days of receipt.

Recipient Products:

- Final Report Outline (draft and final)

CAM Product:

- Style Manual
- Comments on Draft Final Report Outline
- Acceptance of Final Report Outline

Subtask 1.6.2 Final Report

The Recipient shall:

- Prepare a *Final Report* for this Agreement in accordance with the approved Final Report Outline, Style Manual, and Final Report Template provided by the CAM with the following considerations:
 - Ensure that the report includes the following items, in the following order:
 - Cover page (**required**)
 - Credits page on the reverse side of cover with legal disclaimer (**required**)
 - Acknowledgements page (optional)
 - Preface (**required**)
 - Abstract, keywords, and citation page (**required**)
 - Table of Contents (**required**, followed by List of Figures and List of Tables, if needed)
 - Executive summary (**required**)
 - Body of the report (**required**)
 - References (if applicable)

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

- Glossary/Acronyms (If more than 10 acronyms or abbreviations are used, it is required.)
- Bibliography (if applicable)
- Appendices (if applicable) (Create a separate volume if very large.)
- Attachments (if applicable)
- Ensure that the document is written in the third person.
- Ensure that the Executive Summary is understandable to the lay public.
 - Briefly summarize the completed work. Succinctly describe the project results and whether or not the project goals were accomplished.
 - Identify which specific ratepayers can benefit from the project results and how they can achieve the benefits.
 - If it's necessary to use a technical term in the Executive Summary, provide a brief definition or explanation when the technical term is first used.
- Follow the Style Guide format requirements for headings, figures/tables, citations, and acronyms/abbreviations.
- Ensure that the document omits subjective comments and opinions. However, recommendations in the conclusion of the report are allowed.
- Include a brief description of the project results in the Abstract.
- Submit a draft of the report to the CAM for review and comment. The CAM will provide written comments to the Recipient on the draft product within 15 days of receipt
- Consider incorporating all CAM comments into the Final Report. If the Recipient disagrees with any comment, provide a written response explaining why the comment was not incorporated into the final product
- Submit the revised Final Report and responses to comments within 10 days of notice by the CAM, unless the CAM specifies a longer time period or approves a request for additional time.
- Submit one bound copy of the *Final Report* to the CAM along with *Written Responses to Comments on the Draft Final Report*.

Products:

- Final Report (draft and final)
- Written Responses to Comments on the Draft Final Report

CAM Product:

- Written Comments on the Draft Final Report

MATCH FUNDS, PERMITS, AND SUBCONTRACTS

Subtask 1.7 Match Funds

The goal of this subtask is to ensure that the Recipient obtains any match funds planned for this Agreement and applies them to the Agreement during the Agreement term.

While the costs to obtain and document match funds are not reimbursable under this

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

Agreement, the Recipient may spend match funds for this task. The Recipient may only spend match funds during the Agreement term, either concurrently or prior to the use of Energy Commission funds. Match funds must be identified in writing, and the Recipient must obtain any associated commitments before incurring any costs for which the Recipient will request reimbursement.

The Recipient shall:

- Prepare a *Match Funds Status Letter* that documents the match funds committed to this Agreement. If no match funds were part of the proposal that led to the Energy Commission awarding this Agreement and none have been identified at the time this Agreement starts, then state this in the letter.

If match funds were a part of the proposal that led to the Energy Commission awarding this Agreement, then provide in the letter:

- A list of the match funds that identifies:
 - The amount of cash match funds, their source(s) (including a contact name, address, and telephone number), and the task(s) to which the match funds will be applied.
 - The amount of each in-kind contribution, a description of the contribution type (e.g., property, services), the documented market or book value, the source (including a contact name, address, and telephone number), and the task(s) to which the match funds will be applied. If the in-kind contribution is equipment or other tangible or real property, the Recipient must identify its owner and provide a contact name, address, telephone number, and the address where the property is located.
 - A copy of a letter of commitment from an authorized representative of each source of match funding that the funds or contributions have been secured.
- At the Kick-off meeting, discuss match funds and the impact on the project if they are significantly reduced or not obtained as committed. If applicable, match funds will be included as a line item in the progress reports and will be a topic at CPR meetings.
- Provide a *Supplemental Match Funds Notification Letter* to the CAM of receipt of additional match funds.
- Provide a *Match Funds Reduction Notification Letter* to the CAM if existing match funds are reduced during the course of the Agreement. Reduction of match funds may trigger a CPR meeting.

