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Advice 4402-E
(Pacific Gas and Electric Company ID U 39 M)

Advice 3030-E
(Southern California Edison Company ID U 338 E)

Advice 2592-E
(San Diego Gas & Electric Company ID U 902 M)

Public Utilities Commission of the State of California

Subject: **California Energy Systems for the 21st Century Proposed Research and Development Projects and Cooperative Research and Development Agreement**

Pacific Gas and Electric Company (PG&E), Southern California Edison Company (SCE), and San Diego Gas & Electric Company (SDG&E) (collectively referred to as the Joint Utilities) hereby submit for filing this joint Tier 3 Advice Letter requesting approval for the California Energy Systems for the 21st Century (CES-21) proposed multi-year research and development projects and the Cooperative Research and Development Agreement (CRADA).

Purpose

The purpose of this advice letter is to comply with Decision (D.) 12-12-031, Ordering Paragraphs (OPs) 8, 9, 12, and 14 and D.14-03-029, OPs 13, 14, and 15, which direct the Joint Utilities to file for approval of the CES-21 multi-year research and development projects, proposed implementation plan, associated business cases, and CRADA.

Background

The CES-21 Program is a public-private collaborative research and development project between the Joint Utilities and Lawrence Livermore National Laboratory (LLNL). The objective of the CES-21 Program is to address challenges of cyber security and grid integration of the 21st century energy system for California. The CES-21 Program will utilize a team of technical experts from the Joint Utilities and LLNL who will leverage and extend ongoing research in grid cyber security. LLNL will combine data integration with advanced modeling, simulation, and analytical tools to provide problem solving and planning necessary for the challenges of grid integration.

On July 18, 2011, the Joint Utilities filed Application (A.) 11-07-008, which requested authority to recover the costs for funding the CES-21 Program up to a maximum of $152.19 million in program funding over five years, with the funding shared among the Joint Utilities as follows: PG&E – 55%, SCE – 35%, and SDG&E – 10%.

In December 2012, the California Public Utilities Commission (Commission) issued D.12-12-031, which authorized the Joint Utilities to enter into a five-year research and development agreement with LLNL. This decision authorized the Joint Utilities to spend up to $30 million a year for five years on research activities, for a total of $152.19 million. The decision also allocated these costs to each of the utilities (PG&E – 55%, SCE – 35%, and SDG&E – 10%) and adopted a ratemaking mechanism for each utility to permit recovery of those costs.

On September 26, 2013, Governor Brown signed Senate Bill (SB) 96, which among other things, limited the scope of the CES-21 Program, as previously approved by the Commission in D.12-12-031, to cyber security and grid integration research and development projects not to exceed $35 million over a five year period.[1] As part of SB 96, the California legislature directed the Commission to require the Joint Utilities to prepare and submit a joint report by December 1, 2013.[2] In compliance with this legislative directive, the Joint Utility Report described (1) the scope of all proposed research projects, (2) how the proposed projects may lead to technological advancement, (3) how the proposed projects may lead to potential breakthroughs in cyber security and grid integration, and (4) the expected timelines for concluding the projects.[3]

On March 27, 2014, the Commission approved D.14-03-029, which modifies D.12-12-031 to comply with SB 96. In this decision, the Commission:

- Reduces the CES-21 budget to $35 million (including "franchise fees" and "uncollectibles") over a five-year period;[4]
- Limits areas of research to "cyber security" and "grid integration"; [5]
- Modifies the cost allocation to PG&E – 50%, SCE – 41%, and SDG&E – 9%;[6]
- Reduces the governance structure to three Project Managers from PG&E, SCE, and SDG&E;[7]
- Voids any CES-21 program management expenditures incurred to date and caps future administrative expenses to no more than 10% of the total CES-21 budget;[8]

[1] SB 96 added Section 740.5 to the Public Utilities Code.
[2] Public Utilities Code Section 740.5 (e)(1).
[3] Submitted to the Commission on November 27, 2013.
[4] D.14-03-029, OP 2.
[5] Id.
[6] Id., OP 6-8.
[7] Id., OP 9.

- Requires enhanced Legislative and Commission oversight of the CES-21 Program;[9] and
- Revises the CRADA guidelines and project criteria accordingly.[10]

In this Advice Letter, the Joint Utilities seek Commission authorization to implement the CES-21 Program pursuant to D.12-12-031 and D.14-03-029.

Discussion

1. Proposed Research and Development Projects

The purpose of the CES-21 Program is to fund cyber security and grid integration research and development projects at a cost of $35 over a five-year period.[11] For cyber security, the proposed project is "Machine to Machine Automated Threat Response," which will develop capabilities to protect critical infrastructure against cyber-attacks. For grid integration the proposed project is "Flexibility Metrics and Standards," which will focus on defining operating flexibility metrics and targets based on a probability measure of the occurrence, the magnitude, and the duration of ramping shortages at different time intervals.

Machine to Machine Automated Threat Response Cyber Security Project

Cyber-attacks against critical infrastructure are increasing in frequency and sophistication at an alarming rate. Technologies currently used to protect our critical infrastructure against such attacks can be improved upon to deal with the advanced threats. The Machine to Machine Automated Threat Response cyber security reseach project will develop automated response capabilities to protect critical infrastructure against cyber-attacks. Due to the time criticality of these cyber-attacks, the optimum way to effectively protect the critical infrastructure will be through these automated response capabilities. In summary, the result of this research can be envisioned as a threat-aware grid architecture capable of making real-time decisions to increase its survivability and resiliency.

Flexibility Metrics and Standards Grid Integration Project

New operating flexibility metrics are needed for long-term resource planning in California. Improvements to methodology and existing models, or new models, are also needed to reduce the cost, and/or the uncertainty about the resource adequacy of planned resources, to integrate greater amounts of intermittent

[8] Id., OP 10.
[9] Id., 14-16, 20-21
[10] Id., OP 13
[11] Public Utilities Code 740.5(b); D.14-03-029, OP2.

renewables. Improvements to methodology and models are also needed to facilitate the consideration and decision making in regulatory and stakeholder processes of planning issues related to the integration of renewable resources, including: (1) quantification of system operating requirements, (2) estimates of the contribution of different resources to meet those requirements, (3) quantification of system residual need for resources, and (4) evaluation of the cost-effectiveness of resource alternatives with different operating attributes to meet residual system needs. The Flexibility Metrics and Standards grid integration research project will:

- Review and critique existing flexibility metrics and tools now in use and under development by the utilities, CAISO, and others to quantify operating flexibility requirements and the residual resource needs not met by existing or already planned resources.
- Define new flexibility metrics, potentially novel ones, such as insufficient ramping capacity, that a system requires to balance loads and resources during different time intervals.
- Identify how to operationalize the flexibility metrics for long-term planning purposes, either as separate metrics or combined with existing reliability metrics, such as loss of load expectation (LOLE) or PRM requirement.
- Recommend whether new operating flexibility standards or modified reliability standards should be adopted to incorporate the increased need for operating flexibility with greater amounts of intermittent generation.
- Develop prototype new models or improvements to existing resource planning models that incorporate the proposed flexibility metrics with traditional production simulation and reliability models for use in evaluating the cost-effectives of different alternatives to meet identified system needs.

2. CES-21 Program Management

Public Utilities Code Section 740.5(c) and D.14-03-029, OP 9, provide that CES-21 project managers shall be limited to three representatives, one from each of the Joint Utilities. The Joint Utilities propose that the three CES-21 project managers serve as members of a joint utility steering committee responsible for the administration of the CES-21 Program. The three CES-21 project managers will coordinate with LLNL, administer the CES-21 Program and the CRADA, ensure that the CES-21 Program stays within the authorized budget, and submit a joint report summarizing the outcome of all funded projects 60 days following the conclusion of all research and development projects. In addition, the Joint Utilities will submit an annual report to the Commission on the administration and results of the CES-21 Program and will provide project progress reports as required by Energy Division staff.

3. CES-21 Program Budget and Benefits

As authorized in D.14-03-029, OP 2, the CES-21 Program research and development projects shall be limited to $35 million during the five years of the CES-21 Program, unless otherwise authorized by the Commission.

The Joint Utilities request the Commission approve the following program budget for the two research projects listed below in Table 1. Attachment 1 includes the business cases that describe each proposed research and development project in more detail, pursuant to OP 15 of D.14-03-029.

Table 1
CES-21 Proposed Research Budget

CES-21 Proposed Projects – First Program Period	Total Potential Cost / Duration
Cyber Security	
• Machine to Machine Automated Threat Response	$33.0 M / 36 months
Grid Integration	
• Flexibility Metrics and Standards	$2.0 M / 24 months
Total	**$35.0 M / 36 months**

The potential customer benefits associated with each proposed research project are described in the attached business cases for the respective proposed research projects. Where possible, benefits are quantified to illustrate the potential value to customers from the proposed research.

Potential benefits such as improvements to safety, reliability, or cyber security are not strictly quantifiable. There is no Commission-established methodology for precisely monetizing these benefits. For example, it is difficult, if not impossible, to quantify the public safety and reliability benefits for cyber security projects such as the Machine to Machine Automated Threat Response project. This project will reduce the probability of disrupting critical infrastructure services by protecting the California electric grid from cyber security attacks. While it is well documented that blackouts have significant impacts on the economy and the health and well being of its citizens, it is not feasible to estimate the reduced risk of blackouts from this type of cyber security research project. As a result, benefit descriptions included in the business cases in this Advice filing are often more qualitative than quantitative.

Improving the accuracy of flexible resource need determination could result in substantial benefits to California's electricity consumers. An improved understanding of flexibility needs may provide insight into how to best take

advantage of existing and new alternatives such as energy storage. Illustrative benefits for this project were presented in the Joint Utilities' rebuttal testimony filed in A.11-07-008. Since there is no universally adopted methodology or metrics to measure a system's operating flexibility, or to determine how much operating flexibility a system should have, the potential benefits will be realized after the results from this research project are adopted and incorporated into operating practices and investment decisions.

The CES-21 project managers will actively review each research project's progress against the milestones and deliverables.

The project plans, milestones, and deliverables developed for CES-21 projects are adaptive and may evolve as the research progresses and learnings from each phase or task are identified. Significant revisions to the project plans, milestones, and deliverables will be documented and designed to help achieve the project's objectives. The CES-21 project managers will inform the Commission and stakeholders of such changes and course corrections in the annual report, required in D.14-03-029, OP 21.

4. Cooperative Research and Development Agreement (CRADA)

Under the CES-21 Program, PG&E, SCE, SDG&E, and LLNL will execute a CRADA, consistent with OP 10 of D.12-12-031, SB 96, Public Utilities Code Section 740.5, and OP 13 of D.14-03-029, which will be executed upon approval by the Commission and the Department of Energy. The CRADA establishes the terms and conditions of the collaboration between LLNL, PG&E, SCE, and SDG&E for the CES-21 Program. The CRADA is included in Attachment 2 of this Advice filing.

In accordance with D.12-12-031, SB 96, Public Utilities Code Section 740.5 and D.14-03-029, the CRADA conforms to the guidelines established by the Commission:

- The CRADA must restrict research projects to two promising research areas: cyber security and grid integration.
- The CRADA must limit total expenditures to $35 million over a five-year period. There is no annual spending cap. All projects shall be concluded by the fifth anniversary of their start date.
- The Advice Letter seeking approval of the CRADA shall allocate costs with PG&E responsible for 50% of the costs, SCE responsible for 41% of the costs, and SDG&E responsible for 9% of the costs. These utilities may recover these costs using the regulatory mechanisms adopted in this decision.

- The CRADA must agree that all research projects conducted under this proposal must meet the specific criteria adopted in D.14-03-029.
- Project managers for the CES-21 Program shall be limited to three representatives, one representative each from PG&E, SCE, and SDG&E, and shall coordinate with LLNL, administer the CES-21 Program and the CRADA, ensure that the CES-21 Program stays within the authorized budget, submit joint annual reports and joint report following the conclusion of all research and development projects, and conduct workshops prior to supplemental Tier 3 Advice Letter filings.
- The CES-21 Program will utilize outside expertise and knowledge as necessary to meet program requirements within the limits established by D.14-03-029.
- Research proposals must have the support of all three Utilities and provide an explanation if not funded by all utilities.

Intellectual Property Issues

As specified in D.12-12-031, OP 18, the Joint Utilities jointly retain title to any intellectual property or other value produced or derived from the CRADA, and have authority to license, sell or encumber any such intellectual property to Lawrence Livermore National Security, LLC (LLNS) and third parties upon Commission approval under Public Utilities Code Section 851 and subject to the requirement that any such licensing be on fair and reasonable grounds, for a fair and reasonable licensing fee, and also subject to rights granted by law to the U.S. Federal Government under the CRADA. Intellectual property that was in existence prior to or produced outside the CRADA and is identified in advance by the parties to the CRADA, will remain the property of the party owning the intellectual property or proprietary information, unless the parties to the CRADA mutually agree otherwise.

Third Party Activities

The Joint Utilities envision that third parties will be engaged to assist with the proposed research projects. The research projects may collaborate with other research institutions and experts to ensure the best possible research teams are assembled and that each project leverages existing tools and capabilities. Although potential collaborators have been identified in the business cases who may contribute to the projects, no commitments have been made at this time to partner with any particular entity or outside expert. The CRADA provides flexibility for either LLNL or the Joint Utilities to contract with third parties on the research.

5. Request for Commission Approval

The Joint Utilities request that the Commission issue a resolution that:

a. Approves the Machine to Machine Automated Threat Response multi-year project presented in this Advice filing and included in Attachment 1;
b. Approves the Flexibility Metrics and Standards multi-year project presented in this Advice filing and included in Attachment 1;
c. Approves a budget of $35 million for the proposed research and development projects as presented in Table 1; and
d. Approves the CRADA provided in Attachment 2 of this Advice filing.

Protests

Anyone wishing to protest this filing may do so by letter sent via U.S. mail, facsimile or E-mail, no later than May 15, 2014 which is 20 days after the date of this filing. Protests must be submitted to:

CPUC Energy Division
ED Tariff Unit
505 Van Ness Avenue, 4th Floor
San Francisco, California 94102

Facsimile: (415) 703-2200
E-mail: EDTariffUnit@cpuc.ca.gov

Copies of protests also should be mailed to the attention of the Director, Energy Division, Room 4004, at the address shown above.

The protest shall also be sent to the Joint Utilities either via E-mail or U.S. mail (and by facsimile, if possible) at the addresses shown below on the same date it is mailed or delivered to the Commission:

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Pacific Gas and Electric Company
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San Francisco, California 94177
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Any person (including individuals, groups, or organizations) may protest or respond to an advice letter (General Order 96-B, Section 7.4). The protest shall contain the following information: specification of the advice letter protested; grounds for the protest; supporting factual information or legal argument; name, telephone number, postal address, and (where appropriate) e-mail address of the protestant; and statement that the protest was sent to the utility no later than the day on which the protest was submitted to the reviewing Industry Division (General Order 96-B, Section 3.11).

Effective Date

The Joint Utilities request that this Tier 3 advice filing become effective *upon approval by the Commission.*

Notice

In accordance with General Order 96-B, Section IV, a copy of this advice letter is being sent electronically and via U.S. mail to parties shown on the attached list and the service lists for A.11-07-008, A.12-11-003, and R.08-12-009. Address changes to PG&E's General Order 96-B service list should be directed to PG&E at email address PGETariffs@pge.com. For changes to any other service list, please contact the

Commission's Process Office at (415) 703-2021 or at Process_Office@cpuc.ca.gov. Send all electronic approvals to PGETariffs@pge.com. Advice letter filings can also be accessed electronically at: http://www.pge.com/tariffs

Brian Cherry /KHC

Vice President, Regulatory Relations

Attachment 1: CES-21 Proposed Research and Development Project Business Cases
Attachment 2: CES-21 CRADA

cc: Service Lists for A.11-07-008, A.12-11-003, and R.08-12-009

CALIFORNIA PUBLIC UTILITIES COMMISSION

ADVICE LETTER FILING SUMMARY
ENERGY UTILITY

MUST BE COMPLETED BY UTILITY (Attach additional pages as needed)

Company name/CPUC Utility No. **Pacific Gas and Electric Company (ID U39 E)**

Utility type:	Contact Person: Kingsley Cheng
☑ ELC ☐ GAS	Phone #: (415) 973-5265
☐ PLC ☐ HEAT ☐ WATER	E-mail: k2c0@pge.com and PGETariffs@pge.com

EXPLANATION OF UTILITY TYPE

ELC = Electric GAS = Gas
PLC = Pipeline HEAT = Heat WATER = Water

(Date Filed/ Received Stamp by CPUC)

Advice Letter (AL) #: **PG&E 4402-E**
SCE 3030-E
SDG&E 2592-E

Tier: 3

Subject of AL: **California Energy Systems for the 21st Century Proposed Research and Development Projects and Cooperative Research and Development Agreement**

Keywords (choose from CPUC listing): Compliance, Agreements

AL filing type: ☐ Monthly ☐ Quarterly ☐ Annual ☑ One-Time ☐ Other _____

If AL filed in compliance with a Commission order, indicate relevant Decision/Resolution #: D.12-12-031 and D.14-03-029

Does AL replace a withdrawn or rejected AL? If so, identify the prior AL: No

Summarize differences between the AL and the prior withdrawn or rejected AL: _____

Is AL requesting confidential treatment? If so, what information is the utility seeking confidential treatment for: No

Confidential information will be made available to those who have executed a nondisclosure agreement: N/A

Name(s) and contact information of the person(s) who will provide the nondisclosure agreement and access to the confidential information: _____

Resolution Required? ☑Yes ☐No

Requested effective date: **Upon Commission Approval** No. of tariff sheets: N/A

Estimated system annual revenue effect (%): N/A

Estimated system average rate effect (%): N/A

When rates are affected by AL, include attachment in AL showing average rate effects on customer classes (residential, small commercial, large C/I, agricultural, lighting).

