STATE OF CALIFORNIA Edmund G. Brown Jr., *Governor*

PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
SAN FRANCISCO, CA 94102-3298

December 23, 2013

Advice Letters 3379-G/4215-E

Brian K. Cherry
Vice President, Regulation and Rates
Pacific Gas and Electric Company
77 Beale Street, Mail Code B10C
P.O. Box 770000
San Francisco, CA 94177

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

Dear Mr. Cherry:

Advice Letters 3379-G/4215-E are rejected as of December 20, 2013.

Sincerely,

Edward Randolph

Edward F. Randolph, Director
Energy Division

Pacific Gas and Electric Company®

Brian K. Cherry
Vice President
Regulatory Relations

Pacific Gas and Electric Company
77 Beale St., Mail Code B10C
P.O. Box 770000
San Francisco, CA 94177

Fax: 415.973.7226

April 19, 2013

Advice 3379-G/4215-E
(Pacific Gas and Electric Company ID U 39 M)

Advice 2887-E
(Southern California Edison Company ID U 338 E)

Advice 2473-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 Year One Research 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 research projects for the first program period and the Cooperative Research and Development Agreement (CRADA).

Purpose

The purpose of this advice letter is to comply with Ordering Paragraphs (OPs) 8, 9, 12, and 14 of Decision (D.) 12-12-031, which directs the Joint Utilities to obtain approval of the CES-21 year one research projects, budget, and CRADA. On January 24, 2013, the Executive Director of the California Public Utilities Commission (CPUC or Commission) authorized a 30-day extension of the 90-day time period in OP 9 of D.12-12-031 regarding this Tier 3 Advice Letter.

Background

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 problem solving resources to the emerging challenges of the 21st century energy system (electric and natural gas) for California. The CES-21 Program will utilize a joint team of technical experts from the Joint Utilities and LLNL who will combine data integration with the nation's most advanced modeling, simulation, and analytical tools provided by LLNL to provide unprecedented problem-solving and planning necessary to achieve California's ambitious energy and environmental goals for the 21st century. Program activities will be reviewed and approved by the CES-21 Board of Directors.

On July 18, 2011, the Joint Utilities filed Application (A.) 11-07-008 requesting authority to recover the costs for funding the CES-21 Program up to a maximum of $150 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 CPUC issued D.12-12-031 which authorized the Joint Utilities to enter into a five-year research and development agreement with LLNL. This decision authorizes the Joint Utilities to spend up to $30 million a year for five years on research activities, for a total of $150 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.

OP 6 of D.12-12-031 requires that the CES-21 Program be governed by a six member Board of Directors. Three of the Directors will be utility representatives and three Directors, chosen by the utilities, will have experience in research institutes or academic departments relevant to the research proposals. Pursuant to this directive, the Joint Utilities selected the following individuals to serve on the CES-21 Board of Directors:

Jane Yura:	PG&E, Vice President, Gas Operations Standards and Policies
Doug Kim:	SCE, Director of Advanced Technology
Jeff Nichols:	SDG&E, Director, Information Security & information Management
Daniel Kammen:	University of California, Berkeley, Director of Renewable and Appropriate Energy Laboratory and Professor in the Energy and Resources Group
K. Mani Chandy:	California Institute of Technology, Simon Ramo Professor and Professor of Computer Science
T.J. Glauthier:	Former Deputy Secretary of the Department of Energy and Advisory Board member at Stanford, the Lawrence Berkeley National Laboratory, the National Academy of Sciences and various "cleantech" companies

The Director of the CPUC's Energy Division, or the Director's designee, will serve as a non-voting liaison to the Board of Directors.

Since the issuance of D.12-12-031, there have been three meetings of the CES-21 Board of Directors. The first meeting was held on February 20, 2013. It was a workshop scheduled pursuant to OP 14 to discuss the proposed research projects. Attachment 1 includes the workshop presentation material that describes the proposed research projects that were contemplated at that time and the potential benefits and collaborators for those projects.[1] On March 19, 2013, the first Board of Directors meeting was held. At this meeting, the CES-21 Board of Directors selected Steve Larson as Executive Director to manage the CES-21 Program activities. The CES-21 Board of Directors also adopted by-laws which shall govern how the Board shall administer and implement the policies adopted by the CPUC in D.12-12-031.

Finally, on April 11, 2013, the CES-21 Board of Directors approved the proposed 18-month research portfolio and business cases, administrative budget, and CRADA included in this Advice filing.