Products:

- Match Funds Status Letter
- Supplemental Match Funds Notification Letter *(if applicable)*
- Match Funds Reduction Notification Letter *(if applicable)*

Subtask 1.8 Permits

The goal of this subtask is to obtain all permits required for work completed under this Agreement in advance of the date they are needed to keep the Agreement schedule on track. Permit costs and the expenses associated with obtaining permits are not reimbursable under this Agreement, with the exception of costs incurred by University of California recipients. Permits must be identified and obtained before the Recipient may incur any costs related to the use of the permit(s) for which the Recipient will request reimbursement.

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

The Recipient shall:

- Prepare a *Permit Status Letter* that documents the permits required to conduct this Agreement. If no permits are required at the start of this Agreement, then state this in the letter. If permits will be required during the course of the Agreement, provide in the letter:
 - A list of the permits that identifies: (1) the type of permit; and (2) the name, address, and telephone number of the permitting jurisdictions or lead agencies.
 - The schedule the Recipient will follow in applying for and obtaining the permits.

The list of permits and the schedule for obtaining them will be discussed at the Kick-off meeting (subtask 1.2), and a timetable for submitting the updated list, schedule, and copies of the permits will be developed. The impact on the project if the permits are not obtained in a timely fashion or are denied will also be discussed. If applicable, permits will be included as a line item in progress reports and will be a topic at CPR meetings.

- If during the course of the Agreement additional permits become necessary, then provide the CAM with an *Updated List of Permits* (including the appropriate information on each permit) and an *Updated Schedule for Acquiring Permits*.
- Send the CAM a *Copy of Each Approved Permit*.
- If during the course of the Agreement permits are not obtained on time or are denied, notify the CAM within 5 days. Either of these events may trigger a CPR meeting.

Products:

- Permit Status Letter
- Updated List of Permits (*if applicable*)
- Updated Schedule for Acquiring Permits (*if applicable*)
- Copy of Each Approved Permit (*if applicable*)

Subtask 1.9 Subcontracts

The goals of this subtask are to: (1) procure subcontracts required to carry out the tasks under this Agreement; and (2) ensure that the subcontracts are consistent with the terms and conditions of this Agreement.

The Recipient shall:

- Manage and coordinate subcontractor activities in accordance with the requirements of this Agreement.
- Incorporate this Agreement by reference into each subcontract.
- Include any required Energy Commission flow-down provisions in each subcontract, in addition to a statement that the terms of this Agreement will prevail if they conflict with the subcontract terms.
- If required by the CAM, submit a draft of each *Subcontract* required to conduct the work under this Agreement.
- Submit a final copy of the executed subcontract.
- Notify and receive written approval from the CAM prior to adding any new subcontractors (see the discussion of subcontractor additions in the terms and conditions).

Products:

- Subcontracts (*draft if required by the CAM*)

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

TECHNICAL ADVISORY COMMITTEE

Subtask 1.10 Technical Advisory Committee (TAC)

The goal of this subtask is to create an advisory committee for this Agreement. The TAC should be composed of diverse professionals. The composition will vary depending on interest, availability, and need. TAC members will serve at the CAM's discretion. The purpose of the TAC is to:

- Provide guidance in project direction. The guidance may include scope and methodologies, timing, and coordination with other projects. The guidance may be based on:
 - Technical area expertise;
 - Knowledge of market applications; or
 - Linkages between the agreement work and other past, present, or future projects (both public and private sectors) that TAC members are aware of in a particular area.
- Review products and provide recommendations for needed product adjustments, refinements, or enhancements.
- Evaluate the tangible benefits of the project to the state of California, and provide recommendations as needed to enhance the benefits.
- Provide recommendations regarding information dissemination, market pathways, or commercialization strategies relevant to the project products.