Tariff schedules affected: N/A

Service affected and changes proposed: N/A

Pending advice letters that revise the same tariff sheets: N/A

Protests, dispositions, and all other correspondence regarding this AL are due no later than 20 days after the date of this filing, unless otherwise authorized by the Commission, and shall be sent to:

California Public Utilities Commission
Energy Division
EDTariffUnit
505 Van Ness Ave., 4th Flr.
San Francisco, CA 94102
E-mail: EDTariffUnit@cpuc.ca.gov

Pacific Gas and Electric Company
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Vice President, Regulatory Relations
77 Beale Street, Mail Code B10C
P.O. Box 770000
San Francisco, CA 94177
E-mail: PGETariffs@pge.com

PG&E Advice 4402-E
SCE Advice 3030-E
SDG&E Advice 2592-E

Attachment 1

CES-21 Proposed Research and Development Project Business Cases

California Energy Systems for the 21st Century

Machine to Machine Automated Threat Response (MMATR)

Proposed Research Project Business Case

1. Executive Summary

a) Context of MMATR within CES-21:

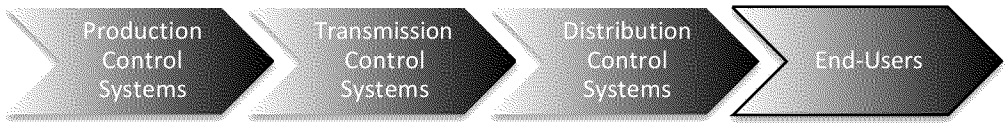
The CES-21 Program is a public-private collaborative research and development project between PG&E, SCE, SDG&E, and Lawrence Livermore National Laboratory (LLNL). The objective of the CES-21 Program is to apply computationally-based and other problem solving resources to the emerging challenges of the 21st century electric system of California. The CES-21 Program will utilize a joint team of technical experts from the Utilities and Lawrence Livermore National Laboratory (LLNL) who will combine data integration with advanced modeling, simulation, and analytical tools to provide problem solving and planning necessary to achieve California's ambitious energy and environmental goals for the 21st century.

CES-21 proposals will leverage a Cooperative Research and Development Agreement (CRADA) between the three California Investor Owned Utilities (IOUs) and LLNL. These organizations will partner with other DOE national laboratories and California universities to achieve CES-21 program goals through individual business cases.

CES-21 program activities align with the energy sector's *Roadmap to Achieve Energy Delivery Systems Cybersecurity* (Roadmap, www.controlsystemsroadmap.net). The Roadmap 2011 update was a collaborative effort that drew on the expertise of more than 80 public and private energy sector stakeholders. It presents a strategic framework and set of short, mid and long-term milestones with the vision that by 2020 resilient energy delivery systems are designed, installed, operated and maintained to survive a cyber-incident while sustaining critical functions.

The following graph shows the Electricity Sector Value Chain. CES-21 Cybersecurity will focus on the Industrial Control Systems (ICS) associated with the value chain and how and automated response to cyber threats will maintain the reliability of the value chain.

Electricity Sector Value Chain



MMATR is applicable to SCADA systems that exist anywhere within the IOU's electrical value chain, that is electricity production, transmission and distribution control systems. The automated ICS data and associated remediation will enable the control systems to respond to threats quickly, ensuring the reliability of the grid for the end-users

b) MMATR Research Project Opportunity Statement:

Cyber-attacks against critical infrastructure are increasing in frequency and sophistication at an alarming rate. Recent successful attacks on the energy sector such as those mounted against RAS-GAS, a Qatari gas firm, and Aramco, a Saudi oil firm, illustrate the point. State of the art technologies currently used to protect our critical infrastructure against such attacks are ill-equipped to deal with the advanced threats.

There is a fundamental difference between cyber-attacks against Information Systems and those against critical infrastructure. Attacks against Information Systems usually target the data and have the potential to impact business processes while attacks against critical infrastructure target control systems and have the potential to disrupt critical services and or destroy the infrastructure. Another marked difference is the speed with which these two types of attacks develop. Attacks against Information systems tend to be slow and may develop over long periods of time while attacks on the infrastructure may end relatively quickly. This distinction is important because it has implications as to how much time defenders have to react to the different kinds of attacks.

The proposed research is intended to develop automated response capabilities to protect critical infrastructure against cyber-attacks. Due to the time criticality of cyber-attacks, the only way to effectively protect the critical infrastructure is through these automated response capabilities.

This MMATR business case leverages the CES-21 CRADA between the three California IOUs and LLNL to develop advanced cyber technology and tools not currently commercially available. This advancement in cyber technology is expected to enable the IOUs to identify and take action on advanced cyber threats to their industrial control systems before they impact California's critical infrastructure.

c) Utility Sponsors:

☒ PG&E ☒ SCE ☒ SDG&E

d) Potential Customer Benefits:

California customers will benefit greatly from avoided (or, shortened outages) due to cyber-attacks. Automated response capability will reduce the number of outages, minimize their impact, and improve recovery times.

Benefit Category	Benefit Description	Customer Benefit
Develops Emerging Technology	**Define and develop "forward looking" technology, strategies and tools.** In partnership with Lawrence Livermore Labs technologies will be developed that will improve cyber security processes and tools above those that are currently commercially available. Research and development of tools will focus on areas not expected to be served by the commercial sector in the near term. Modeling and simulation will be used to design more resilient networks and test proposed courses of action. These processes and tools will enable the California Utilities to pursue moderate-risk/high-reward solutions to critical cyber security problems.	**Reduces the threat of system damage to critical infrastructure systems that could impact utility rates in California**

Benefit Category	Benefit Description	Customer Benefit
Improves Public Safety	**Increase the security of California's critical infrastructure.** This project aligns with the White House Comprehensive National Security Initiative to protect our nation's infrastructure. *In July 2012 President Obama wrote in the Wall Street Journal:* Taking the Cyber-attack Threat Seriously "It doesn 't take much to imagine the consequences of a successful cyber-attack. In a future conflict, an adversary unable to match our military supremacy on the battlefield might seek to exploit our computer vulnerabilities here at home. Taking down vital banking systems could trigger a financial crisis. The lack of clean water or functioning hospitals could spark a public health emergency. And as we've seen in past blackouts, the loss of electricity can bring businesses, cities and entire regions to a standstill". Successful penetration or disruption of the California electric grid will cause serious damage to national security and public safety.	**Reduces the disruption of critical infrastructure services and negative impact to:** • **California's health & human services** • **Loss of revenue to California's businesses**
Develops Processes for Proactive Defense Against Cyber Threats	**Create a line of defense against today's advanced persistent** threats by enhancing shared situational awareness of network vulnerabilities, threats, and events to enable the California Utilities to act quickly to reduce vulnerabilities and prevent intrusion. Advanced threat analytics (using machine learning and other algorithmic techniques) and software analysis will be explored as possible foundations for new cybersecurity defensive technology.	**Improves the responsiveness to cyber threats and reduces the disruption of critical infrastructure services in California**

Benefit Category	Benefit Description	Customer Benefit
Build California Talent in Cyber Defense	**Strengthen cybersecurity environment by expanding cyber education;** coordinating and redirecting research and development efforts across the California Utilities and working to define and develop strategies to deter hostile or malicious activity in cyberspace	**Leverages the cyber talent among the California Utilities that will reduce disruption of critical infrastructure services in California**
Develops Processes to Plan for Emerging Threats	**Define and develop enduring deterrence strategies and programs.** California Utilities have implemented traditional approaches to the cybersecurity problem. These measures have been effective in the current environment but need to transition to the next level of threat protection to protect California's Critical Infrastructure. This Initiative will build a cyber defense strategy that will improve warning capabilities appropriate responses for both state and non-state actors.	**Improves the responsiveness to cyber threats and reduces the disruption of critical infrastructure services in California**

e) Research Challenges and Hurdles to Overcome:

The research challenges include:

- Current lack of integration between disparate systems
- Lack of automated response strategies
- Lack of standard nomenclature and semantics to describe indicators and responses
- Lack of research into interplay of complex responses (e.g. response to one threat may increase exposure to others
- Lack of modeling and simulation tools for communications / power systems that scale to the state and national levels
- Automated response can be harmful in networks where situational awareness is inadequate. Mitigations will have to be studied.
- Decision logic for automated response is often not "one-size-fits-all". A configurable logic engine within certain minimum security standards must be developed.
- Current lack of tools/techniques for identifying the advanced persistent threat (APT) in industrial control system (ICS) networks

f) Duplication and synergies:

The CES-21 program has proactively coordinated with the Department of Energy's Cybersecurity for Energy Delivery Systems (CEDS) program, which also aligns R&D activities with the energy sector's Roadmap. While there is currently research underway in the energy sector that will develop automatic recognition of and response to cyber threats, further research in this area is needed due to the complexity and diversity of energy delivery system architectures, components and systems as well as the dynamic threat landscape. In the CES-21 Cyber team's research, current R&D specifically for Utilities, related to automated response to Cyber threats is in a state of rudimentary infancy. The CES-21 Cyber team will coordinate our efforts with others doing research in this are to negate the possibility of duplication. This research area is well-aligned with the strategic framework articulated in the energy sector's Roadmap.

Products are available (e.g. smart routers, switches and firewalls) that can accept and execute some of the response actions. This proposed research will evaluate and leverage these commercially available products where applicable.

2. Proposal Description

a) Background

The cyber security industry is making great strides in the areas of protection and detection capabilities. For example, government programs such as Einstein 1, 2, and 3, ADAMS, and CINDER promise to protect government information systems by improving situational awareness and improving detection and protection capabilities. However, for the most part, when it comes to reacting to attacks, these systems rely on alerting those under attack to take remedial action. Manual responses may be adequate for cyber-attacks against information systems and their data but manual responses to cyber-attacks against critical infrastructure may not be fast enough to keep attackers from damaging the critical infrastructure. What's needed is an automated response capability to protect the critical infrastructure against cyber-attacks.

The automated response capability would essentially mimic a military strategy developed by USAF Colonel John Boyd and applied to the combat operations process known as the OODA loop. According to Boyd, decision-making occurs in a recurring observe-orient-decide-act (OODA) loop. In combat, the opponent who can process this cycle quicker has the advantage. In cyber security as in war, the ability to observe and react to threats more rapidly than the attacker will significantly enhance the system's ability to survive an attack. The advancement in cyber technology will enable the IOUs to identify and take action on advanced cyber threats before they impact California's critical infrastructure.

b) Objective

The objective is to conduct research leading to the development of automated response capabilities to protect critical infrastructure against cyber-attacks, specifically APTs. Due to the time criticality of these cyber-attacks, the only way to effectively protect the critical infrastructure will be through automated response capabilities. Automated responses may take the form of:

- Network segmentation, disconnection, or segregation
- Traffic shaping, routing and firewalling
- Session termination and resets
- Traffic and application whitelisting
- System quarantining or disconnection
- Component reboot/reload
  Implementation of other automated response strategies

Conceptually, armed with the proposed automated response capability, a critical infrastructure under attack would:

1. **Become aware of the attack**. The system would learn about the attack, as well as the type of attack, from sensors in its environment or external, capable of providing attack indicators.
2. **Notify relevant sub networks and subsystems.** Since the critical infrastructure is a system of systems, all information will need to flow to the pieces and fragments that can take the appropriate actions.
3. **Select and perform an appropriate response**. Decision logic on each system or component using the type of attack and the overall context, would select a response or responses that would improve its resilience to the attack while trying to maintain its basic operational functionality.
4. **Continue to maintain situational awareness**. Each component of the critical infrastructure is in a constant state of monitor - response to improve the overall chance of effectiveness.

There is much work to be done in order to make cybersecurity automated response capability a reality. Some of the major research efforts include:

- Integration of existing security solutions to improve situational awareness
- Adoption of standard lexicon and taxonomy to describe attacks
- Development and selection of appropriate response strategies
- Development of automated system parameter tuning to increase response effectiveness and reduce false positives
- Automated Response Capability product development

The proposed research includes plans to leverage work already underway at national laboratories and academia. Examples include the Department of Energy's Cybersecurity

Risk Information Sharing Program (CRISP) and Department of Energy's Cybersecurity for Energy Delivery Systems Program (CEDS), which has both R&D and operational components.

This project will incorporate a structured threat exchange language such as Structured Threat Information eXpression (STIX™) and a threat exchange service such as Trusted Automated eXchange of Indicator Information (TAXII™), both developed by the Department of Homeland Security and undergoing adoption by the ES-ISAC.

LLNL will provide leadership and will work with California technology companies to commercialize the research into useful products that enhance the survivability of California's critical electric utility infrastructure systems to cyber-attacks.

c) Expected results

The result of this research can be envisioned as a threat-aware grid architecture capable of making real-time decisions to increase its survivability and resiliency.
CES cybersecurity innovations and breakthroughs may include:

- An open architecture for distributed threat detection and automatic, localized response:
  - with status reporting to peers
  - permitting centralized maintenance.
  - aware of its environment and changes to it
  - providing forensically sound evidence collection and handling for the use of law enforcement and intelligence services.
  - including open and non-proprietary systems, algorithms, and workflows that provide a basis for a commercially viable prototype.
- Secure procedures and processes for the management, command, and control of ICS defenses.
- Standard descriptive semantics for threats, responses, infrastructure, and processes.
- Models of ICS systems within the California Utilities grid which are useful for further analyses.
- Recommended responses to threats and threat types.

3. Research Approach Assessment

Challenge	Assessment	Reason
Developing the language and semantics to describe indicators and their recognition	Likely to succeed	MITRE has already started on the synergistic Structured Threat Information Expression (STIX) and Trusted Automated Exchange of Indicator Information (TAXII) under direction from the DHS
Developing the suite of actions to be undertaken within the network to provide a level of resilience	Likely to succeed	There are a fixed number of things within the control of an intelligent process – this approach is an aggregation of existing capabilities
Developing the language and semantics to describe the actions to be taken, the sequencing and the priority	Likely to succeed	There are a number of systems that use If-Then rules to perform distributed functionality that can be leveraged
Detecting APT-type attacks on/within ICS networks	Challenging	ICS security has largely ignored APT-style attacks. The grid was not designed or built with this kind of threat in mind.
Simulating or modeling threats and response scenarios on a large, complex grid network	Challenging	Although pieces have been simulated nothing for the grid at the required scale has been attempted before
Deriving resiliency configurations based on attack scenarios	Challenging	The interplay between attacks scenarios and the combinatorics of possible actions to be taken may prove complex

4. Implementation Plan and Schedule

a) Work plan

Use Case Generation

This task will generate use cases for potential cyber security solutions to be developed in the CES-21 Cyber program. Project participants will meet with utility subject matter experts (SMEs) to learn about operational needs in cyber security, to learn about realities of operating the grid in a reliable and secure manner, and to solicit feedback on prototype technologies developed by the program. These meetings will be frequent during program initiation and then occur on a regular basis throughout the remainder of the program.

Aggregate and Normalize Data

The team will develop a comprehensive understanding of the IOU's ICS network architecture, devices on the network, and data available from network devices. Both IOU device catalogs and network mapping technology will be used to accomplish this. We will build a prototype data aggregator to collect ICS data pertinent to defending the network. Existing data models will be used where available and then extended or created to fill gaps. This task will continue at a low level throughout most of the project in order to stay current with new device and data types.

Modeling/Simulation

We will start by defining a "Modeling/Simulation R&D Strategy" for the CES-21 Cyber program. Experts in modeling and simulation as well as IOU grid operators will team to determine what elements of modeling/simulation will be most beneficial to supporting other program tasks such as "Tools for Course of Action Analysis" and "Generate Defensive Actions." Because modeling and simulation can be performed with many degrees of resolution (e.g. neighborhood, city, region, State of California) at varying levels of effort, we will investigate resolution requirements with grid operators and determine the optimal grid representations for modeling/simulation. Subsequent work will build and/or extend existing modeling/simulation tools to meet requirements outlined in the "Modeling/Simulation R&D Strategy." The modeling/simulation tools will then be used by other program tasks.

Establish Test Bed

A test bed or multiple test beds are necessary to test prototype technologies. We will evaluate existing test beds at the IOUs, national laboratories, and colleges and universities. The most comprehensive and applicable test bed(s) will be selected for use by the CES-21 Cyber program for testing newly developed defensive technologies and investigating grid behavior in a controlled non-production environment. New test bed capabilities may be developed where gaps are identified.

Advanced Threat Detection

This task will focus on detection of "zero-day" or unknown cyber threats to ICS networks. This task is a low-level effort aimed at developing case studies to guide detection of heretofore unseen threats, building prototype algorithms to identify and detect them, and developing a research plan that outlines options for future investigation of this area.

Standardized Indicator Language

Cyber indicators are already being distributed by government entities and private industry though a common data format has not been established. This task will evaluate the most used indicator languages and choose one for use

within the CES-21 Cyber program. We will attempt to influence industry groups and government decision-makers where appropriate to use a common language for data exchange. We may develop our chosen language further to encompass additional needs that the IOUs have for such a technology. The team will share any modifications to the chosen standard with the original author and community.