Discussion

1. Request to extend CES-21 Year One funding authorization to 18 months and for flexibility on CES-21 Program costs

The CES-21 Program is an entirely new type of public-private collaborative project for the Joint Utilities that requires careful coordination and execution. The regulatory timeline adopted in D.12-12-031 effectively requires that the Joint Utilities begin planning to seek funding authorization for program year two within the first six months of the year one cycle. Given its start-up nature, the first six to twelve months will be a critical period for putting new systems and processes in place. To provide adequate time for the staging and start-up of research projects, the Joint Utilities plan to request through a companion Petition for Modification of D.12-12-031 to be filed shortly after this Advice filing the ability to extend the CES-21 Year One funding authorization from one year to 18 months. This will allow for an orderly ramp-up of the CES-21 proposed projects and provide a more realistic opportunity for achieving project deliverables prior to submitting the second program year Advice filing. The CES-21 proposed research projects presented in this advice letter reflect this initial 18-month funding proposal.

In order to most efficiently and effectively manage the research projects under the CES-21 Program, the Joint Utilities seek flexibility on the timing of authorized expenditures. To accomplish this, the Joint Utilities will request in an upcoming Petition for Modification of D.12-12-031 the authority to roll over any unspent funds from one program year to the next, so long as the total CES-21 Program costs do not exceed the authorized funding limit of $150 million. The Petition for Modification will also request authorization to extend the duration of the total

[1] Not all the projects identified at the workshop are included in the research portfolio proposed in this Advice filing. Since the workshop, the Hydro Modeling and Simulation project has been eliminated from the portfolio and other projects have been significantly modified.

program beyond 5 years to allow adequate time to complete the research projects and accommodate the extended first year transition period.

In addition to year-over-year expenditure flexibility, the Joint Utilities require some discretion to move funds between research projects to effectively manage the program and address unforeseen circumstances as the program is executed. The consequence of not allowing any flexibility to shift funds will be either unspent/idle funding or regulatory delay while a Commission review is completed, even for relatively small funding changes. Therefore, the Joint Utilities request through this Advice filing the flexibility to move funds between the five cost categories (i.e., Cyber Security, Electric Resource Planning, Electric System Operations, Gas System Operations, and Common Costs), subject to approval of the CES-21 Board of Directors and a cap of 5% of the CES-21 first year budget or $1.5 million. Furthermore, the Joint Utilities propose that the Executive Director have discretion to shift funds between projects or activities within the five expenditure categories as long as the budget for that category is maintained as proposed herein.

2. CES-21 Program Budget and Benefits

As authorized in D.12-12-031 and in the CRADA, the research shall be limited to $30 million in a program year and limited to $150 million during the five years of the CES-21 Program, unless otherwise authorized by the CPUC.

The Joint Utilities request the Commission approve the following 18-month program budget for the eleven research projects listed below in Table 1. These research projects range in length from 21 to 66 months. Attachment 2 includes the business cases that describe each proposed research project in more detail, pursuant to OP 12.c of D.12-12-031.

Table 1
CES-21 Proposed Research Budget

CES-21 Proposed Projects – First Program Period	Estimated 18 Month Costs	Total Potential Cost / Duration
Cyber Security		
• Advanced Threat Analysis Capability	$5.4 M	$27.0 M / 66 months
• Modeling and Simulation	$1.7 M	$8.9 M / 66 months
Electric Resource Planning		
• Ensemble Weather Forecasting	$1.9 M	$2.4 M / 21 months
• Flexibility Metrics and Standards	$1.4 M	$5.2 M /42 months
• Planning Engine	$2.0 M	$2.4 M / 21 months
Electric System Operations		
• Distribution Modeling and Optimization	$2.5 M	$5.1 M / 30 months
• Real Time Hybrid Digital Simulation	$1.9 M	$11.4 M / 66 months
• Integrated Transmission and Distribution Model	$1.5 M	$6.7 M / 54 months
• Electric System Monitoring and Control	$1.2 M	$1.5 M / 21 months
Gas System Operations		
• Geographic Data Integration for Risk Management	$1.2 M	$2.0 M / 30 months
• Advanced Modeling and Simulation Environment	$1.6 M	$5.1 M / 42 months
Common Costs		
• Advanced Computing Services[1]	$5.0 M	$25.0 M / 66 months
• Workforce Preparedness	$0.25 M	$2.25 M / 66 months
• Program Management	$2.6 M	$13.0 M / 66 months
Total	**$30 M**	**$118 M**

[1] Scaled to Project Needs

The potential research benefits of the CES-21 Program are expected to exceed the $150 million in project costs. The potential customer benefits associated with each proposed research project are described in the business case for that research. Where possible, benefits are quantified to illustrate the potential value to customers from the proposed research. Most of these potential benefits were also described at the February 20, 2013, workshop and were summarized in the workshop presentation.