The TAC may be composed of qualified professionals spanning the following types of disciplines:

- Researchers knowledgeable about the project subject matter;
- Members of trades that will apply the results of the project (e.g., designers, engineers, architects, contractors, and trade representatives);
- Public interest market transformation implementers;
- Product developers relevant to the project;
- U.S. Department of Energy research managers, or experts from other federal or state agencies relevant to the project;
- Public interest environmental groups;
- Utility representatives;
- Air district staff; and
- Members of relevant technical society committees.

The Recipient shall:

- Prepare a *List of Potential TAC Members* that includes the names, companies, physical and electronic addresses, and phone numbers of potential members. The list will be discussed at the Kick-off meeting, and a schedule for recruiting members and holding the first TAC meeting will be developed.
- Recruit TAC members. Ensure that each individual understands member obligations and the TAC meeting schedule developed in subtask 1.11.
- Prepare a *List of TAC Members* once all TAC members have committed to serving on the TAC.
- Submit *Documentation of TAC Member Commitment* (such as Letters of Acceptance) from each TAC member.

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

Products:

- List of Potential TAC Members
- List of TAC Members
- Documentation of TAC Member Commitment

Subtask 1.11 TAC Meetings

The goal of this subtask is for the TAC to provide strategic guidance for the project by participating in regular meetings, which may be held via teleconference.

The Recipient shall:

- Discuss the TAC meeting schedule with the CAM at the Kick-off meeting. Determine the number and location of meetings (in-person and via teleconference) in consultation with the CAM.
- Prepare a *TAC Meeting Schedule* that will be presented to the TAC members during recruiting. Revise the schedule after the first TAC meeting to incorporate meeting comments.
- Prepare a *TAC Meeting Agenda* and *TAC Meeting Back-up Materials* for each TAC meeting.
- Organize and lead TAC meetings in accordance with the TAC Meeting Schedule. Changes to the schedule must be pre-approved in writing by the CAM.
- Prepare *TAC Meeting Summaries* that include any recommended resolutions of major TAC issues.

Products:

- TAC Meeting Schedule (draft and final)
- TAC Meeting Agendas (draft and final)
- TAC Meeting Back-up Materials
- TAC Meeting Summaries

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

IV. TECHNICAL TASKS

*Products that require a draft version are indicated by marking “(draft and final)” after the product name in the “Products” section of the task/subtask. If “(draft and final)” does not appear after the product name, only a final version of the product is required. **Subtask 1.1 (Products)** describes the procedure for submitting products to the CAM.*

TASK 2 Procure, Commission, and Validate Experimental Equipment

The goal of this task is to procure key equipment such as high temperature cryostat and nanomanipulator, and integrate equipment with the data acquisition system and validate its high-temperature characteristics.

The Recipient shall:

- Purchase, install, and calibrate experimental equipment for characterizing properties for single Si-nw and Si-nw arrays. Equipment purchased will be integrated with the existing data acquisition system in the Recipient’s thermal energy science and technology lab.
- Perform a literature search of methods and data used for measuring TE properties of nanowires.
- Assemble and document information, highlighting properties to be used for validating system.
- Validate the experimental setup and system.
- Prepare *Letter of Completion for Experimental Equipment Validation* that confirms the completion of experimental equipment validation and contains brief description of the methods and data selected for validating the experimental setup and the results of that validation.

Products:

- Letter of Completion for Experimental Equipment Validation

TASK 3 Micro Fabrication of Single Wire Measurement Platform

The goal of this task is to fabricate the measurement platforms (heater and sensor) for the measurement of TE properties of single Si-nw. Thermal conductivity, electrical conductivity and Seebeck coefficient Si-nw will be measured using this platform. Heater and sensor platforms will be calibrated.