Software/Device Vulnerability Analysis

This task will focus on finding latent vulnerabilities in ICS device software using novel techniques. This task is a low-level effort that will investigate the existing tools in this field, build a prototype tool, and develop an R&D roadmap that outlines options for future investigation of this area.

Tools for Course of Action Analysis

We will investigate and develop technologies for taking defensive actions on ICS devices. The team will work closely with the IOUs to insure logic for automated and semi-automated responses meshes with their grid operation workflow.

Generate Defensive Actions

This task will focus on making changes to ICS networks in the face of cyber threats. The team will survey existing automated response systems for ICS networks (if any), work with grid operators to build a catalog of potential defensive actions, develop response actions, test those actions on our test bed network(s) and/or modeling/simulation framework, and integrate them into grid operations.

Secure System Interface Environment

Research and identify a secure system interface environment for energy systems and sensors. As sensors grow across the intelligent smart grid an interface environment is needed that will allow for simple sensor interfaces and provide a high level of security and cyber protection for system sensors. Interfaces are typically expensive to develop and maintain. Sensor replacement, changes to existing sensor firmware and the addition of new sensors often requires interface upgrades or changes. This process can be costly and may delay sensor implementation while the interface is developed/upgraded, tested, implemented and introduce vulnerabilities. This task will research a common, secure interface environment that can function as a cyber security component that enhances overall security objectives.

MMATR Integration

The program will be executed using a spiral development methodology enabling resources to be quickly focused in areas that are yielding results. The

main integration timeline is set up in 6 month R&D cycles with each cycle culminating in an internal review.

b) Resource requirements

LLNL, IOU, and potential partner resources are required in the following areas:

- System architecture
- Software development
- Cyber security analysis
- Network analysis
- Software reverse engineering
- Cyber security incident response
- Modeling
- Grid infrastructure, controls, and communications networks

Work Breakdown Resource Allocation Budget

The total projected budget estimate for the three year period of task execution for MMATR is $33,000,000. The budget is shown in the table below divided per year and by entity. Management administrative expenses will be limited to 10% of the total CES-21 budget and is spread over CES-21 management of MMATR and Grid Integration tasking. The Joint IOU Program Managers will move task dollars between years or into additional years as needed dependent on task completion. The Joint IOU Program Managers will seek CPUC approval if there is more than a 5% spending shift proposed between categories proposed in the MMATR or Grid Integration Business Cases as submitted in this Advice Letter.

Entity	PM1-12	PM13-24	PM25-36
LLNL and subcontract	11,000,000	7,700,000	3,800,000
Utility	3,500,000	3,500,000	3,500,000
Total	**$14,500,000**	**$11,200,000**	**$7,300,000**

5. Benefits Estimate and Methodology

The utilities have a large investment in infrastructure across California. The technologies for interconnectivity of control systems, though getting better, still show vulnerabilities, some known and some unknown. Any extended threat that succeeds could cause an outage, locally,

regionally or statewide. The research on outages on a regional scale shows millions of dollars in lost business revenues and productivity with a small to moderate outage. This investment in Cyber Security research and development will focus on creating a Cyber Security effort that curtails or interdicts those threats before they become an outage or has other lasting effects on the California grid.

California Energy Systems for the 21st Century

Flexibility Metrics and Standards

Proposed Research Project Business Case

1. Executive Summary

a) Context of the project within CES-21:

The CES-21 Program is a public-private collaborative research and development project between PG&E, SCE, SDG&E, and Lawrence Livermore National Laboratory (LLNL). The objective of the CES-21 Program is to apply computationally-based and other problem solving resources to the emerging challenges of the 21st century electric system of California. The CES-21 Program will utilize a joint team of technical experts from the Utilities and Lawrence Livermore National Laboratory (LLNL) who will combine data integration with advanced modeling, simulation, and analytical tools to provide problem solving and planning necessary to achieve California's ambitious energy and environmental goals for the 21st century.

CES-21 proposals will leverage a Cooperative Research and Development Agreement (CRADA) between the three California Investor Owned Utilities (IOUs) and LLNL. These organizations will partner with other DOE national laboratories and California universities to achieve CES-21 program goals through individual business cases.

b) Research Project Opportunity Statement:

New operating flexibility metrics are needed for long-term resource planning in California. Improvements to methodology and existing models, or new models, are also needed to reduce the cost, and/or the uncertainty about the resource adequacy of planned resources, to integrate greater amounts of intermittent renewables. Improvements to methodology and models are also needed to facilitate the consideration and decision making in regulatory and stakeholder processes of planning issues related to the integration of renewable resources, including: (1) quantification of system operating requirements, (2) estimates of the contribution of different resources to meet those requirements, (3) quantification of system residual need for resources, and (4) evaluation of the cost-effectiveness of resource alternatives with different operating attributes to meet residual system needs.

Traditional resource planning methods have used reserve margin metrics and standards, expressed as the expected frequency of Stage 3 events[1], or as a planning reserve margin

[1] Stage 3 is initiated by the CAISO when operating reserves are forecasted to be less than 3 percent. See: http://www.caiso.com/Documents/EmergencyFactSheet.pdf

(PRM), to ensure that enough capacity is procured and available for operating the system. In the past, because of the small amounts of renewables in the system, the uncertainty and intermittency of generation like wind and solar was dwarfed by the uncertainty in electric load. Also, in the past, conventional resource additions provided the operating flexibility required by the uncertainty and intermittency of electric load.

Today, California has an aggressive green energy plan, built around renewable resources and other preferred resources that offer little or no operating flexibility. The uncertainty and intermittency of renewable generation require the system to be more flexible than it is today. As a result, past planning and operating metrics and standards need to be updated to incorporate the increased need for operating flexibility with greater amounts of intermittent generation.

This project proposes to:

- Review and critique existing flexibility metrics and tools now in use and under development by the utilities, CAISO, and others to quantify operating flexibility requirements and the residual resource needs not met by existing or already planned resources.
- Define new flexibility metrics, potentially novel ones, such as insufficient ramping capacity, that a system requires to balance loads and resources during different time intervals.
- Identify how to operationalize the flexibility metrics for long-term planning purposes, either as separate metrics or combined with existing reliability metrics, such as loss of load expectation (LOLE) or PRM requirement.
- Recommend whether new operating flexibility standards or modified reliability standards should be adopted to incorporate the increased need for operating flexibility with greater amounts of intermittent generation.
- Develop prototype new models or improvements to existing resource planning models that incorporate the proposed flexibility metrics with traditional production simulation and reliability models for use in evaluating the cost-effectives of different alternatives to meet identified system needs.

c) Utility Sponsors:

☒ PG&E ☐ SCE ☒ SDG&E

SCE is placing its highest priority on addressing utility cyber security issues. As such, SCE will not be supporting or allocating resources to the Flexibility Metrics and Standards project.

d) Potential Customer Benefits:

This project is expected to ultimately help:

- Reduce operating and capital costs.

- Improve reliability by reducing the uncertainty about the adequacy of planned resource to integrate greater amounts of intermittent renewables.
- Improve the efficient consideration in regulatory and stakeholder forums of planning issues related to the integration of renewable, including: (1) quantification of system operating requirements, (2) estimates of the contribution of different resources to meet those requirements, (3) quantification of system residual need for resources, and (4) evaluation of the cost-effectiveness of resources alternatives, including different operating flexibility policies or standards, with different operating attributes to meet residual system needs.

Since there is no universally adopted methodology or metrics to measure a system's operating flexibility, or to determine how much operating flexibility a system should have, the above potential benefits would be realized after the results from this research project are adopted and incorporated into operating practices and investment decisions. These benefits may depend on actions by regulatory and/or governing bodies to be fully realized.

e) Research Challenges and Hurdles to Overcome:

There is no consensus in the industry as to:

- How to measure operating flexibility.
- The types of operating flexibility a system with large amounts of intermittent generation requires to balance loads and resources.
- How operating flexibility requirements change as a function of the operating characteristics of its loads and resources.
- How to express the required operating flexibility in the context of existing planning and reliability metrics and standards used today.
- The contribution of existing and new resources to meet the system operating requirements, including demand response and energy storage.
- How to best determine the residual resource need, or the cost-effectiveness of resources with different operating attributes to meet those needs.

f) Unique Capabilities Offered by LLNL:

Developing a solution to these issues requires the formulation of metrics to guide operational decision-making, statistical analysis of the frequency and magnitude of ramping conditions, and the development of algorithms to operate the system taking into account the forecasts of ramping conditions. LLNL has developed extensive capabilities in the probabilistic forecasting of atmospheric conditions that will be the basis for applying the metrics and algorithms. LLNL has also been at the forefront of deploying stochastic unit commitment models and works closely with Energy Exemplar in the further development of such models. For example, LLNL recently concluded this November 2013 a study for the California Energy Commission to analyze the value of energy storage and demand response for renewable integration in California. LLNL has also established research relationships with the Power Systems Engineering Research

Consortium (PSERC), IBM, Energy Exemplar (Plexos developers), UC Berkeley, Princeton, and others. This provides an environment for development and deployment of advanced models and solution algorithms for grid management. In addition, the research will leverage over five decades of experience with high performance computing platforms and the associated ecosystem that supports them.

The problem requires a wide range of analysis capabilities including formulation of metrics, atmospheric modeling and operational modeling and decision-making. Substantial computational power is required to support these activities. This wide range of capabilities can be found with LLNL and its potential partners. As per the table below, alternate approaches will not achieve the goals of this proposal.

Alternatives	Assessment
Private consultants and power system software vendors	Generally have limited computational capability to evaluate alternative approaches
Universities	Usually cannot cover the range of capabilities needs, although the project expects to partner for specific requirements
Other National Laboratories	Do not have the combination of a wide range of atmospheric modeling, high performance computing, electricity production cost modeling, and experience in decision and operational modeling

g) Third Party Partnerships and solicitations:

Some aspects of this effort may be best performed by other parties. LLNL will seek partnerships with such parties according the standard operating procedures, including sole source and competitive solicitation, according the specific needs and market analysis.

h) Duplication and synergies:

This project has undergone preliminary due diligence to ensure no undue duplication of research with other CES-21 projects, IOU and CEC EPIC projects, and any other efforts.[2] The project team also intends to leverage related research and monitor new developments in this area to take advantage of potential synergies with other research initiatives.

[2] A letter dated January 21, 2014 from the California Energy Commission to Pacific Gas and Electric Company states that this business case has been reviewed and there is no duplication of effort.

2. Proposal Description

a) Background

Today, California's electric grid uses LOLE or PRM as reliability metrics. These metrics have corresponding standards or standards that serve as guidelines for electric resource planning.

Current reliability metrics and standards were developed for an electric grid that did not have as much non-dispatchable and intermittent resources as the future grid envisioned by California's Clean Energy Plan. The metrics that have historically been used to monitor and ensure a stable grid operation were designed in a different era that do not capture the range and diversity of available control mechanisms that would be present on the grid of the future, nor do they capture the inherent uncertainty and variability of new intermittent generation sources and load changes. Thus metrics that capture this and provide a broader scope of control options are needed.

There may be no simple "one size fits all" capacity level such as a PRM level, but instead a relationship or ratio between the amount of flexible capacity available to a system and the degree of variability and forecast uncertainty of that system's combined load and intermittent generation. Alternatively, it may be possible to express flexibility needs as a portion of the overall generation fleet. As a result, there is a need to update planning criteria, not only to integrate intermittent renewables. There is also a potential for greater volatility of demand due to distributed photovoltaic generation, price-sensitive customers using "smart meters", as well as potential for flexibility benefits from price-sensitive customers that should be considered.

The need for operationally flexible capacity (supply or demand-side) will depend on the characteristics of the electricity portfolio, including:

- System inertia available to the system, which affect the import levels into California.
- Variability and forecast uncertainty of electricity demand and variable electricity supplies.
- Correlation between variability of demand and supply.
- The availability of exiting flexible generation able to balance loads and resources continuously.

Today, CAISO and the utilities use off-the-shelf production simulation models to test the adequacy of the system to meet traditional operating reliability and new flexibility requirements under a given scenario. If resources are not adequate, the model estimates resource deficiencies, and after a trial and error process estimates the amount of conventional resources needed to clear resource deficiencies. Because simulations are time consuming, a day or more is needed to evaluate a single weather scenario for a single year. As a result, system analyses are often limited to single weather conditions and few load and resource scenarios, rather than performing a

stochastic simulation to properly account for reliability risks. In addition, modeling simplifications are made (such as use of hourly granularity instead of one-minute or five-minute granularity), which may result in an inadequate representation of actual system flexibility needs.

In Track 2 of the CPUC 2012 long-term procurement plan proceeding, the CAISO investigated the need for resources for several scenarios adopted by the CPUC for this proceeding, and found a need for as much as 5,378 MW of capacity in 2022.[3] Track 2 was intended to determine the system's flexibility needs. After opening a new Track 4 in the 2012 LTPP to study the need for resources created by the closure of the San Onofre Nuclear Generating Station (SONGS), and considering indications that system flexibility needs may be low or non-existent depending on the level of local capacity procurement authorized in the new Track 4, the CPUC decided to cancel or defer further consideration of system flexibility needs until the next LTPP cycle expected to start 2014.[4] Although CAISO, with the assistance of Energy+Environmental Economics, Inc. (E3), and others, and Southern California Edison Company have invested considerable time and effort developing new approaches to estimate the residual need for flexible resources, these approaches require further examination and development before the methodology and models built based on these approaches is accepted by parties in the next LTPP cycle and similar forums.

Similar efforts are under way or needed to define continued enhancements to resource adequacy (RA) requirements, including definition of rules for counting the contribution of resources for flexible and non-flexible or generic RA.[5] CAISO has also a parallel Flexible Resource Adequacy Criteria and Must-Offer Obligation initiative intended to implement the recently adopted flexible capacity requirements in the CPUC's June 2013 RA decision, while creating opportunities for all types of flexible capacity, including demand response, storage, and renewable resources to contribute to meet flexible capacity requirements. Those efforts unfortunately lack an agreed or adopted quantitative framework for measuring the contribution of resources (supply or demand-side resource) towards RA requirements.

b) Objective

This project will define new operating flexibility metrics and standards based on a probability measure of the occurrence, the magnitude, and the duration of ramping shortages at different time intervals. These metrics will be applied using production simulation and reliability models of the California system to determine their robustness

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[3] Upward ancillary service and load following shortage in the Replicating Transmission Planning Scenario. See CAISO's Deterministic Operational Flexibility Modeling Results

[4] Assigned Commissioner and Administrative Law Judge's ruling dated September 16, 2013.

[5] CPUC's Energy Division draft proposal to develop Qualifying Capacity (QC) and Effective Flexible Capacity (EFC) methodologies for energy storage (ES) and supply-side demand response (DR) resources dated September 16, 2013.

under a wide range of realistic scenarios of weather conditions, and loads and renewable generation scenarios.

The ability to meet upward and downward ramping requirements depends on the state of the generators at the time the ramp occurs (i.e., generator is online or committed and likely to be online when needed, and has the ability to ramp up or down given its expected operating level at the time flexibility is needed). The generator state, in turn, depends on the quality of forecasts information used for unit commitment and the dispatching procedures during the day.

c) Expected results

This project will develop new metrics to measure the probability that the system will be unable to ramp up and down quickly enough to meet the ramping events that are possible with high levels of renewables. If properly constructed and employed, such a metric could be used to assess the system's adequacy, and to provide insight as to the most efficient approaches to improving the system's ability to meet ramping events.

This project proposes to:

- Review and critique existing flexibility metrics and tools now in use and under development by the utilities, CAISO, and others to quantify operating flexibility requirements and the residual resource needs not met by existing or already planned resources.
- Define new flexibility metrics, potentially novel ones, such as insufficient ramping capacity, that a system requires to balance loads and resources during different time intervals.
- Recommend whether new operating flexibility standards or modified reliability standards should be adopted to incorporate the increased need for operating flexibility with greater amounts of intermittent generation.
- Identify how to operationalize the flexibility metrics for long-term planning purposes, either as separate metrics or combined with existing reliability metrics, such as LOLE or PRM requirement.
- Develop prototype new models or improvements to existing resource planning models that incorporate the proposed flexibility metrics with traditional production simulation and reliability models for use in evaluating the cost-effectives of different alternatives to meet identified system needs.

3. Market Research

CAISO Stochastic Model

In addition to running Plexos production simulations for individual load and resource scenarios, the California ISO has developed a stochastic simulation model to measure the probability of upward ramping deficiencies over ten- and twenty-minute time horizons using the uncertainty embedded in hourly inputs used for Plexos simulation, including loads, wind, solar and hydro generation, unit outages and intra-hourly flexibility

requirements (regulation and load following). The model has no unit commitment or chronological constraints. The model uses a single period of time where the conditions are similar in all hours of the period. The model considers only a single weather year since it relies on Plexos inputs for that weather year. It is not clear whether the model can measure other flexibility metrics for different time intervals or for downward direction.

A simulation is done over those random variables, and for each hour, generation is dispatched to meet the load and ramp. Inability to meet a ramping requirement is computed for each scenario in the simulation, thereby producing an expected MWh ramping shortfall.

The University College Dublin's Flexibility Metric

A group of academics at the University College Dublin have been working on designing flexibility metrics for power systems [Mark O'Malley et al]. This group has prepared a paper and a prototype model based on conversations PG&E has had with the group. The group is also working with another metric that addresses the shortcomings of the initial metric (such as not differentiating ramping deficiencies at different times during the day). The new metric takes a given fixed unit commitment schedule and computes the probability of not having enough flexibility over different time horizons. It accounts for the flexibility of units operating. However, it does not account for random forced outages. The prototype model is set up with flexibility source and sink nodes (representing intermittent generation and load on one hand, and flexible generators on the other) with a transmission system linking them. The Dublin group has limited resources and time to further develop flexibility metrics and build a fully operational model.