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 Advanced Threat Analysis Capability 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.

The CES-21 Board of Directors along with the Executive Director, and the CPUC's Energy Division liaison will actively review each research project's progress against the milestones and deliverables identified in the business cases.

The project plans, milestones, and deliverables described in the business cases are adaptive and may evolve as the research progresses and learnings from each phase or task are identified. Revisions to any project plans, milestones, and deliverables will be documented and designed to help achieve the project's objectives. Each business case also includes specific stage gates through which the project must pass in order to continue. If a research project does not successfully pass a stage gate, the research team, with oversight from the CES-21 Board of Directors, will assess whether to re-scope the research project or terminate that work. This will ensure that the CES-21 Program is focused only on projects with the highest potential benefits and customer value. In addition, a stage-gate approach will ensure flexibility to address emerging needs in later years of the Program.

<u>Program Management Budget</u>

The Joint Utilities have included in the 18-month program a CES-21 program management budget of $2.6 million that will support the effective and efficient management of the research program. The CES-21 program management budget will cover the cost of effectively managing the current year's research program and planning the next year's program. It will also provide for appropriate compensation for the three non-utility Directors on the Board and the Executive Director functions.

The following type of activities are included in the program management function:

- Program oversight and coordination
- Budget management, forecasting, monitoring, and controls
- New research project identification and development
- Compliance with contracting requirements and goals (e.g. supplier diversity)
- Contracting and competitive solicitations
- Soliciting and managing third party activities
- CES-21 Board of Director meetings, workshops, and stakeholder meetings (year-in-review and upcoming year)
- Compliance with regulatory requirements (e.g., advice filings; reporting)
- External CES-21 Program communications and outreach
- Soliciting and managing co-funding opportunities (i.e., U.S. Department of Energy (DOE))

The following table shows the Joint Utilities' cost estimate for program management activities for the first 18-month program year:

Table 2
Estimated CES-21 Program Management Expenditures over 18 months

Program Management Activities	Cost Estimate
Joint Utilities and LLNL Program Oversight and Coordination	$995,000
Office of Executive Director	$500,000
Board of Directors Compensation and Reimbursement	$95,000
Preparation of Second Program Year Research Portfolio and Budget	$800,000
Third Party Management	$100,000
External Communications and Outreach	$110,000
Total	**$2,600,000**

a. Joint Utilities and LLNL Program Oversight and Coordination

Each Utility and LLNL will be responsible for maintaining program oversight and coordination in order to support CES-21. This program management function includes budget management with each of the Joint Utilities and at LLNL, forecasting of resources needs to support the program, and monitoring and control of the research projects to ensure deliverables are being met. In addition, the Joint Utilities and LLNL will ensure compliance with all contracting requirements and goals, including supplier diversity.

The cost estimate for program oversight and coordination is $995,000.

b. Office of the Executive Director

The primary role of the CES-21 Executive Director will be to design, develop, and implement strategic plans for the CES-21 Program as well as manage the day-to-day CES-21 operations in collaboration with the Board of Directors and program management staff from LLNL. In addition, the Executive Director will facilitate coordination with the CPUC, California Energy Commission (CEC), and California Independent System Operator (CAISO), including on regulatory issues such as advice letters, workshops, briefings, seminars, regulatory proceedings, and inquiries. An important element of the Executive Director's responsibilities will be to promote close working relationships between the LLNL research team members and the Joint Utilities' team members, to ensure the Joint Utilities' research needs are being addressed and that other stakeholders' issues are considered, and to ensure CES-21 research initiatives are consistent with D.12-12-031 and directives of the CPUC. Furthermore, the Executive Director will conduct outreach to encourage collaborative opportunities with state and federal government institutions as well as academia, research institutes, industrial entities, and other state officials. It will be critical for the Executive Director to make every effort to ensure research initiatives are not duplicative of research in other areas. In particular, the Executive Director will maintain a close relationship with CEC and Joint Utilities' Energy Program Investment Charge (EPIC) managers, Electric Power Research Institute (EPRI), and DOE funded research (e.g. American Recovery and Reinvestment Act (ARRA), Advanced Research Projects Agency-Energy (ARPA-E)) to integrate work plans in order to be supportive and not duplicative. Lastly, the Executive Director will represent CES-21 in industry and public forums, making presentations as appropriate regarding CES-21 accomplishments, operations, and strategies.