The Recipient shall:

- Fabricate single wire measurement platform using microfabrication techniques.
- Obtain calibration curves for the measurement platform.
- Prepare *Letter of Completion for Measurement Platform Fabrication and Calibration* that confirms the completion of the measurement platform and contains a brief description of the calibration procedures and results.
- Prepare a *CPR Report* per Task 1.3.
- Participate in CPR.

Products:

- Letter of Completion for Measurement Platform Fabrication and Calibration
- CPR Report

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

TASK 4 Silicon Nanowire Template, Etch, and Doping Optimization

The goals of this task are to (1) fabricate a variety of p-type Si-nws with a range of morphologies and doping concentrations to be characterized for relevant TE properties; and (2) understand the acceptable process parameter limits used to form the Si-nw arrays.

The Recipient shall:

- Investigate a range of process parameters used to form the Si-nw catalyst template.
- Investigate a range of process parameters used to etch the Si-nw array.
- Investigate a range of starting wafer p-type dopant concentrations used to etch the Si-nws.
- Investigate doping techniques and conditions to optimize doping concentration without damaging the Si-nws.
- Summarize findings in a *Si-nw Templating, Etch, and Doping Brief Report*.

Products:

- Si-nw Templating, Etch, and Doping Brief Report

TASK 5 Individual Silicon Nanowire Thermoelectric Property Characterization

The goals of this task are to (1) correlate the TE properties to the templating, etch, starting wafer, and doping parameters; (2) demonstrate the TE potential of Si-nws; and (3) select the optimum Si-nw recipe for a TE application.

The Recipient shall:

- Characterize the TE properties of individual Si-nws and correlate the results to the templating, etch, and doping parameters.
- Identify recommended process procedures for the Si-nws that produces the best TE properties.
- Summarize findings in an *Individual Si-nw Thermoelectric Property Brief Report*.
- Prepare a *CPR Report* per Task 1.3
- Participate in CPR

Products:

- Individual Si-nw Thermoelectric Property Brief Report
- CPR Report

TASK 6 Free-standing Silicon Nanowire Array Development

The goal of this task is to form a free-standing Si-nw array with ohmic contacts on both array surfaces.

The Recipient shall:

- Investigate a range of suitable materials capable of filling the Si-nw array.
- Investigate a method to remove the Si-nw array from the starting wafer handle.
- Investigate a technique to uniformly expose the Si-nw tips for metallic contact.
- Investigate a front side metallization layer capable of forming an ohmic contact to the front of the Si-nws.
- Demonstrate non-optimized electrical conductance through the metallized array.
- Summarize findings in a *Free-standing Si-nw Fill and Metallization Brief Report*.

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

Products:

- Free-standing Si-nw Fill and Metallization Brief Report

TASK 7 Silicon Nanowire Array Property Characterization

The goal of this task is to understand and characterize the TE, interfacial, and mechanical properties of a Si-nw array compared to individual Si-nws.

The Recipient shall:

- Develop, fabricate, and utilize a testbed for Si-nw array TE measurements.
- Characterize the difference between the TE properties of individual Si-nws and arrays of Si-nws.
- Investigate the interfacial properties between the Si-nw array and metallization layers.
- Investigate the mechanical properties of the freestanding TE array.
- Identify areas of concerns and improvements.
- Identify conditions that will damage the array.
- Summarize findings in a *Si-nw Array Property and Characterization Brief Report*

Products:

- Si-nw Array Property and Characterization Brief Report

TASK 8 Silicon Nanowire Array-Based Device Optimization and Fabrication

The goals of this task are to (1) optimize the Si-nw leg fabrication and metallization; (2) develop packaging materials for the Si-nw array based legs; and (3) demonstrate device soaking and cycling performance.