E3's simplified simulation model

E3 has recently developed a new model called REFLEX to estimate resource need first relative to a traditional 1-day-in -10 year loss of load metric and second after considering flexibility requirements expressed as "endogenous[6]" cost inputs that allows the model to consider flexibility costs in its economic commitment and dispatch. This is in contrast to an "exogenous" modeling of ramping proposed by the Dublin group. E3 only models California and does not account for transmission limitations between northern and southern California. E3 uses historical distributions of ramping from other transmission areas to model flows into and out of California. This is one of the simplifications of the model – compare this to the WECC-wide simulations models used today. A similar approach is used for hydro. Historical actual upward ramping and downward ramping distributions are used, and a point on those distributions is assumed as being available from hydro.

[6] Endogenous in the sense that all of the unit commitment and dispatch decisions (variables and constraints, if you prefer) are included in the same low-level optimization model with the modeling of the flexibility metric.

To simulate load, wind and solar and model the coupling between them, E3 groups the historical data into months, and then into low and high load days. Load is further grouped into working weekdays vs. weekends and NERC holidays. E3's model draws 24-hourly load, and wind and solar generation during the simulation, drawing from consistent bins (same month, and all three load, wind, and solar from either the high load or the low load bucket). The "high load" bin is smaller than the "low load" bin, so that the more extreme events are matched together. The flexibility is modeled by E3 as a convex function computed outside of the optimization and then approximated and incorporated into the optimization.

EPRI

The Electric Power Research Institute (EPRI) also has several ongoing projects related to system flexibility. The primary project is an effort to develop industry-wide standard flexibility metrics for planning purposes as well as tools which streamline the application of those metrics. While several general metrics and tools have been developed, the process of developing industry-consensus and applying these metrics in specific planning contexts is just beginning. Other EPRI projects seek to understand the ability of various resources and market designs to provide flexibility.

This project will consider the above and other new approaches to incorporate operating flexibility in commitment and dispatch decisions, and select an approach based on a preselected criteria, including accuracy and timely of results.

4. Research Approach Assessment

Challenge	Assessment	Reason
Meaningful definition of metrics that cover all circumstances of concern and are useful for operations	Medium	Progress has been made already. If more complex metrics are required, they can be accounted for in the operational modeling
Coupling the metric(s) with the day-ahead dispatch in base model	Medium	If necessary, iterative methods of computing robust solutions can be developed using parallel computing
Evaluating the practicality and usefulness of new operating flexibility standards to guide the planning of new resources	Medium	Flexibility standards require evaluating the trade-offs between the cost of acquiring additional flexibility for the system, and the cost or risks associated with not having sufficient flexibility

5. Research Team and Partnership Opportunities

Position	Name (organization)	Email
IOU Sponsor	Antonio Alvarez (PG&E)	aja6@pge.com
Research Director	Tom Edmunds (LLNL)	edmunds2@llnl.gov

Potential Partner	Reason for Partnering
Princeton University	Princeton's Castle Lab has developed sampling methods for identifying robust operational decisions by sampling multiple future states and accounting for possible future decisions. These are amenable to parallel computing
E3	Simplifications made by E3 can be reviewed and improved, and new capabilities added such as incorporating transmission constraints and improving the representation of certain inputs.
Astrape Consulting	Astrape Consulting developed a hybrid resource adequacy and production cost model named the Strategic Energy and Risk Valuation Model (SERVM) that stochastically simulates unit performance, weather conditions, load growth uncertainty, and resource outages.
EPRI	Research will expedite the timeline planned to deliver new metrics and models now planned by EPRI for completion in 3 to 4 years
University College, Dublin	Has conducted research on similar problems.

6. Implementation Plan and Schedule

a) Work plan

This project will define the objectives and the requirements for flexibility metrics. Several candidate mathematical forms will be developed along with proposed algorithms or methods for computing the metrics. The approaches may be analytic or simulation based. Analytic approaches combine the statistics over rates and duration of load ramps, with the statistics over available ramping capability to estimate the probability that the required ramp rates exceed the available ramping capacity. Simulation approaches will test a series of days (over several years) with statistically valid forecasts, and generator dispatch scenarios to directly observe the frequency of insufficient ramping.

Phase 1: Define problem and characteristics of tools needed to address the problem (PM1-2)

In this first phase, the project will define the problem and review methodologies and analytical tools that could be used to solve the problem. The purpose of this initial step is to develop a clear description of the analytical

framework that will be used to design a methodological and modeling approach to design flexibility metrics. Traditional reliability modeling addresses the analytical question regarding the amount of capacity that satisfies a reliability target such as a one day in 10 years outage expectation or that equalizes the cost of adding new generation resources with the corresponding reduction in outage costs. This question is addressed in a stochastic environment where shortfalls in available generating capacity relative to customer load are assessed based on distributions of weather conditions driving customer loads and generating unit unavailability. In a generating system in which there is a substantial risk of customer outages or equipment damage due to insufficient operating flexibility to balance loads and resources (even when there is enough capacity overall), resource expansion questions need to consider not only capacity shortfalls and but also operating flexibility shortfalls such as insufficiently ramping up and down capability to balance loads and resources, as well as the cost of meeting these shortfalls with changes in unit commitment or dispatch, or operating flexibility policies or standards. The question of what operating flexibility metrics and standards to use for planning will be addressed in a stochastic environment that additionally considers the weather uncertainty affecting loads and intermittent resources.

Major tasks:

1) (IOU, LLNL) Gather and analyze pertinent data.
2) (IOU, LLNL) Decide characteristics of methodology and analytical tools needed to solve the problem.
3) (IOU, LLNL) Determine if and how to incorporate findings from current efforts in flexibility (SCE study, CAISO/E3, and others as applicable.)

Phase 2: Select a base model (PM1-4)

Based on the characteristics identified in the prior phase, select a base model. In this phase the project will review and critique existing flexibility metrics and tools now in use and under development by the utilities, CAISO, and others to identify gaps or shortfalls in metrics. For purposes of providing a cost estimate, we will assume Plexos is the base model, given CAISO and IOU experience with the model and LLNL's past use of Plexos for its probabilistic analysis of demand response and energy storage for the CEC completed in 2013. The base model may change depending upon the results of Phase 1. However, for purposes of planning the phases below, and estimating the project's cost, we assume this project uses Plexos and builds on the work done by LLNL for the CEC

Major tasks:

1) (IOU, LLNL, CAISO, consultant) Review and critique existing flexibility metrics and tools now in use and under development in consultation with CAISO and model vendors.

2) (IOU, LLNL, CAISO, consultant) Select base model in consultation with CAISO.

Phase 3: Develop the infrastructure to generate multiple weather dependent data (load, hydro, wind, solar) (PM1-11)

Due to budget considerations, the project will leverage LLNL's previous work for the CEC and use the Weather Research and Forecasting (WRF) model to reproduce a range of temperature, wind and solar conditions prevailing in California and the Western Electricity Coordinating Council (WECC) for 30 scenarios to build 6 weather ensembles for each of two different weather years. A third weather year will be included if resources allow. Leveraging LLNL's scripts already developed for the CEC project, weather parameters for these scenarios will be used to generate load, wind and solar generation for Plexos simulations. Load and intermittent generation would have 5-minute interval inputs for Plexos.

Major tasks:

1) (LLNL) Develop the infrastructure and generate multiple weather dependent data for 6 weather ensembles for up to three different weather years.

Phase 4: Develop the infrastructure to automate the running of many scenarios in batch mode through the optimizer (PM5-7)

Set up model so it can be run in batch mode with dozens of predefined scenarios. Use this to produce several scenarios that can be analyzed manually, and in the future by using the prototype code developed in later phases of the project, and used to begin gaining insight into what a long term procurement plan should look like. Develop methods to automate storage of the results into a database or other convenient form for subsequent analysis. Due to budget considerations, the project will leverage the team's experience and run the weather scenarios in Plexos. The scenarios will be then aggregated and weighted based on the weight assumed for each weather year. Plexos will perform a day-ahead unit commitment and 5 minute economic dispatch. Instead of using a stochastic unit commitment considering the 30 weather scenarios available for an hour of a weather year, each of the 30 scenarios will be run separately considering Monte Carlo outages and operating flexibility requirements calculated based on the uncertainty represented by the 30 scenarios in a weather year.

Major tasks:

1) (LLNL) Set up selected model; gather test data.
2) (LLNL) Develop code to speed up run time and manage storage inputs/output.

Phase 5: Develop Candidate Flexibility Metrics (PM1-10)

Based on the previous phase's results, the appropriate models and simulation codes will be developed or extended – leveraging existing products whenever possible. Methods will help determine which metrics can best communicate the system's flexibility requirements, and how the metrics can then be adjusted or changed as necessary in the future as the system changes.

In this phase, the project will review prior flexibility metrics used by CAISO, utilities and others to represent the flexibility requirements of the system that need to be considered for commitment and dispatch purposes. Two flexibility metrics will be used and tracked: Net Load Following and Net Load Ramping, as explained below.

Major tasks:

1) (IOU, LLNL) Develop a prototype Net Load Following metric in consultation with CAISO. This metric would define the additional flexible capacity that the system needs to respond to variability and forecast uncertainty of net load within the operating day (intra-day and intra-hourly), which is not already covered by the Frequency Response or Regulation metrics. This load following metric would identify needs for flexible capacity that can be re-dispatched or started within minutes to manage the remaining operating variability and forecast uncertainty not covered by frequency and AGC responsive capacity. Sources of flexible capacity to satisfy a selected load following standard will also include supply- and demand-side alternatives.
2) (IOU, LLNL) Develop a prototype Net Load Ramping metric in consultation with CAISO. This metric would define the additional flexible capacity that the system needs to balance a forecasted net load for the operating day or a commitment period, which is not already covered by the Frequency Response, Regulation metrics, or Net Load Following metrics, which are intended to measure the intra-hour variability and forecast uncertainty from day-ahead or commitment times.

Phase 6: Develop a prototype model to calculate flexibility metrics (PM11-13)

The prototype model is stand-alone code intended to calculate the supply and demand for flexibility for the selected metrics, the expected deficiencies and probability of deficiencies of flexible capacity. In this phase, the code will track and calculate the flexibility metric deficiencies, but will not yet be integrated with the unit-commitment and dispatch model.

The inputs to the metrics prototype are: (1) the unit commitment and dispatch coming out of a Plexos run, showing the available flexible capacity to meet the flexibility requirements at different time intervals (say every hour or 15 minutes) for different time horizons (e.g., 5 min, 15 min, 1 hour, 2 hours, etc.), and (2) the distribution of loads and intermittent generation at the end of each

time horizon for each of the 30 weather paths considered in each weather year from which the demand for flexibility is calculated for each time horizon.

The output is the expected amount of various types of "flexibility not served" in MW per hour considering the 30 weather scenarios, and the probability of any flexibility not being served. Both upward and downward flexibility metrics will be calculated for various assumed flexibility standards to inform a future development of flexibility standards.

Major tasks:

1) (LLNL, consultant or model vendor) Develop code to calculate flexibility metrics, and benchmark flexibility metrics calculated from existing reduced order models developed by current efforts (SCE study, CAISO/E3, and others as applicable).

Phase 7: Integrate the flexibility metric prototype with the base model (P12-16)

Initially, we anticipate an iterative process using LLNL's HPC with a separate code that: 1) takes the inputs from the unit commitment and dispatch model and from the flexibility metric prototype model developed in prior phases, and 2) decides whether to change the unit commitment and dispatch to minimize costs after satisfying the flexibility standards given the marginal cost of flexibility.

The ultimate goal is to integrate the selected flexibility metrics and standards into a larger optimization which can be solved on workstations used by the utilities, CAISO and other parties in 4 hours per weather year. The project will suggest ways to reduce run such as: 1) clustering the 30 weather scenarios into 6 scenarios, as LLNL did for the CEC Project, 2) simplifying the representation of the system without losing significant accuracy, and 3) running and archiving cases off-line that support interpolation routines.

Major tasks:

1) (LLNL, consultant or model vendor) Integrate the flexibility metric prototype.

Phase 8: Test and evaluate the results from the three-model integrated optimization (PM17-18)

In this phase, the results from the integrated optimization will be tested and evaluated. Further adjustments to the code may be necessary as part of this phase. As a first step in validation we will run the new flexibility metrics on two very different grid configurations (e.g. different amounts of non-dispatchable generation). The metrics should reveal this difference. For the purposes of this project, evaluation criteria will be qualitative. Additionally, the project will develop an approach for conducting more rigorous quantitative validation,

including metrics sensitivity to inputs. As with any research project, unforeseen obstacles and unexpected results may arise. Any significant changes in direction, scope, timeline, or budget will be handled according to established CES-21 practices.

Major tasks:

1) (IOU, LLNL, consultant or model vendor) Select or build grid test case scenarios/models.
2) (IOU, LLNL, consultant or model vendor) Test and evaluate the results based on qualitative criteria.
3) (IOU, LLNL, consultant or model vendor) Develop approach for quantitative validation and sensitivity analyses.

Phase 9: Document the model (PM12-18)

Major tasks:

1) (IOU, LLNL, consultant or model vendor) Document new or improved model. Documentation will be developed as prototype versions are developed and tested, and assembled into a single document for users in the last 2 months of the project.

b) Milestones/Deliverables

Phase	Type	Description	Due Date	Responsible
1	Milestone	Define problem and characteristics of needed tools	PM 2	IOU, LLNL
2	Milestone	Select Base Model	PM 4	IOU, LLNL
3	Deliverable	Software infrastructure to generate multiple weather dependent data (load, hydro, wind, solar) to input into selected base model (prototype code).	PM7	LLNL
4	Deliverable	Software infrastructure to automate the running of many scenarios in selected model (prototype code)	PM7	LLNL
5	Deliverable	Flexibility metrics report	PM10	IOU, LLNL
6	Deliverable	Software to calculate the expected amounts and probability of flexibility deficiencies (prototype code at LLNL)	PM13	LLNL
7	Deliverable	Software to optimize commitment and dispatch that integrates the flexibility metrics (prototype code)	PM16	LLNL
8	Milestone	Software tested and sample produced for agreed scenarios	PM18	LLNL, IOU

Phase	Type	Description	Due Date	Responsible
9	Deliverable	Final project report with model documentation and recommendations for future work	PM18	LLNL, IOU

c) Resource requirements

The proposed project will require five persons with different levels of involvement for different times during the project's duration. This estimate includes individuals from LLNL, PG&E, and potential partner resources.

These individuals will be supported by utility staff to the extent needed, also at various times during the duration of the project. The five individuals will include:

- Project lead
- Weather modeler
- Production simulation modeler
- Computer scientist
- Report writer/editor

7. Cost Estimate

The total budget for this Grid Integration Business Case estimated for an 18 month period is $2,000,000, which is divided in six month periods and shown in the following table. Management administrative expenses will be limited to 10% of the total CES-21 budget and is spread over CES-21 management of MMATR and Grid Integration tasking. The Joint IOU Program Managers will move task dollars between years or into additional years as needed dependent on task completion. The Joint IOU Program Managers will seek CPUC approval if there is more than a 5% spending shift proposed between categories proposed in the MMATR or Grid Integration Business Cases as submitted in this Advice Letter.

Entity	PM1-6	PM7-12	PM13-18	Total ($k)
LLNL and subcontract labor	500	550	800	1,850
Utility labor	50	50	50	150
Total	550	600	850	2,000

8. Benefits of Proposed Project

a) Benefits estimate

If successful, with the adoption of flexibility metrics and standards by the CAISO and others for operating and investment decisions, this project will ultimately help:

- Reduce operating and capital costs.
- Improve reliability by reducing uncertainty about the adequacy of planned resource to integrate greater amounts of intermittent renewables.
- Improve the efficient consideration in regulatory and stakeholder forums of planning issues related to the integration of renewable, including: (1)

quantification of system operating requirements, (2) estimates of the contribution of different resources to meet those requirements, (3) quantification of system residual need for resources, and (4) evaluation of the cost-effectiveness of resources alternatives, including different operating flexibility policies or standards, with different operating attributes to meet residual system needs.

Improving the accuracy of flexible resource need determination could result in substantial benefit to California electricity consumers. Improved understanding of flexibility needs may provide insight into the how to best take advantage of existing and new alternatives such as energy storage. Illustrative benefits for this project were quantified in the IOUs rebuttal testimony field in connection with the CES-21 application.[7]

b) The proposed project may lead to technological advancement

As a national energy policy leader, it is critically important for California to support cutting edge research and development (R&D) in the area of grid integration, particularly with respect to grid integration of renewable resources. This is an area for further investment in order to move from the current levels of renewable resource integration, to a much larger scale integration including the levels outlined in California's Renewable Portfolio Standard of 33% renewables integration by 2020.

Grid integration is a "cross cutting" research category that relates to electric resource planning and electric system operations, two of the four original research categories previously adopted in D.12-12-031. The challenges of grid integration, particularly with respect to grid integration of renewable resources, are widely recognized as an important research area for the state. In particular, in order to achieve important environmental goals, California's electric system is going through a significant transformation, replacing conventional generation with increasing amounts of intermittent renewable resources, and other resources that have limited operating flexibility.