The $500,000 cost estimate includes compensation for the Executive Director, the cost of support services necessary to carry out the Executive Director's responsibilities, and reimbursement for reasonable expenses.

c. Board of Directors Compensation and Reimbursement

The Board of Directors are responsible for administering and implementing the CES-21 Program, as approved and authorized by the CPUC. In accordance with the CES-21 by-laws, the Board of Directors will approve a strategic plan, annual budgets, and allocation of staff and other resources to provide services under individual work orders requested by the Joint Utilities. The Board of Directors will also approve all funding of projects to support the work orders, including procurement of equipment, facilities, tools, computer software, and hardware. In addition, the Board of Directors will provide an annual report to the Commission's Executive Director. In this capacity, the Board of Directors will hold quarterly meetings (unless otherwise required) and advisory meetings to conduct the official business of the CES-21 Program.

The $95,000 cost estimate includes compensation for the three non-utility Directors and reimbursement for reasonable expenses.

d. Preparation of Second Program Year Research Portfolio and Budget

The Joint Utilities and LLNL will be responsible for preparing the second CES-21 program year research portfolio and budget. This work will begin approximately 9 months prior to the start of the second program year due to the regulatory timeline adopted by the CPUC. In order to accomplish this, the Joint Utilities and LLNL will evaluate the 18-month research progress as well as developments in energy policy and advances in energy technologies.

The $800,000 cost estimate for this activity is based on an assessment of the LLNL, Joint Utilities, and other resources that will be required to develop new research concepts, the research portfolio, workplans, and cost estimates for the second program year.

e. Third Party Management

The CES-21 Program will actively explore collaborative activities with third party vendors and research institutions in order to achieve the research project objectives as approved by the Board of Directors. The CES-21 Program intends to sponsor workshops with third parties and hold solicitations to further evaluate these opportunities.

The $100,000 cost estimate for third party management will cover the cost of outreach and development of third-party commercial arrangements.

f. External Communications and Outreach

The Joint Utilities recognize the constant need for external communications and outreach to support the CES-21 Program. The Executive Director, the Joint Utilities, and LLNL will develop and execute an integrated communications program that effectively presents the CES-21 to regulators, legislators, research institutions, and the media.

The cost estimate for this activity is $110,000.

While the Joint Utilities will strive to operate within this proposed budget, there is more uncertainty than usual over this cost estimate given the start-up nature of the program. The Joint Utilities propose to subject the CES-21 Program to a not-to-exceed 10% administrative cost cap, which would result in a program management (PM) budget cap of $3 million. Any recovery of PM costs in excess of $3 million for the first program year will be subject to review and approval by the CPUC in a future Advice filing.

Workforce Preparedness

The CES-21 Workforce Preparedness program will ensure the tools and technologies developed in the CES-21 research areas are effectively integrated with current and future Utility and other Stakeholder staff. A budget of $250,000 is proposed for each program year. Activities will include workshops, tutorials, hands-on practice, and testing with various simulated real world planning and operations scenarios. Students of the program will be guided through steps that will transition them from the current work tools environment to use of the new tools, interpretation of results from those tools, and understanding of the capabilities and limitations of the tools. Elements of workforce preparedness will also focus on establishing a workforce that is prepared to create even better tools for the future so the program may endure after each research project is completed.

Key delivery elements of the program include:
- Physical, in person, group training both at the Utility offices and at LLNL
- Video and web training, both real time and taped for use later
- Written course material for study
- Case studies and simulation examples
- Collaborative activities with key teaching faculty at colleges and universities throughout California to incorporate elements of this program into college curricula

The first 18 months will be a start-up period since many of the new tools will have yet to be developed. Deliverables in the first year include:
- Create collaborative activities between workforce development staff at LLNL, the Joint Utilities, and stakeholder organizations and college and university teaching staff
- Create the basic infrastructure of the training program including selection of web tools, video resources, and network of instruction locations
- Create effective documentation and examples of research by working hand-in-hand with research area team members so results can be effectively converted to course material

<u>Advanced Computing Services</u>

The complexity of today's energy industry challenges requires new tools and techniques. While traditional desktop simulations work well for a variety of analyses and applications, the high power computing capabilities of LLNL will provide a quantum leap in the Joint Utilities' ability to analyze more data faster.

LLNL, as one of the preeminent centers in the world for solving complex problems with modeling development and engineering, will leverage its advanced computing capabilities. The cost for these services is estimated to be approximately $5 million for the first 18 months.