The Recipient shall:

- Improve the metallization to obtain promising time-zero resistance and soaking resistance.
- Optimize the Si-nw procedure for p-type Si-nw legs to match device geometric and performance requirements.
- Determine the required leg geometry and properties to be paired with Magnesium Silicide Stannide and achieve the desired TE device performance in the 300-800 centigrade range.
- Investigate baseplates and bonding materials to develop a p-type Si-nw array and n-type magnesium silicide stannide base TE device.
- Fabricate a prototype Si-nw Array-based TE device.
- Perform soaking and cycling experiments to measure the device performance.
- Prepare a *Si-nw Array Based Device Performance Report* that includes but is not limited to the following:
 - Modifications to the etch, fill, and metallization procedures to achieve geometric and performance requirements of the Si-nw legs.
 - Procedures and material used to package the Si-nw legs into a device; and
 - Preliminary test data that demonstrates the device soaking and cycling performance.

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

Products:

- Si-nw Array Based Device Performance Report

TASK 9 Techno-economic Model

The goal of this task is to perform a product market-fit analysis of the Si-nw TE technology.

The Recipient shall:

- Develop a techno-economic analysis of the Si-nw array based on key process and manufacturing parameters.
- Identify main costs and performance drivers with main assumptions.
- Prepare a *Si-nw Report on Thermoelectric Device Techno-Economic Model*.

Products:

- Si-nw Report on Thermoelectric Device Techno-Economic Model Report

TASK 10 Evaluation of Project Benefits

The goal of this task is to report the benefits resulting from this project.

The Recipient shall:

- Complete three Project Benefits Questionnaires that correspond to three main intervals in the Agreement: (1) *Kick-off Meeting Benefits Questionnaire*; (2) *Mid-term Benefits Questionnaire*; and (3) *Final Meeting Benefits Questionnaire*.
- Provide all key assumptions used to estimate projected benefits, including targeted market sector (e.g., population and geographic location), projected market penetration, baseline and projected energy use and cost, operating conditions, and emission reduction calculations. Examples of information that may be requested in the questionnaires include:
 - For Product Development Projects and Project Demonstrations:
 - Published documents, including date, title, and periodical name.
 - Estimated or actual energy and cost savings, and estimated statewide energy savings once market potential has been realized. Identify all assumptions used in the estimates.
 - Greenhouse gas and criteria emissions reductions.
 - Other non-energy benefits such as reliability, public safety, lower operational cost, environmental improvement, indoor environmental quality, and societal benefits.
 - Data on potential job creation, market potential, economic development, and increased state revenue as a result of the project.
 - A discussion of project product downloads from websites, and publications in technical journals.
 - A comparison of project expectations and performance. Discuss whether the goals and objectives of the Agreement have been met and what improvements are needed, if any.
 - Additional Information for Product Development Projects:
 - Outcome of product development efforts, such copyrights and license agreements.
 - Units sold or projected to be sold in California and outside of California.

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

- Total annual sales or projected annual sales (in dollars) of products developed under the Agreement.
- Investment dollars/follow-on private funding as a result of Energy Commission funding.
- Patent numbers and applications, along with dates and brief descriptions.
- Additional Information for Product Demonstrations:
 - Outcome of demonstrations and status of technology.
 - Number of similar installations.
 - Jobs created/retained as a result of the Agreement.
- For Information/Tools and Other Research Studies:
 - Outcome of project.
 - Published documents, including date, title, and periodical name.
 - A discussion of policy development. State if the project has been cited in government policy publications or technical journals, or has been used to inform regulatory bodies.
 - The number of website downloads.
 - An estimate of how the project information has affected energy use and cost, or have resulted in other non-energy benefits.
 - An estimate of energy and non-energy benefits.
 - Data on potential job creation, market potential, economic development, and increased state revenue as a result of project.
 - A discussion of project product downloads from websites, and publications in technical journals.
 - A comparison of project expectations and performance. Discuss whether the goals and objectives of the Agreement have been met and what improvements are needed, if any.
- Respond to CAM questions regarding responses to the questionnaires.