While all of the research topics proposed by the utilities under the electric resource planning and electric system operations categories enable improved grid integration of renewable resources, the Flexibility Metrics and Standards project, as previously adopted, is an essential building block and is anticipated to provide benefits to customers through improved long term resource planning.

[7] Decision 12-12-031, p. 2.

In light of the revised research funding cap established by SB 96, the utilities have narrowed the scope of the initially proposed Flexibility Metrics and Standards project. Specifically, the Flexibility Metrics and Standards project is intended to:

- Review and critique existing flexibility metrics and tools now in use and under development by the utilities, CAISO, and others to quantify operating flexibility requirements and the residual resource needs not met by existing or already planned resources.
- Define new flexibility metrics, potentially novel ones, such as insufficient ramping capacity, that a system requires to balance loads and resources during different time intervals.
- Recommend whether new operating flexibility standards or modified reliability standards should be adopted to incorporate the increased need for operating flexibility with greater amounts of intermittent generation.
- Identify how to operationalize the flexibility metrics for long-term planning purposes, either as separate metrics or combined with existing reliability metrics, such as LOLE or PRM requirement.
- Develop prototype new models or improvements to existing resource planning models that incorporate the proposed flexibility metrics with traditional production simulation and reliability models for use in evaluating the cost-effectives of different alternatives to meet identified system needs.

c) The proposed projects may lead to potential breakthroughs in grid integration

New operating flexibility metrics are needed for long-term resource planning in California. Improvements to methodologies and existing models, or new models, are also needed to reduce the cost and/or the uncertainty about the resource adequacy of planned resources to integrate greater amounts of intermittent renewables. Improvements to methodologies and models are also needed to facilitate the consideration and decision making in regulatory and stakeholder processes of planning issues related to the integration of renewable resources, including: (1) quantification of system operating requirements, (2) estimates of the contribution of different resources to meet those requirements, (3) quantification of system residual need for resources, and (4) evaluation of the cost-effectiveness of resources alternatives with different operating attributes to meet residual system needs.

Traditional resource planning methods have used reserve margin metrics and standards, expressed as a percentage of forecast electric demand, to ensure that enough capacity is procured and available for operating the system. In the past, because of the small amounts of renewables in the system, the uncertainty and intermittency of generation like wind and solar was dwarfed by the uncertainty in electric load. Also, in the past, conventional resource additions provided the operating flexibility required by the uncertainty and intermittency of electric load.

SB 96 requires the Commission to ensure that the research parameters reflect a new contribution to cyber security and grid integration and that there is not a duplication of research being done by other private and governmental entities. Although the California Independent System Operator, the California Energy Commission, and others, have invested in efforts to develop new stochastic approaches to estimate the residual need for flexible resources, these approaches require further examination and development before the methodology and models built based on these approaches are ready for use in resource planning or policy decisions. In particular, this research project is targeting potential breakthroughs to determine:

- Weather uncertainty effects on customer load and renewable generation;
- The electric grid's operational flexibility requirements; and
- Operating limits of the existing or planned grid to integrate additional amounts of intermittent renewable generation
- Additional resources and cost to integrate additional renewable generation.

These breakthroughs would significantly enhance existing planning methodologies and models to facilitate the assessment and implementation of future energy policy initiatives and help achieve California's ambitious environmental goals.

Attachment 2

CES-21 CRADA

This draft CRADA is preliminary and is subject to approval by the National Nuclear Security Administration.

STEVENSON-WYDLER (15 USC 3710)
COOPERATIVE RESEARCH AND DEVELOPMENT AGREEMENT

Between

LAWRENCE LIVERMORE NATIONAL SECURITY, LLC

and

PACIFIC GAS & ELECTRIC COMPANY

and

SOUTHERN CALIFORNIA EDISON COMPANY

and

SAN DIEGO GAS & ELECTRIC COMPANY

For

The 21st Century Energy Systems Project

LLNL Case No. TC02200.0

Lawrence Livermore National Laboratory
Lawrence Livermore National Security, LLC, Livermore, CA 94551
Industrial Partnerships Office
April 11, 2013

This draft CRADA is preliminary and is subject to approval by the National Nuclear Security Administration.

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STEVENSON-WYDLER (15 USC 3710)
COOPERATIVE RESEARCH AND DEVELOPMENT AGREEMENT
(hereinafter CRADA) NO. TC02200.0

between

LAWRENCE LIVERMORE NATIONAL SECURITY, LLC
under its U.S. Department of Energy Contract No. DE-AC52-07NA27344

and

PACIFIC GAS & ELECTRIC COMPANY

and

SOUTHERN CALIFORNIA EDISON COMPANY

and

SAN DIEGO GAS & ELECTRIC COMPANY

for

The 21st Century Energy Systems Project

This CRADA is between Lawrence Livermore National Security, LLC (hereinafter referred to as "LLNS"), a limited liability company incorporated in the State of Delaware and having its statewide administration address 2300 First Street, Suite 204, Livermore, California 94550-3153, Pacific Gas & Electric Company (hereinafter referred to as "PG&E"), a California corporation having its principal place of business at 77 Beale Street, San Francisco, California 94177, Southern California Edison Company (hereinafter referred to as "SCE"), a California corporation having its principal place of business at 2244 Walnut Grove Avenue, Rosemead, California 91770 and San Diego Gas & Electric Company (hereinafter referred to as "SDG&E"), a California corporation having its principal place of business at 8326 Century Park Court, San Diego, California 92123. PG&E, SCE and SDG&E are each hereinafter referred to as a "Participant" to this CRADA and jointly referred to as the "Participants" to this CRADA. LLNS, PG&E, SCE, and SDG&E are each hereinafter referred to as a "Party" or collectively as the "Parties" to this CRADA.

LLNS is entering into this CRADA under the National Competitiveness Technology Transfer Act of 1989 (15 USC 3710) and the terms of its Contract No. DE-AC52-07NA27344 with the United States Department of Energy (DOE) for the operation of the Lawrence Livermore National Laboratory (LLNL). Work to be performed by LLNS employees is expected to be at the LLNL facility, owned by DOE, at 7000 East Avenue, Livermore, California 94550.

Article I. Definitions

A. "Government" means the Federal Government of the United States of America and agencies thereof.

B. "DOE" means the Department of Energy, an agency of the Federal Government.

C. "Contracting Officer" means the DOE employee administering LLNS's DOE contract.

D. "Generated Information" means information produced in the performance of this CRADA.

E. "Proprietary Information" means information which embodies (i) trade secrets or (ii) commercial or financial information which is privileged or confidential under the Freedom of Information Act (5 USC 552 (b)(4)), either of which is developed at private expense outside of this CRADA and which is marked as Proprietary Information.

F. "Other Protected Information" means information separate and apart from "Proprietary Information" and "Protected CRADA Information" which is (i) not developed at Government expense, (ii) clearly marked as being protected from public disclosure or other uses or (iii) is defined as privileged or confidential under the Freedom of Information Act (5 USC 552 (b)(4)).

G. "Protected CRADA Information" means Generated Information which is marked as being Protected CRADA Information by a Party to this CRADA and which would have been Proprietary Information had it been obtained from a non-federal entity.

H. "Subject Invention" means any invention of LLNS or Participant conceived or first actually reduced to practice in the performance of work under this CRADA.

I. "Intellectual Property" means Patents, Copyrights, Trademarks, Mask Works, Protected CRADA Information, and other forms of comparable property rights protected by Federal Law and other foreign counterparts, except trade secrets.

J. "Trademark" means a distinctive mark, symbol, or emblem used in commerce by a producer or manufacturer to identify and distinguish its goods or services from those of others.

K. "Service Mark" means a distinctive word, slogan, design, picture, symbol or any combination thereof, used in commerce by a person to identify and distinguish its services from those of others.

L. "Mask Work" means a series of related images, however fixed or encoded, having or representing the predetermined, three-dimensional pattern of metallic, insulating, or semiconductor material present or removed from the layers of a semiconductor chip product; and in which series the relation of the images to one another is that each image has the pattern of the surface of one form of the semiconductor chip product (17 USC 901(a)(2)).

M. "Background Intellectual Property" means the Intellectual Property identified by the Parties in Appendix C, Background Intellectual Property, which was in existence prior to or is first produced outside of this CRADA, except that in the case of inventions in those identified items, the inventions must have been conceived outside of this CRADA and not first actually reduced to practice under this CRADA to qualify as Background Intellectual Property.

Article II. Statement of Work

Appendix A, Statement of Work, is an integral part of this CRADA. The work to be performed under this CRADA is on a "BEST EFFORTS BASIS" by the Parties.

Article III. Term, Funding & Costs

A. The effective date of this CRADA shall be the latter date of (1) the date on which it is signed by the last of the Parties, or (2) the date on which it is approved by DOE. The work to be performed under this CRADA shall be completed within five (5) years from the effective date.

B. The total estimated project cost is Thirty Five Million Dollars ($35,000,000). PG&E's estimated cost is Seventeen Million, Five Hundred Thousand Dollars ($17,500,000).SCE's estimated cost is Fourteen Million, Three Hundred Fifty Thousand Dollars ($14,350,000). SDG&E's estimated cost is Three Million, One Hundred Fifty Thousand Dollars ($3,150,000).

C. No Party shall have an obligation to continue or complete performance of its work at a contribution in excess of its estimated contribution as contained in Article III, Paragraph B, including any subsequent amendment.

D. Each Party agrees to use reasonable efforts to provide at least thirty (30) days notice to the other Parties if the actual cost to complete performance will exceed its estimated cost.

E. Advance funding sufficient to finance ninety (90) days of work shall be paid by the Participants before the work shall commence. Sufficient advance funds shall be provided to maintain a continuous ninety (90) days of advance funding during the life of the project. Failure to provide such advance funding is cause for CRADA termination. This CRADA contemplates Participants funding prior to the performance and completion by LLNS of its obligations hereunder. Such funding shall not constitute any form of acceptance or waiver by the Participants of any available legal or equitable rights or remedies, whether involving refunds, damages or otherwise.

Article IV. Personal Property

All tangible personal property produced or acquired under this CRADA shall become the property of the Participant whose funds were used to obtain it. No Government funds shall be used to produce or acquire tangible personal property under this CRADA. Such property is identified in Appendix A, Statement of Work. Personal Property shall be disposed of as directed by the owner at the owner's expense. All jointly funded property shall be owned by those

Participants that have contributed funding to acquire the specific property, with ownership to be proportional to the Participant's contribution to the funding that was used to acquire the specific property.

Article V. Disclaimer

THE GOVERNMENT, THE PARTICIPANTS, AND LLNS MAKE NO EXPRESS OR IMPLIED WARRANTY AS TO THE CONDITIONS OF THE RESEARCH OR ANY INTELLECTUAL PROPERTY, GENERATED INFORMATION, OR PRODUCT MADE OR DEVELOPED UNDER THIS CRADA, OR THE OWNERSHIP, MERCHANTABILITY, OR FITNESS FOR A PARTICULAR PURPOSE OF THE RESEARCH OR RESULTING PRODUCT. NEITHER THE GOVERNMENT, THE PARTICIPANTS, NOR LLNS SHALL BE LIABLE FOR SPECIAL, CONSEQUENTIAL OR INCIDENTAL DAMAGES ATTRIBUTED TO SUCH RESEARCH OR RESULTING PRODUCT, INTELLECTUAL PROPERTY, GENERATED INFORMATION, OR PRODUCT MADE OR DEVELOPED UNDER THIS CRADA. FURTHER, NEITHER THE GOVERNMENT, THE PARTICIPANTS, NOR LLNS SHALL BE LIABLE FOR INDIRECT OR PUNITIVE DAMAGES TO THE EXTENT ALLOWED BY LAW. WITHOUT LIMITING THE GENERALITY OF THE FOREGOING, NEITHER OF THE PARTICIPANTS NOR LLNS SHALL HAVE ANY (A) DUTY HEREUNDER TO INVESTIGATE WHETHER ANY OF THEIR RESPECTIVE BACKGROUND INTELLECTUAL PROPERTY, TRADE SECRETS OR INTELLECTUAL PROPERTY INFRINGES UPON ANY THIRD PARTY PATENT, TRADEMARK, COPYRIGHT, TRADE SECRET OR OTHER INTELLECTUAL PROPERTY RIGHT EXCEPT WHERE NOTICE HAS BEEN GIVEN THAT A USE MAY BE INFRINGING BY A THIRD PARTY OR (B) OBLIGATION OF INDEMNIFICATION, DEFENSE OR OTHER LIABILITY HEREUNDER IN THE CASE OF ANY ACTUAL OR ALLEGED INFRINGEMENT THEREOF, EXCEPT WHERE USE IS MADE AFTER A NOTIFICATION OF POTENTIAL INFRINGEMENT AND WITHOUT A GOOD FAITH DETERMINATION THAT THE USE DOES NOT INFRINGE ON SUCH THIRD PARTY'S RIGHTS.

Article VI. Product Liability

The Participants will indemnify the Government and LLNS for all damages, costs and expenses, including attorney's fees, arising from personal injury or property damage occurring as a result of the making, using or selling of a product, process or service by or on behalf of a Participant, its assignees, or licensees except for LLNS pursuant to Article XV.B and C, which was derived

from the work performed under this CRADA. In respect to this Article, neither the Government nor LLNS shall be considered assignees or licensees of any Participant, as a result of reserved Government and LLNS's rights, except for LLNS pursuant to Article XV.B and C. The indemnity set forth in this paragraph shall apply only if Participant shall have been informed as soon and as completely as practical by LLNS and/or the Government of the action alleging such claim and shall have been given an opportunity, to the maximum extent afforded by applicable laws, rules, or regulations, to participate in and control its defense, and LLNS and/or Government shall have provided all reasonably available information and reasonable assistance requested by Participant. No settlement for which a Participant would be responsible shall be made without such Participant's consent unless required by final decree of a court of competent jurisdiction.

Article VII. Obligations as to Proprietary Information and Other Protected Information

A. Each Party agrees to not disclose Proprietary Information and Other Protected Information provided by another Party to anyone other than the CRADA Participants and LLNS without written approval of the providing Party, except (1) to Government employees who are subject to the statutory provisions against disclosure of confidential information set forth in the Trade Secrets Act (18 USC 1905) or (2) when required in order to comply with any regulatory or legal requirement applicable to a Party to this Agreement; provided however, any such disclosure shall be subject to prior written notice to the owner of the Proprietary Information or Other Protected Information.

B. If Proprietary Information or Other Protected Information is orally disclosed to a Party, it shall be identified as such, orally, at the time of disclosure and confirmed in a written summary thereof, appropriately marked by the disclosing party, within thirty (30) days as being Proprietary Information or Other Protected Information.

C. All Proprietary Information and Other Protected Information shall be protected from the effective date of this CRADA, unless such Proprietary Information or such Other Protected Information: (1) becomes publicly known without the fault of the recipient, (2) shall come into recipient's possession without breach by the recipient of any of the obligations set forth herein, or (3) is independently developed by recipient's employees who did not have access to such Proprietary Information or Other Protected Information.

D. Proprietary Information and Other Protected Information in tangible form shall be returned to the disclosing Party or destroyed with a certificate of destruction submitted to the disclosing Party upon termination or expiration of this CRADA, or during the term of this CRADA upon request by the disclosing Party.

Article VIII. Obligations as to Protected CRADA Information

A. Each Party may designate as Protected CRADA Information, any Generated Information produced by its employees which is generated with any Participant funds pursuant to this CRADA and meets the definition of Article I.G and, at the request of any Party, will so designate any Generated Information which meets the definition of Article I.G. All such designated Protected CRADA Information shall be appropriately marked.

B. For a period of five (5) years from the date Protected CRADA Information is produced, the Parties agree not to further disclose such Protected CRADA Information except:

(1) as necessary to perform this CRADA;

(2) as provided in Article XI (Reports and Abstracts);

(3) as requested in writing by the DOE Contracting Officer to be provided to other DOE facilities for use only at those DOE facilities with the same protection in place;

(4) as reasonably required in order to comply with any regulatory or legal requirement applicable to a Party to this CRADA; or

(5) as mutually agreed in writing by the Parties in advance.

C. The obligations of Paragraph B shall end sooner for any Protected CRADA Information which shall: (1) become publicly known without fault of any Party, (2) shall come into a Party's possession without breach by that Party of the obligations of Paragraph B, or (3) shall be independently developed by a Party's employees who did not have access to the Protected CRADA Information.

Article IX. Rights in Generated Information

The Parties agree that they shall have no obligations of nondisclosure or limitations on their use of, and the Government shall have unlimited rights in, all Generated Information produced and information provided by the Parties under this CRADA, except for (a) information which is marked as being Copyrighted (subject to Article XIII) or as Protected CRADA Information (subject to Article VIII, Paragraph B) or as Proprietary Information or Other Protected Information (subject to Article VII), or (b) information that discloses a Subject Invention.

Article X. Export Control

THE PARTIES UNDERSTAND THAT MATERIALS AND INFORMATION RESULTING FROM THE PERFORMANCE OF THIS CRADA MAY BE SUBJECT TO EXPORT CONTROL LAWS AND THAT EACH PARTY IS RESPONSIBLE FOR ITS OWN COMPLIANCE WITH SUCH LAWS.

Article XI. Reports and Abstracts

A. The Parties agree to produce the following deliverables, subject to any applicable restrictions on disclosure as provided in this CRADA:

(1) an initial abstract suitable for public release at the time this CRADA is approved by DOE;

(2) other abstracts (final when work is complete, and others as substantial changes in scope and dollars occur);

(3) a final report, upon completion or termination of this CRADA, to include a list of Subject Inventions;

(4) [Reserved]

(5) other topical/periodic reports where the nature of research and magnitude of dollars justify; and

(6) computer software in source and executable object code format as defined within the Statement of Work or elsewhere within this CRADA documentation.

Each of the above-identified deliverables shall include the project identification number as described in DOE's Research and Development (R&D) Tracking System Data and Process Guidance Document (http://www.osti.gov/rdprojects/guidance.jsp). The Parties acknowledge that no financial report of the Participants' in-kind contributions to the project are required. LLNL represents that no financial reports of the Participants' in-kind contributions are required under LLNL's Contract No. DE-AC52-07NA27344 with the United States Department of Energy (DOE) or this CRADA.

B. The Parties acknowledge that LLNS has the responsibility to provide the above information at the time of its completion to the DOE Office of Scientific and Technical Information, with the appropriate marking in place as may apply to the information generated under this CRADA. LLNL will provide all Participants with a copy of the above information to the extent permitted by contract or law.

C. The Participants agree to provide the above information, appropriately marked, to LLNS to enable full compliance with Paragraph B of this Article, with the understanding that the LLNS will assure that the appropriate marking required for information under this CRADA remains in place before the information is disclosed to DOE or others as further described in Paragraph B of this Article.

D. The Parties acknowledge that LLNS and DOE have a need to document the long-term economic benefit of the cooperative research being done under this CRADA. Therefore, the Participants shall respond to LLNS's reasonable requests, during the term of this CRADA and for a period of three (3) years thereafter for pertinent information. LLNS shall respond to Participants' reasonable requests, during the term of this CRADA and for a period of three (3) years thereafter for pertinent information.

Article XII. Pre-Publication and Pre-Release Review

A. The Parties anticipate that their employees may wish to publish technical developments and/or research findings generated in the course of this CRADA and that reports will be provided to the DOE as described in Article XI above. On the other hand, the Parties recognize that an objective of this CRADA is to provide business advantages to the Participants. In order to reconcile publication/DOE reporting requirements and business concerns, the Parties agree to a review procedure as follows:

1. Each Party ("Submitter") shall submit to the other Parties ("Recipients"), in advance, proposed written and oral publications pertaining to work under this CRADA and all reports intended to be submitted to the DOE as described in Article XI above. Proposed oral publications shall be submitted to Recipients in the form of a written presentation synopsis and a written abstract.

2. The Recipients shall provide a written response to the Submitter within thirty (30) days, either objecting or not objecting to the proposed publication or report to be provided to the DOE. The Submitter shall consider all objections of the Recipients and shall not unreasonably refuse to incorporate the suggestions and meet the objections of the Recipients. The proposed publication or report to be provided to the DOE shall be deemed not objectionable for purposes of this provision, unless the proposed publication contains Proprietary Information, Other Protected Information, Protected CRADA Information, a Subject Invention, Intellectual Property, export control information, or material that would create potential statutory bars to filing the United States or corresponding foreign patent applications, in which case express written permission shall be required for publication.

B. The Parties agree that no Party will use the name of another Party or its employees in any promotional activity, such as advertisements, with reference to any product or service resulting from this CRADA, without prior written approval of the other Party.

Article XIII. Copyrights

A. The Parties may assert Copyright in any of their Generated Information. Assertion of Copyright generally means to enforce or give any indication of an intent or right to enforce such as by marking or securing Federal registration.

B. Ownership and authority to license Copyrights first arising or created under this CRADA is allocated in Appendix A of this CRADA.

C. In the absence of any allocation of rights to the ownership and authority to license Copyrights in Appendix A of this CRADA, Copyrights to original information for which authorship takes place during the performance of work under this CRADA shall be jointly owned and licensed by the Participants, subject to any obligation of protection as

required in Articles VII and VIII, and other provisions of this Article. The Participants hereby grant to LLNS a nonexclusive, nontransferable, irrevocable, paid-up Copyright license to reproduce, prepare derivative works, and perform publicly and display publicly all Copyrightable works produced in the performance of this CRADA, subject to the restrictions this CRADA places on disclosure of Proprietary Information, Protected CRADA Information, and Subject Inventions .

D. For Generated Information, the Parties acknowledge that the Government has for itself and others acting on its behalf, a royalty-free, nontransferable, nonexclusive, irrevocable, worldwide Copyright license to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the Government, all Copyrightable works produced in the performance of this CRADA for research and development purposes, subject to the restrictions this CRADA places on publication of Proprietary Information and Protected CRADA Information.

E. For all Copyrighted computer software produced in the performance of this CRADA, the Party owning the Copyright will provide the source code, an expanded abstract as described in Appendix B, Energy Science and Technology Software Center, the executable object code and the minimum support documentation needed by a competent user to understand and use the software, to DOE's Energy Science and Technology Software Center, P. O. Box 62, Oak Ridge, TN 37831-1020. The expanded abstract will be treated in the same manner as Generated Information in Paragraph D of this Article.

F. LLNS and the Participants agree that, with respect to any Copyrighted computer software produced in the performance of this CRADA, DOE has the right, at the end of the period set forth in Article VIII, Paragraph B hereof and at the end of each two-year interval thereafter, to request LLNS and the Participants and any assignee or exclusive licensee of the Copyrighted software to grant a nonexclusive, partially exclusive, or exclusive license to a responsible applicant upon terms that are reasonable under the circumstances, provided such grant does not cause a termination of any licensee's right to use the Copyrighted computer software. If LLNS or the Participants or any assignee or exclusive licensee refuses such request, LLNS and the Participants agree that DOE has the right to grant the license if DOE determines that LLNS and the Participants, assignee, or licensee has not made a satisfactory demonstration that it or its assignee, licensee or agent is actively pursuing commercialization of the Copyrighted computer software.

Before requiring licensing under this Paragraph F, DOE shall furnish to LLNS/Participants written notice of its intentions to require LLNS/Participants to grant the stated license, and LLNS/Participants shall be allowed thirty (30) days (or such longer period as may be authorized by the cognizant DOE Contracting Officer for good cause shown in writing by LLNS/Participants) after such notice to show cause why the license should not be required to be granted.

LLNS/Participants shall have the right to appeal the decision by DOE to the grant of the stated license to the Invention Licensing Appeal Board as set forth in Paragraphs (b) - (g) of 10 CFR 781.65, "Appeals".

G. The Parties agree to place Copyright and other notices, as appropriate for the protection of Copyright, in human-readable form onto all physical media, and in digitally encoded form in the header of machine-readable information recorded on such media such that the notice will appear in human-readable form when the digital data are offloaded or the data are accessed for display or printout.

Article XIV. Reporting Subject Inventions

A. The Parties agree to disclose to each other each Subject Invention which may be patentable or otherwise protectable under the Patent Act. The Parties agree that LLNS and Participants will disclose their respective Subject Inventions to DOE and each other within two (2) months after the inventor first discloses the Subject Invention in writing to the person(s) responsible for Patent matters of the disclosing Party.

B. These disclosures should be in sufficiently complete technical detail to convey a clear understanding, to the extent known at the time of the disclosure, of the nature, purpose and operation of the Subject Invention. The disclosure shall also identify any known actual or potential statutory bars (i.e., printed publications describing the Subject Invention or the public use or "on sale" of the Subject Invention in this country). The Parties further agree to disclose to each other any subsequently known actual or potential statutory bar that occurs for a Subject Invention disclosed but for which a Patent application has not been filed. All Subject Invention disclosures shall be marked as confidential under 35 USC 205.

Article XV. Title to Subject Inventions

Wherein DOE has granted the Participants and LLNS the right to elect to retain title to their respective Subject Inventions, and wherein the Participants have the option to choose an exclusive license, for reasonable compensation, for a pre-negotiated field of use to LLNS's Subject Inventions,

A. Title and authority to license Subject Inventions first arising or produced under this CRADA is allocated in Appendix A of this CRADA.

B. In the absence of any allocation of rights to the title and authority to license Subject Inventions in Appendix A of this CRADA, the Participants have the option to jointly retain title to any Subject Invention, and the title and authority to license such Subject Inventions shall be allocated to each Participant in proportion to its contribution amount specified in the applicable Statement of Work for the development of such Subject Inventions; provided however, that upon request, the Participants shall license such Intellectual Property to LLNS and third-parties on fair, reasonable and non-discriminatory grounds, including but not limited to a fair and reasonable licensing cost

in compliance with Ordering Paragraph 18 of Decision No. 12-12-031 of the California Public Utilities Commission.

C. The Participants hereby grant to LLNS a nonexclusive, nontransferable, irrevocable, paid-up license to practice or to have practiced every Subject Invention under this CRADA, subject to mutual agreement to a fair and reasonable licensing cost in compliance with Ordering Paragraph 18 of Decision No. 12-12-031 of the California Public Utilities Commission.

D. The Participants acknowledge that LLNS has offered to the Participants the option to choose an exclusive license for a pre-negotiated field of use for reasonable compensation for any Subject Invention made in whole or in part by a LLNS employee.

E. The Parties acknowledge that DOE may obtain title to each Subject Invention reported under Article XIV for which a Patent application or applications are not filed pursuant to Article XVI and for which any issued Patents are not maintained by any Party to this CRADA.

F. The Parties acknowledge that the Government retains a nonexclusive, nontransferable, irrevocable, paid-up license to practice or to have practiced for or on behalf of the United States every Subject Invention under this CRADA throughout the world for research and development purposes. The Parties agree to execute a Confirmatory License to affirm the Government's retained license.

Article XVI. Filing Patent Applications

A. The Parties agree that, unless allocated differently in Appendix A of this CRADA, the Participants shall have the first opportunity to jointly file U.S. and foreign Patent applications. The Participants shall agree between themselves as to who will file Patent applications on any Subject Invention. If Participants do not file such applications within one (1) year after election, then LLNS may file Patent applications on such Subject Inventions and retain title to such Subject Inventions. If a Patent application is filed by a Party ("Filing Party"), the inventing Party shall reasonably cooperate and assist the Filing Party, at the Filing Party's expense, in executing a written assignment of the Subject Invention to the Filing Party and in otherwise perfecting the Patent application, and the Filing Party shall have the right to control the prosecution of the Patent application.

B. The Parties agree that DOE has the right to file Patent applications in any country if no Party desires to file a Patent application for any Subject Invention. Notification of such negative intent shall be made in writing to the DOE Contracting Officer within three (3) months of the decision of the non-Inventing Parties to not file a Patent application for the Subject Invention pursuant to Article XV or not later than sixty (60) days prior to the time when any statutory bar might foreclose filing of a U.S. Patent application.

C. The Parties agree to include within the beginning of the specifications of any U.S. Patent applications and any Patent issuing thereon (including foreign Patents) covering a Subject Invention, the following statement: "This invention was made under a CRADA TC02200.0 among Pacific Gas & Electric Company, Southern California Edison Company, San Diego Gas & Electric Company, and Lawrence Livermore National Laboratory operated for the United States Department of Energy. The Government has certain rights in this invention."

D. A Party electing title or filing a Patent application in the United States or in any foreign country shall advise the other Parties and DOE if it no longer desires to continue prosecution, pay maintenance fees, or retain title in the United States or any foreign country. The other Parties and then DOE will be afforded the opportunity to take title and retain the Patent rights in the United States or in any such foreign country.

E. Each Party agrees to provide the project manager of the other Parties upon request with a copy of each Patent application it files on any Subject Invention.

Article XVII. Trademarks

The Parties may seek to obtain Trademark/Service Mark protection on products or services generated under this CRADA in the United States or foreign countries. The Party originating the Trademark/Service Mark on products or services generated under this CRADA in the United States or foreign countries, shall have the full right, title, and interest in such Trademark or Service Mark subject only to the Government's retained right to use the mark on any similar goods or services as set forth below. The Parties hereby acknowledge that the Government shall have the right to indicate on any similar goods or services produced by or for the Government that such goods or services were derived from and are a DOE version of the goods or services protected by such Trademark/Service Mark, with the Trademark and the owner thereof being

specifically identified. In addition, the Government shall have the right to use such Trademark/Service Mark in print or communications media.

Article XVIII. Mask Works

Reserved.

Article XIX. Cost of Intellectual Property Protection

Each Party shall be responsible for payment of all costs relating to Copyright, Trademark, and Mask Work filing; U.S. and foreign Patent application filing and prosecution; and all costs relating to maintenance fees for U.S. and foreign Patents hereunder which are solely owned by that Party. Government/DOE laboratory funds contributed as DOE's cost share to a CRADA cannot be given to a Participant for payment of the Participant's costs of filing and maintaining Patents or filings for Copyrights, Trademarks, or Mask Works.

Article XX. Reports of Intellectual Property Use

The Participants agree to submit, for a period of three (3) years from the date of termination or completion of this CRADA and upon request of DOE, a nonproprietary report no more frequently than annually on the efforts to utilize any Intellectual Property arising under this CRADA.

Article XXI. DOE March-In Rights

The Parties acknowledge that DOE has certain march-in rights to any Subject Inventions in accordance with 48 CFR 27.304-1 (g) and 15 USC 3710a(b)(1)(B) and (C).

Article XXII. U.S. Competitiveness

The Parties agree that a purpose of this CRADA is to provide substantial benefit to the U.S. economy.

A. In exchange for the benefits received under this CRADA, the Participants therefore agree to the following:

1. Products embodying Intellectual Property developed under this CRADA shall be substantially manufactured in the United States; and

2. Processes, services, and improvements thereof which are covered by Intellectual Property developed under this CRADA shall be incorporated into a Participant's manufacturing facilities in the United States either prior to or simultaneously with implementation outside the United States. Such processes, services, and improvements, when implemented outside the United States, shall not result in reduction of the use of the same processes, services, or improvements in the United States.

B. LLNS agrees to include a U.S. Industrial Competitiveness clause in accordance with its prime contract with respect to any licensing and assignments of its intellectual property arising from this CRADA, except that any licensing or assignment of its intellectual property rights to any Participant shall be in accordance with the terms of Paragraph A of this Article.

Article XXIII Research and Development Tax Credits (R&D Credits)

A. R&D Credits are currently available pursuant to §23609 of the California Revenue and Taxation Code. Although Federal R&D Credits, as provided by §41 of the Internal Revenue Code (Code), are currently unavailable for amounts paid or incurred after December 31, 2013, the Parties have reason to believe that as in prior years §41 will be extended to cover payments by Participants subject to this CRADA. .

B. The Parties agree that research conducted pursuant to the CRADA should qualify as Participants' contract research expense, as described in §41(b)(3) of the Internal Revenue Code (and corresponding California tax law) and as such they intend that this CRADA be interpreted to enable qualification of payments by Participants as contract research expenses eligible for the R&D Credit. Treasury Regulation §1.41-2(e) sets forth the requirements for R&D Credit eligibility for contract research, which include that the research be performed pursuant to an agreement entered into prior to the performance of the qualified research; that the research be performed on behalf of the taxpayer (See Section C.1., below); and that the taxpayer bears the expense even if the research is not successful (See Section C.2., below). To qualify for the Federal credit the research must

also be conducted within the United States and to qualify for the California credit the research must be conducted within California.

1. Section 1.41-2(e)(3) of the Treasury Regulations further provide that research will be conducted on behalf of a taxpayer if the taxpayer has a right to the results of the research, including a non-exclusive right. The Parties acknowledge and agree that, notwithstanding any provision to the contrary, the terms of this CRADA shall be construed to satisfy the requirements of this paragraph 3. To the extent LLNS retains rights to the research in addition to conducting research on a Participant's behalf, LLNS (and any partner or member thereof) shall only claim credits under Section 41 of the Code to the extent allowed by Treasury Regulation §1.41-4A(d)(3), providing rules for claiming the credit when research is funded by others.

2. The Parties agree that each Participant bears the expense of the research even if the research is not successful because the research is being conducted by LLNS on a best efforts basis.

3. All research funded by a Participant shall be conducted within California, unless a Participant otherwise agrees in writing.

C. LLNS Cooperation and Accounting. LLNS shall cooperate with Participants in obtaining eligibility for the R&D Credit by making personnel available and providing appropriate records, upon the request of a Participant, to enable the Participant to pursue eligibility for the Credits. This includes, but is not limited to, making personnel available to discuss issues regarding credit eligibility with the Internal Revenue Service or Franchise Tax Board.

D. LLNS shall not be liable for the failure of a Participant to be eligible for any R&D Credit, provided it has acted in good faith. LLNS shall be reimbursed by a Participant for all costs incurred at the request of a Participant, or in the ratio of funding, if such work is requested by more than one Participant. LLNS shall not be required to pursue any work under this Article without guaranteed reimbursement from Participants.

E. LLNS Status. LLNS is a "Federal Laboratory", as the term is used in Section 4(6) of the Stevenson-Wydler Technology Innovation Act of 1980 (15 USC 3703(6), as in effect on the date of the Energy Tax Incentives Act of 2005 (See §41(b)(3)(d)(iv) of the Code).

F. Good Faith and Fair Dealing Regarding Tax Law Changes. The Parties agree that the tax laws are subject to change and modification and agree to deal in good faith, subject to sound business practices, to maximize eligibility for tax benefits that may be provided to Participants for their payments under the CRADA.

Article XXIV. Assignment of Personnel

A. Each Party may assign personnel to another Party's facility as part of this CRADA to participate in or observe the research to be performed under this CRADA. Such personnel assigned by the assigning Party shall not during the period of such assignments be considered employees of the receiving Party for any purposes, including but not limited to any requirements to provide workers' compensation, liability insurance coverage, payment of salary or other benefits, or withholding of taxes.