The Energy Commission may send the Recipient similar questionnaires after the Agreement term ends. Responses to these questionnaires will be voluntary.

Products:

- Kick-off Meeting Benefits Questionnaire
- Mid-term Benefits Questionnaire
- Final Meeting Benefits Questionnaire

TASK 11 Technology/Knowledge Transfer Activities

The goal of this task is to develop a plan to make the knowledge gained, experimental results, and lessons learned available to the public and key decision makers.

The Recipient shall:

- Prepare an *Initial Fact Sheet* at start of the project that describes the project. Use the format provided by the CAM.
- Prepare a *Final Project Fact Sheet* at the project's conclusion that discusses results. Use the format provided by the CAM.
- Prepare a *Technology/Knowledge Transfer Plan* that includes:

Exhibit A Scope of Work

Lawrence Berkeley National Lab / Alphabet Energy Inc.

- An explanation of how the knowledge gained from the project will be made available to the public, including the targeted market sector and potential outreach to end users, utilities, regulatory agencies, and others.
- A description of the intended use(s) for and users of the project results.
- Published documents, including date, title, and periodical name.
- Copies of documents, fact sheets, journal articles, press releases, and other documents prepared for public dissemination. These documents must include the Legal Notice required in the terms and conditions. Indicate where and when the documents were disseminated.
- A discussion of policy development. State if project has been or will be cited in government policy publications, or used to inform regulatory bodies.
- The number of website downloads or public requests for project results.
- Additional areas as determined by the CAM.
- Conduct technology transfer activities in accordance with the Technology/Knowledge Transfer Plan. These activities will be reported in the Progress Reports.
- When directed by the CAM, develop *Presentation Materials* for an Energy Commission-sponsored conference/workshop(s) on the project.
- When directed by the CAM, participate in annual EPIC symposium(s) sponsored by the California Energy Commission.
- Provide at least (6) six *High Quality Digital Photographs* (minimum resolution of 1300x500 pixels in landscape ratio) of pre and post technology installation at the project sites or related project photographs.
- Prepare a *Technology/Knowledge Transfer Report* on technology transfer activities conducted during the project.

Products:

- Initial Fact Sheet (draft and final)
- Final Project Fact Sheet (draft and final)
- Presentation Materials (draft and final)
- High Quality Digital Photographs
- Technology/Knowledge Transfer Plan (draft and final)
- Technology/Knowledge Transfer Report (draft and final)

V. PROJECT SCHEDULE

Please see the attached Excel spreadsheet

STATE OF CALIFORNIA

STATE ENERGY RESOURCES
CONSERVATION AND DEVELOPMENT COMMISSION

RESOLUTION - RE: DOE-LAWRENCE BERKELEY NATIONAL LABORATORY

RESOLVED, that the State Energy Resources Conservation and Development Commission (Energy Commission) adopts the staff CEQA findings contained in the Agreement or Amendment Request Form (as applicable); and

RESOLVED, that the Energy Commission approves Agreement EPC-16-042 from GFO-16-302 with the Department of Energy's Lawrence Berkeley National Laboratory for a \$2,000,000 grant to develop a cost-effective process for creating advanced thermoelectric materials constructed from silicon nanowire arrays. If successful, the project will create a cost-effective system that will recover waste heat to generate supplemental electricity and help reduce energy use in the industrial sector; and

FURTHER BE IT RESOLVED, that the Executive Director or his/her designee shall execute the same on behalf of the Energy Commission.

CERTIFICATION

The undersigned Secretariat to the Commission does hereby certify that the foregoing is a full, true, and correct copy of a Resolution duly and regularly adopted at a meeting of the California Energy Commission held on April 12, 2017.

AYE: [List of Commissioners]

NAY: [List of Commissioners]

ABSENT: [List of Commissioners]

ABSTAIN: [List of Commissioners]

Cody Goldthrite,
Secretariat