B. The receiving Party shall have the right to exercise routine administrative and technical supervisory control of the occupational activities of such personnel during the assignment period and shall have the right to approve the assignment of such personnel and/or to later request their removal by the assigning Party.

C. The assigning Party shall bear any and all costs and expenses with regard to its personnel assigned to the receiving Party's facilities under this CRADA. The receiving Party shall bear facility costs of such assignments.

Article XXV. Force Majeure

No failure or omission by LLNS or Participants in the performance of any obligation under this CRADA shall be deemed a breach of this CRADA or create any liability if the same shall arise from any cause or causes beyond the control of LLNS or any Participant, including but not limited to the following, which, for the purpose of this CRADA, shall be regarded as beyond the control of the Party in question: Acts of God; acts or omissions of any government or agency thereof; compliance with requirements, rules, regulations, or orders of any governmental authority or any office, department, agency, or instrumentality thereof; fire; storm; flood;

earthquake; accident; acts of the public enemy; war; rebellion; insurrection; riot; sabotage; invasion; quarantine; restriction; transportation embargoes; or failures or delays in transportation.

Article XXVI. Administration of the CRADA

LLNS enters into this CRADA under the authority of its prime contract with DOE. LLNS is authorized to and will administer this CRADA in all respects unless otherwise specifically provided for herein. Administration of this CRADA may be transferred from LLNS to DOE or its designee with notice of such transfer to the Participants, and LLNS shall have no further responsibilities except for the confidentiality, use, and/or nondisclosure obligations of this CRADA.

Article XXVII. Records and Accounting for Government Property

Each Participant shall maintain records of receipts, expenditures, and the disposition of all Government property in its custody related to this CRADA.

Article XXVIII. Notices

A. Any communications required by this CRADA, if given by postage prepaid first class U.S. Mail or other verifiable means addressed to the Party to receive the communication, shall be deemed made as of the day of receipt of such communication by the addressee, or on the date given if by verified facsimile. Address changes shall be given in accordance with this Article and shall be effective thereafter. All such communications, to be considered effective, shall include the number of this CRADA.

B. The addresses, emails, telephone numbers and facsimile numbers for the Parties are as follows:

1. For LLNS:

U.S. Mail Only:
Lawrence Livermore National Security, LLC
Lawrence Livermore National Laboratory
Industrial Partnerships Office
P.O. Box 808, L-795
Livermore, CA 94551

FedEx, UPS, Freight:
Lawrence Livermore National Security, LLC
Lawrence Livermore National Laboratory
Industrial Partnerships Office
7000 East Avenue, L-795
Livermore, CA 94550

a. FORMAL NOTICES AND COMMUNICATIONS, COPIES OF REPORTS

Attn: [to be inserted]_____
Tel: _____
Fax: _____
Email: _____

b. PROJECT MANAGER, REPORTS, COPIES OF FORMAL NOTICES AND COMMUNICATIONS

Attn: [to be inserted]_____
Tel: _____
Fax: _____
Email: _____

2. For PG&E:

U.S. Mail Only:
Pacific Gas & Electric Company
77 Beale Street
San Francisco, CA 94177

FedEx, UPS, Freight:
Same as U.S. Mail

a. FORMAL NOTICES AND COMMUNICATIONS, COPIES OF REPORTS

Attn: [to be inserted]_____
Tel: _____
Fax: _____
Email: _____

b. PROJECT MANAGER, REPORTS, COPIES OF FORMAL NOTICES AND COMMUNICATIONS

Attn: [to be inserted]_____
Tel: _____
Fax: _____
Email: _____

3. For SCE:

U.S. Mail Only:
Southern California Edison
2244 Walnut Grove Avenue
Rosemead, CA 91770

FedEx, UPS, Freight:
Same as U.S. Mail

a. FORMAL NOTICES AND COMMUNICATIONS, COPIES OF REPORTS

Attn: [to be inserted]_____
Tel: _____
Fax: _____
Email: _____

b. PROJECT MANAGER, REPORTS, COPIES OF FORMAL NOTICES AND COMMUNICATIONS

Attn: [to be inserted]_____
Tel: _____
Fax: _____
Email: _____

3. For SDG&E:

U.S. Mail Only:
San Diego Gas & Electric Company
8326 Century Park Court
San Diego, CA 92123

FedEx, UPS, Freight:
Same as U.S. Mail

a. FORMAL NOTICES AND COMMUNICATIONS, COPIES OF REPORTS

Attn: [to be inserted]_____
Tel: _____
Fax: _____
Email: _____

b. PROJECT MANAGER, REPORTS, COPIES OF FORMAL NOTICES AND COMMUNICATIONS

Attn: [to be inserted]_____
Tel: _____

Fax: _____

Email: _____

Article XXIX. Disputes

At the request of a Party, after reasonable attempt to settle without arbitration, any controversy or claim arising out of or relating to the CRADA shall be settled by arbitration conducted in the State of California in accordance with the then current and applicable rules of the American Arbitration Association. Judgment upon the award rendered by the Arbitrator(s) shall be nonbinding on the Parties.

Article XXX. Entire CRADA and Modifications

A. This CRADA with its Appendices contains the entire agreement between the Parties with respect to the subject matter hereof, and that all prior representations or agreements relating hereto have been merged into this document and are thus superseded in totality by this CRADA. This CRADA shall not be effective until approved by DOE.

B. Any agreement to materially change any terms or conditions of this CRADA or the appendices shall be valid only if the change is made in writing, executed by the Parties hereto, and approved by DOE.

Article XXXI. Termination

This CRADA may be terminated by a Party upon thirty (30) days written notice to the other Parties. This CRADA may also be terminated by LLNS in the event of failure by any Participant to provide the necessary advance funding, as agreed in Article III, or by the Participants in the event of a failure by any Party to fulfill its obligations under this CRADA, including to use funds provided by the Participants under Article III in conformity with the requirements of this CRADA and for the project contemplated hereunder.

In the event of termination by a Party, each Party shall be responsible for its share of the costs incurred through the effective date of termination, as well as its share of the costs incurred after the effective date of the termination, and which are related to the termination. Following termination of the CRADA and payment of costs for which Participants are responsible, LLNL

will refund any amount remaining from advance funds provided by the Participants pursuant to Article III of this CRADA.

The confidentiality, use, and/or non-disclosure obligations of this CRADA shall survive any termination of this CRADA.

Article XXXII. Third Party Rights in Intellectual Property

The Parties acknowledge that the Statement of Work in Appendix A of this CRADA describes work that may be performed by third parties and/or subcontractor(s) to one or more of the Parties and that separate agreement(s) with such third parties may be needed with respect to intellectual property owned by such third parties.

FOR LLNS: LAWRENCE LIVERMORE NATIONAL SECURITY, LLC
LAWRENCE LIVERMORE NATIONAL LABORATORY

BY: _____

NAME: _____

TITLE: _____

DATE: _____

FOR PG&E: PACIFIC GAS & ELECTRIC COMPANY

BY: _____

NAME: _____

TITLE: _____

DATE: _____

This draft CRADA is preliminary and is subject to approval by the National Nuclear Security Administration.

FOR SCE: **SOUTHERN CALIFORNIA EDISON COMPANY**

BY: _____

NAME: _____

TITLE: _____

DATE: _____

FOR SDG&E: **SAN DIEGO GAS AND ELECTRIC COMPANY**

BY: _____

NAME: _____

TITLE: _____

DATE: _____

APPENDIX A

STATEMENT OF WORK

Related to LLNL Case No. TC02200.0

21st Century Energy Systems Project

Purpose

This is a collaborative effort between Lawrence Livermore National Security, LLC as manager and operator of Lawrence Livermore National Laboratory (LLNL), Pacific Gas & Electric Company (PG&E), Southern California Edison Company (SCE), and San Diego Gas & Electric Company (SDG&E). PG&E, SCE and SDG&E are collectively referred to as the California Investor Owned Utilities (IOUs). The purpose of this Cooperative Research and Development Agreement (CRADA) is to apply computationally based problem solving resources to the emerging challenges of the 21st century energy system. This CRADA project intends to produce deliverables to address California's energy challenges in cyber security and grid integration.

1) Background

New laws and regulations and technological innovations often drive changes in California's energy system. Many changes, such as the introduction of renewable generation, electrified vehicles and smart meters, are directly visible to consumers. There are a myriad of other advanced innovations woven into the energy network that are virtually invisible from the consumer experience, like intermittency management of renewables, energy storage for electrified vehicles, data management of smart-meter information, and cyber security of these new smart devices.

Cyber Security

The cyber security industry is making great strides in the areas of protection and detection capabilities. For example, government programs such as Einstein 1, 2, and 3, ADAMS, and CINDER promise to protect government information systems by improving situational awareness and improving detection and protection capabilities. However, for the most part, when it comes to reacting to attacks, these systems rely on alerting those under attack to take remedial action. Manual responses may be adequate for cyber-attacks against information systems and their data, but manual responses to cyber-attacks against critical infrastructure may not be fast enough to keep attackers from damaging the critical infrastructure. What's needed is an automated response capability to protect the critical infrastructure against cyber-attacks.

The automated response capability would essentially mimic a military strategy developed by U.S. Air Force Colonel John Boyd and applied to the combat operations process known as the OODA loop. According to Boyd, decision-making occurs in a

recurring observe-orient-decide-act (OODA) loop. In combat, the opponent who can process this cycle quicker has the advantage. In cyber security as in war, the ability to observe and react to threats more rapidly than the attacker will significantly enhance the system's ability to survive an attack. The advancement in cyber technology will enable the IOUs to identify and take action on advanced cyber threats before they impact California's critical infrastructure.

This activity leverages the relationship between the three California Investor Owned Utilities (IOUs), in collaboration with Lawrence Livermore National Laboratory (LLNL) to develop the automated response capabilities needed to protect the state's critical infrastructure against cyber-attacks.

Grid Integration

Current reliability metrics and targets were developed for an electric grid that did not have as much non-dispatchable and intermittent resources as the future grid envisioned by California's Clean Energy Plan. The metrics that have historically been used to monitor and ensure a stable grid operation were designed in a different era that do not capture the range and diversity of available control mechanisms that would be present on the grid of the future, nor do they capture the inherent uncertainty and variability of new intermittent generation sources and load changes. Thus metrics that capture this and provide a broader scope of control options are needed.

Today, California Independent System Operator (CAISO) and the IOUs use off-the-shelf production simulation models to test the adequacy of the system to meet traditional operating reliability and new flexibility requirements under a given scenario. If resources are not adequate, the model estimates resource deficiencies, and after a trial and error process estimates the amount of conventional resources needed to clear resource deficiencies. Because simulations are time consuming, a day or more is needed to evaluate a single weather scenario for a single year. As a result, system analyses are often limited to single weather conditions and few load and resource scenarios, rather than performing a stochastic simulation to properly account for reliability risks. In addition, modeling simplifications are made (such as use of hourly granularity instead of one-minute or five-minute granularity), which may result in an inadequate representation of actual system flexibility needs.

2) Expected Accomplishments and Goals

The result of the cyber security research can be envisioned as a threat-aware grid architecture capable of making real-time decisions to increase its survivability and resiliency.

CES-21 cyber security innovations and breakthroughs to be developed include:

- An open architecture for distributed threat detection and automatic, localized response:

  - with status reporting to peers,
  - permitting centralized maintenance,
  - aware of its environment and changes to it,
  - providing forensically sound evidence collection and handling for the use of law enforcement and intelligence services, and
  - including open and non-proprietary systems, algorithms, and workflows that provide a basis for a commercially viable prototype.
- Secure procedures and processes for the management, command, and control of industrial control system (ICS) defenses;
- Standard descriptive semantics for threats, responses, infrastructure, and processes;
- Models of industrial control systems within the IOUs' grid which are useful for further analyses; and
- Recommended responses to threats and threat types.

The grid integration research will develop new metrics to measure the probability that the IOU's grid system will be unable to ramp up and down quickly enough to meet the ramping events that are possible with high levels of renewables. When properly constructed and employed, such a metric could be used to assess the system's adequacy and to provide insight as to the most efficient approaches to improving the system's ability to meet ramping events.

Scope of the Project

1) Technical Objectives

The cyber security research is intended to develop automated response capabilities to protect critical infrastructure against cyber-attacks, specifically advanced persistent threats. Due to the time criticality of these cyber-attacks, the only way to effectively protect the critical infrastructure will be through automated response capabilities. Automated responses may take the form of:

- Network segmentation, disconnection, or segregation
- Traffic shaping, routing and firewalling
- Session termination and resets
- Traffic and application whitelisting
- System quarantining or disconnection
- Component reboot/reload
- Implementation of other automated response strategies

The grid integration research will define operating flexibility metrics and targets based on a probability measure of the occurrence, the magnitude, and the duration of ramping shortages at different time intervals. These metrics will be applied using production simulation and reliability models of the California system to determine their robustness

under a wide range of realistic scenarios of weather conditions, and loads and renewable generation scenarios.

2) Tasks

The following tasks, listed by work breakdown (WBS) level, will be executed during this CRADA. LLNL will monitor the progress of these tasks and provide a monthly report.

1.0 Cyber Security

1.1 Use Case Generation

This task will generate use cases for potential cyber security solutions to be developed in the CES-21 cyber security research program. The initial use cases will be prepared in the first three months and will be updated during the CES-21 program when determined appropriate by the LLNL and IOU Program Managers. Project participants will meet with IOU subject matter experts (SMEs) to learn about operational needs in cyber security, to learn about realities of operating the grid in a reliable and secure manner, and to solicit feedback on prototype technologies developed by the program. These meetings will be frequent during program initiation and then occur on a regular basis throughout the remainder of the program on a schedule and at locations mutually agreed to by the LLNL and IOUs' Program Managers.

1.2 Data Aggregation

LLNL and the IOUs technical team (the team) will develop a comprehensive understanding of the IOU's ICS network architecture, devices on the network, and data available from network devices. Both IOU device catalogs and network mapping technology will be used to accomplish this. We will build a prototype data aggregator to collect ICS data pertinent to defending the network. Existing data models will be used where available and then extended or created to fill gaps. This task will utilize LLNL Intellectual Property.

1.3 Modeling/Simulation

The team will start by defining a "Modeling/Simulation R&D Strategy" for the CES-21 cyber security program. Experts in modeling and simulation as well as IOU grid operators will team to determine what elements to include in the strategy. The team will execute the CES program using an 'agile' methodology with dynamic task planning, enabling resources to be quickly focused in areas that are yielding results. The main integration timeline is set up in 6 month research and development cycles, and each cycle culminates in a review by LLNL and the IOUs of which modeling/simulation will be most beneficial to supporting other program tasks such as "Tools for Course of Action Analysis" and "Generate Defensive Actions." Because modeling and simulation can be performed with many degrees of resolution (e.g.

neighborhood, city, region, State of California) at varying levels of effort, the research team working on this project task will investigate resolution requirements with IOU grid operators and determine the optimal grid representations for modeling/simulation. Subsequent work will build and/or extend existing modeling/simulation tools to meet requirements outlined in the "Modeling/Simulation R&D Strategy." The modeling/simulation tools will then be used by other program tasks. This task will utilize Open Source and LLNL Intellectual Property.

1.4 Physical Test Bed

A test bed or multiple test beds are necessary to test prototype cyber security technologies. The team will evaluate existing test beds at the IOUs, national laboratories, and colleges and universities. The most comprehensive and applicable test bed(s) will be selected for use by the CES-21 cyber security research team for testing newly developed defensive technologies and investigating grid behavior in a controlled non-production environment. New test bed capabilities may be developed where gaps are identified.

1.5 Advanced Threat Detection

This task will focus on detection of unknown cyber threats to ICS networks. This class of threat is often referred to as the "Advanced Persistent Threat" (APT). This task is a low-level effort aimed at developing case studies to guide detection of APT, building prototype algorithms to identify and detect these threats, and developing a research plan that outlines options for future investigation of this area. This task will utilize LLNL Intellectual Property.

1.6 Standardized Indicator Language

Cyber indicators are already being distributed by government entities and private industry though a common data format has not been established. This task will evaluate the most used indicator languages and choose one for use within the CES-21 cyber security program. Together, LLNL and the IOUs may develop the chosen language further to encompass additional needs that the IOUs have for such a technology. The team will share any modifications to the chosen standard with the original author and community.

1.7 Software/Device Vulnerability Analysis

This task will focus on finding latent vulnerabilities in ICS device software using novel techniques. This task is a low-level effort that will investigate existing tools in this field and develop an R&D roadmap that outlines options for future investigation of this area. This task will utilize Open Source Intellectual Property.

1.8 Tools for Course of Action Analysis

The team will investigate and develop technologies for making automated defensive decisions on ICS networks. The team will work closely with IOU grid operators to learn about the realities of operating a secure, reliable grid. The team will investigate existing decision-making technologies both within and outside of the ICS industry. The team expects to spend a considerable amount of time developing and testing logic for automated and semi-automated reasoning systems so that chosen technologies will not destabilize grid operations. This task will utilize LLNL Intellectual Property.

1.9 Generate Defensive Actions

This task will focus on researching ways of making changes to ICS networks in the face of cyber threats. The team will survey existing automated response systems for ICS networks (if any), work with IOU grid operators to build a catalog of potential defensive actions, develop response actions, test those actions on the test bed network(s) chosen in Task 1.4 and/or via the modeling/simulation framework of Task 1.3. The team will integrate the viable actions into their grid operations.

1.10 M2MATR Integration

LLNL and the IOUs will develop an integrated Machine 2 Machine Automated Threat Response (M2MATR) toolset. The research and development program will be executed using a spiral development methodology enabling resources to be quickly focused in areas that are yielding results. The main integration timeline is set up in 6 month R&D cycles with each cycle culminating in an internal review by the IOUs and LLNL.

2.0 Grid Integration

2.1 Definition of problem and needed tools

Define the problem and review methodologies and analytical tools that could be used to solve the problem. The purpose of this initial step is to develop a clear description of the analytical framework that will be used to design a methodological and modeling approach to design flexibility metrics. Traditional reliability modeling addresses the analytical question regarding the amount of capacity that satisfies a reliability target such as a one day in 10 years outage expectation or that equalizes the cost of adding new generation resources with the corresponding reduction in outage costs. This question is addressed in a stochastic environment where shortfalls in available generating capacity relative to customer load are assessed based on distributions of weather conditions driving customer loads and generating unit unavailability. In a generating system in which there is a substantial risk of customer outages or equipment damage due to insufficient operating

flexibility to balance loads and resources (even when there is enough capacity overall), resource expansion questions need to consider not only capacity shortfalls and but also operating flexibility shortfalls such as insufficiently ramping up and down capability to balance loads and resources, as well as the cost of meeting these shortfalls with changes in unit commitment or dispatch, or operating flexibility policies or standards. The question of what operating flexibility metrics and targets to use for planning will be addressed in a stochastic environment that additionally considers the weather uncertainty affecting loads and intermittent resources.

2.2 Base model selection

Based on the characteristics identified in the prior Task 2.1, a base model will be selected. In this task, the team will review and critique existing flexibility metrics and tools now in use and under development by the utilities, CAISO, and others to identify flexibility needs. Initially, the Plexos software from Energy Exemplar ("Plexos") will be used as the base model given CAISO's and IOUs' experience with the model and LLNL's past use of Plexos for its probabilistic analysis of demand response and energy storage. The IOU and LLNL Program Managers may mutually agree to change the base model depending upon the results of Task 2.1.

2.3 Generate multiple weather dependent data

Leverage LLNL's previous work with the Weather Research and Forecasting (WRF) model and use WRF to reproduce a range of temperature, wind and solar conditions prevailing in California and the Western Electricity Coordinating Council (WECC) for 30 scenarios to build 6 weather ensembles for each of two different weather years. Leveraging LLNL's scripts already developed, weather parameters for these scenarios will be used to generate load, wind and solar generation for simulations in the base model chosen in Task 2.2. Load and intermittent generation would have 5 minute interval inputs. This task will utilize Open Source and LLNL Intellectual Property.

2.4 Automated running of scenarios

Set up the base model so it can be run in batch mode with predefined scenarios. Use this to produce a list of scenarios of output that can be analyzed by hand, and later with the use of the prototype code developed in later tasks of the grid integration project, and used to begin gaining insight into what the long term procurement plan should look like. Develop methods to automate storage of the results into a database or other convenient form for subsequent analysis. The scenarios will then be aggregated and weighted based on the weight assumed for each weather year. Plexos will perform a day-ahead unit commitment and 5 minute economic dispatch. Instead of using a stochastic unit commitment considering the 30 weather scenarios

available for an hour of a weather year, each of the 30 scenarios will be run separately considering Monte Carlo outages and operating flexibility requirements calculated based on the uncertainty represented by the 30 scenarios in a weather year.

2.5 Definition of flexibility metrics

Based on the previous Task 2.4 results, LLNL and the IOUs will identify and develop or extend appropriate models and simulation codes – leveraging existing products whenever possible. Methods will help determine which metrics can best communicate the IOU grid system's flexibility requirements, and how the metrics can then be adjusted or changed as necessary in the future as the grid system changes. In this task, the team will review prior flexibility metrics used by CAISO, utilities and others to represent the flexibility requirements of the system that need to be considered for commitment and dispatch purposes.

2.6 Prototype model to calculate metrics

Develop a prototype model as stand-alone code intended to calculate the supply and demand for flexibility for the selected metrics, the expected deficiencies and probability of deficiencies of flexible capacity. In this task, the code will be used to track and calculate the flexibility metric deficiencies, but will not yet be integrated with the unit-commitment and dispatch model. The inputs to the metrics prototype are: (1) the unit commitment and dispatch coming out of a base model simulation run, showing the available flexible capacity to meet the flexibility requirements at different time intervals (such as every hour or 15 minutes) for different time horizons (such as 5 min, 15 min, 1 hour, 2 hours, etc.), and (2) the distribution of loads and intermittent generation at the end of each time horizon for each of the 30 weather paths considered in each weather year from which the demand for flexibility is calculated for each time horizon. The output is the expected amount of various types of "flexibility not served" in MW per hour considering the 30 weather scenarios, and the probability of any flexibility not being served. Both upward and downward flexibility metrics will be calculated for various assumed flexibility standards to inform a future development of flexibility standards.

2.7 Integrate flexibility metrics in base model

LLNL will develop a prototype optimization infrastructure following an iterative process using LLNL's HPC with software that: 1) takes the inputs from the unit commitment and dispatch model and from the flexibility metric prototype model developed in prior phases, and 2) decides whether to change the unit commitment and dispatch to minimize costs after satisfying the flexibility targets given the marginal cost of flexibility. The goal is to

integrate the selected flexibility targets into a larger optimization which can be solved on workstations used by the IOUs, CAISO and other parties in 4 hours per weather year. LLNL will suggest ways to reduce run time by: 1) clustering the 30 weather scenarios into 6 scenarios, and 2) simplifying the representation of the system without losing significant accuracy.

2.8 Test of model and sample analysis

The results from the integrated optimization Task 2.7 will be tested and evaluated. Further adjustments to the integrated optimization code may be necessary as part of this task. As a first step in validation, LLNL will run the new flexibility metrics on two very different grid configurations (such as vastly different amounts of non-dispatchable generation). The metrics should reveal a difference. For the purposes of this CES-21 grid integration work, evaluation criteria will be qualitative. Additionally, the team will develop an approach for conducting more rigorous quantitative validation, including metrics sensitivity to inputs.

2.9 Prepare model for use

LLNL and the IOUs will develop user documentation as prototype versions are developed and tested, and assembled into a single document for users in the last two months of the CES-21 grid integration project.

3.0 Project Close-out

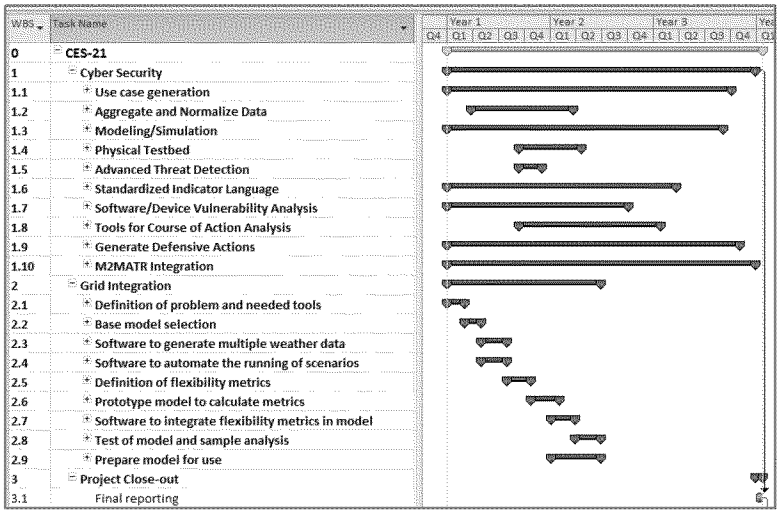
3.1 Final reporting

LLNL will prepare the final report and abstract due within thirty (30) days of completion or termination of the project, as required under Article XI of the CRADA.

4.0 Allocation of Intellectual Property, including Subject Inventions

Pursuant to Articles VII, VIII, IX, XIII, and XV of the CRADA and CPUC Decision 12-12-031, PG&E, SCE and SDG&E jointly retain title to any intellectual property or other value produced or derived from this Statement of Work, and have the discretion and authority to license, sell or encumber any such intellectual property to LLNS and third parties upon CPUC approval under Public Utilities Code Section 851 and subject to the requirement that any such licensing be on fair, reasonable and non-discriminatory grounds, for a fair and reasonable licensing fee, and also subject to rights granted by law to the U.S. Federal Government under the CRADA. Intellectual property that was in existence prior to or produced outside the CRADA and that is identified in advance by the parties as Background Intellectual Property or Proprietary Information in the CRADA, will remain the property of the party owning the intellectual property or proprietary information, unless the Parties mutually agree otherwise.

Estimated Schedule



Deliverables

WBS	Description	Due Date	Responsible	Disposition
1	**Cyber Security**			
1.10	**Document describing spiral 1 results**	**Y1Q2**	**LLNL/IOUs**	**Protected CRADA Information**
1.10	**Document describing spiral 2 results**	**Y1Q4**	**LLNL/IOUs**	**Protected CRADA Information**

WBS	Description	Due Date	Responsible	Disposition
1.10	Document describing spiral 3 results	Y2Q2	LLNL/IOUs	Protected CRADA Information
1.10	Document describing spiral 4 results	Y2Q4	LLNL/IOUs	Protected CRADA Information
1.10	Document describing spiral 5 results	Y3Q2	LLNL/IOUs	Protected CRADA Information
1.10	Document describing spiral 6 results	Y3Q4	LLNL/IOUs	Protected CRADA Information
1.10	Final cyber security project report	Y3Q4	LLNL/IOUs	Open
2	**Grid Integration**			
2.9	Document describing the model and end of grid integration project report available	Y2Q2	LLNL/IOUs	Open
3	**Project Close-out**			
3.1	Final Report and Abstract	Y3Q4	LLNL/IOUs	Open

This draft CRADA is preliminary and is subject to approval by the National Nuclear Security Administration.

Appendix B
ENERGY SCIENCE AND TECHNOLOGY SOFTWARE CENTER
Abstract Format

Related to LLNL Case No. TC02200.0

1. *Identification*

Provide the following two fields to be used to uniquely identify the software. The software acronyms plus the short or KWIC (keywords in context) title will be combined to be used as the identification of the software.

Software Acronym (limit 20 characters). The name given to the main or major segment of module package usually becomes the name of the code package. If an appropriate name is not obvious, invent one which is related to the contents.

Short or KWIC title (limit 80 characters). This title should tell something of the nature of the code system: calculational method, geometry, or any feature that distinguishes this code package from another. It should be telegraphic in style, with no extraneous descriptors, but more than a string of keywords and phrases. The word "code" (alone) and "program" do not belong in a description of a code "package".

2. *Author Name(s) and Affiliations*

List author(s) or contributor(s) names followed by the organizational affiliation. If more than one affiliation is applicable, please pair authors with their affiliations.

3. *Software Completion Date*

List approximate date(s) that the version of the executable module(s), which will be created by the submitted program modules, was first used in an application environment.

4. *Brief Description*

Briefly describe the purpose of the computer program, state the problem being solved, and summarize the program functions and capabilities. This will be the primary field used for announcement purposes.

5. *Method of Solution*

Provide a short summary of the mathematical methods, engineering principles, numerical algorithms, and procedures incorporated into the software.

6. *Computer(s) for Which Software is Written*

List the computer(s), i.e., IBM3033, VAX6220, VAX, IBM PC, on which this submittal package will run.

7. *Operating System*

Indicate the operating system used, release number, and any deviations or exceptions, i.e., is the operating system "off the shelf" with no modifications, or has the operating system been modified/customized. If modified, note modifications in field 11.

8. *Programming Language(s) Used*

Indicate the programming language(s) in which the software is written along with approximate percentage (in parentheses) of each used. For example, FORTRAN IV (95%), Assembler (5%).

9. *Software Limitations*

Provide a short paragraph on any restrictions implied by storage allocation, such as the maximum number of energy groups and mesh points, as well as those due to approximations used, such as implied argument-range limitations. Also to be used to indicate the maximum number of users, etc. or other limitations.

10. *Unique Features of the Software*

Highlight the advantages, distinguishing features, or special capabilities which may influence the user to select this package over a number of similar packages.

11. *Related and Auxiliary software*

If the software supersedes or is an extension of earlier software, identify the original software here. Identify any programs not considered an integral part of this software but used in conjunction with it (e.g., for preparing input data, plotting results, or coupled through use of external data files). Note similar library software, when known.

12. *Other Programming or Operating Information or Restrictions*

Indicate file naming conventions used, e.g., (filename), DOC (DOC is a filename extension normally used to indicate a documentation file), additional subroutines, function libraries, installation support software, or any special routines required for operation of this package other than the operating system and programming language requirements listed in other fields. If proprietary software is required, this should also be indicated.

13. *Hardware Requirements*

List hardware and installation environment requirements necessary for full utilization of the software. Include memory and RAM requirements, in addition to any nonstandard features.

14. *Time Requirements*

Include any timing requirement estimations, both wall clock and computer clock, necessary for the execution of the package. Give enough detail to enable the potential user to estimate the execution time for a given choice of program parameters (e.g., 5-10 min.).

15. *References*

List citations of pertinent publications. List (by author, title, report, bar code or order number if available, and date). References are to be broken down into two groupings.

(a) Reference documents that are provided with the submittal package.

(b) Any additional background reference materials generally available.

16. *Categorization and Keywords*

(a) Subject Classification Code - chosen from the Subject Classification Guide (Appendix E of ESTSC-I), this one-letter code designation is to be supplied by the submitter.

(b) Keywords - Submitters should include keywords as taken from the ESTSC thesaurus listing (Appendix F of ESTSC-I). Keywords chosen that are not on the list will be subject to ESTSC approval before being added to the thesaurus. Subsequent revision lists will be available. ESTSC may also add additional keywords to aid in the indexing of the material.

17. *Category*

The subject classification chosen for the Center subject classification guide is shown.

KEYWORDS: This is a listing of the keywords associated with the program, supplied by the program author and/or Center, based on the Center Thesaurus.

18. *Sponsor*

This is the name of the program office or division and the agency responsible for funding the software development effort.

Appendix C

BACKGROUND INTELLECTUAL PROPERTY

Related to LLNL Case No. TC02200.0

Each Party may use any other Party's Background Intellectual Property identified hereunder solely in performance of research under the Statement of Work. This CRADA does not grant to any Party any option, grant, or license to commercialize, or otherwise use another Party's Background Intellectual Property. Licensing of Background Intellectual Property, if agreed to by the Parties, shall be the subject of separate licensing agreements between the Parties.

LLNS:

LLNL has reviewed its files and notes the following Background Intellectual Property:

[To be inserted– pending approval of projects]

PG&E:

PG&E has reviewed its files and notes the following Background Intellectual Property:

[To be inserted– pending approval of projects]

SCE:

SCE has reviewed its files and notes the following Background Intellectual Property:

[To be inserted– pending approval of projects]

SDG&E:

SDG&E has reviewed its files and notes the following Background Intellectual Property:

[To be inserted– pending approval of projects]

Each Party has used reasonable efforts to list all relevant Background Intellectual Property, but Intellectual Property may exist that is not identified. No Party shall be liable to another Party because of failure to list Background Intellectual Property.

PG&E Gas and Electric
Advice Filing List
General Order 96-B, Section IV

1st Light Energy
AT&T
Alcantar & Kahl LLP
Anderson & Poole
BART
Barkovich & Yap, Inc.
Bartle Wells Associates
Braun Blaising McLaughlin, P.C.
CENERGY POWER
California Cotton Ginners & Growers Assn
California Energy Commission
California Public Utilities Commission
California State Association of Counties
Calpine
Casner, Steve
Center for Biological Diversity
City of Palo Alto
City of San Jose
Clean Power
Coast Economic Consulting
Commercial Energy
County of Tehama - Department of Public Works
Crossborder Energy
Davis Wright Tremaine LLP
Day Carter Murphy
Defense Energy Support Center
Dept of General Services
Division of Ratepayer Advocates
Douglass & Liddell
Downey & Brand
Ellison Schneider & Harris LLP
G. A. Krause & Assoc.
GenOn Energy Inc.
GenOn Energy, Inc.
Goodin, MacBride, Squeri, Schlotz & Ritchie
Green Power Institute
Hanna & Morton
In House Energy
International Power Technology
Intestate Gas Services, Inc.
K&L Gates LLP
Kelly Group
Linde
Los Angeles County Integrated Waste Management Task Force
Los Angeles Dept of Water & Power
MRW & Associates
Manatt Phelps Phillips
Marin Energy Authority
McKenna Long & Aldridge LLP
McKenzie & Associates
Modesto Irrigation District
Morgan Stanley
NLine Energy, Inc.
NRG Solar
Nexant, Inc.
North America Power Partners
Occidental Energy Marketing, Inc.
OnGrid Solar
Pacific Gas and Electric Company
Praxair
Regulatory & Cogeneration Service, Inc.
SCD Energy Solutions
SCE
SDG&E and SoCalGas
SPURR
San Francisco Public Utilities Commission
Seattle City Light
Sempra Utilities
SoCalGas
Southern California Edison Company
Spark Energy
Sun Light & Power
Sunshine Design
Tecogen, Inc.
Tiger Natural Gas, Inc.
TransCanada
Utility Cost Management
Utility Power Solutions
Utility Specialists
Verizon
Water and Energy Consulting
Wellhead Electric Company
Western Manufactured Housing Communities Association (WMA)