LLNL's advanced computing capabilities center around three technological foci: computational advancement, data science and informatics, and collaboration and outreach.

a. Computational Advancement

- High Performance Computing (HPC) for Simulation

  LLNL's HPC platform is focused on addressing highly complex problems and research needs of all CES-21 projects. This will involve the use of world class computing power using some of the most capable computing available in the world today. Services include the operation and maintenance of the platform, user support, system-administration, necessary base high performance computing operating and solving software (including some system software licensing costs), help lines, and consulting services on use of the machine.

- Virtualization Test-bed

  LLNL provides the resources for enabling non-HPC-enabled software to run on LLNL's HPC platforms (initially, before they are ported and scaled). Any required software will be integrated into the Advanced Computing workflow, allowing input and output directly to shared disks, common databases, or possibly directly via client-server interactions with HPC-enabled back-end solutions. This enables streamlined mixed platform computation.

- Porting and Software Tuning

  LLNL will adapt codes to run more efficiently on HPC platforms, making the research projects themselves more efficient. This work includes porting, coupling of codes, optimization, and prototyping of methods using existing tools to identify the most cost-effective solution.

b. Data Science and Informatics

- Data Science Services

  LLNL will provide both platforms for doing advanced data analytics (e.g. Hadoop-like services), as well as provision of analytics research services that leverage existing lab programs and research activities in big data to serve the needs of CES-21 projects. This includes analytics, machine learning, and informatics techniques.

- Storage and Security

  LLNL offers large scale dedicated storage of raw data, using data management processes and workflow to ensure data provenance is known. Data will also be made anonymous or summarized as necessary to ensure no customer specific information is shared. Secure web-based data sharing portals will make data available to stakeholders according to established data sharing policies.

- Visualization

  LLNL will develop tools for visualizing and interpreting the results of high fidelity simulations, including any necessary data post processing. These may range from existing in-house tools, open source tools, or other third party tools. LLNL will also perform customizations that are needed to serve the data visualization needs of CES-21 projects.

c. Collaboration and Outreach

- Commercial Software License Management

  LLNL will be responsible for the management of software licenses necessary to accomplish project objectives, in particular as it relates to using software on multi-processor machines.

- Collaboration Tools

  LLNL will also be responsible for the maintenance and development of a common software tool suite for CES-21 projects. This will be a web-based suite providing valuable collaboration tools, most of which are integrated, including Confluence (wiki), Jira (issue tracking), and Stash (version control).

- Technology Transfer

  LLNL will support the transition of the software tools developed in CES-21 to the Joint Utilities and their approved vendors and collaborators. This could include supporting commercialization pathways with software vendors, developing an open source community with software service providers, and transitioning software to Joint Utilities-supported platforms (e.g. cloud solutions or reduced order models).

3. Cooperative Research and Development Agreement (CRADA)

Under the CES-21 Program, PG&E, SCE, SDG&E, and LLNL have negotiated a CRADA, consistent with OP 10 of D.12-12-031, which will be executed upon approval by the Commission and the DOE. 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 3 to this Advice filing.

In accordance with D.12-12-031, the CRADA conforms to the guidelines established by the CPUC:

- The CRADA Should Restrict Research Projects to Four Promising Areas (D.12-12-031, p. 50-55, OP 10)
- The CRADA Shall Limit Yearly and Total Expenditures (D.12-12-031, p. 55-56, OP 10)
- Implementing Advice Letters Shall Allocate and Recover Costs Consistent with the Cost Allocation and Recovery Proposals (D.12-12-031, p. 56-57, OP 10)
- Research Projects Conducted Under the CRADA Must Meet Specific Criteria (D.12-12-031, p. 57-58)
- The Board of Directors Shall Number Six with Three Members Chosen from Academia or Research Institutes (D.12-12-031, p. 64-65, OP 10)

Intellectual Property Issues

As specified in OP 18 of D. 12-12-031, the Joint Utilities have the option to jointly retain title and authority to license any intellectual property produced or derived from the CRADA, and upon request the Joint Utilities will license such intellectual property on fair, reasonable and non-discriminatory grounds to Lawrence Livermore National Security, LLC (LLNS) and third parties for a fair and reasonable licensing fee, subject to Commission approval as appropriate and also subject to rights retained by the U.S. Federal Government under the CRADA. (D.12-12-031, OP 18)

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. After approval of the business cases by the CPUC, workshops will be convened in each of the research areas for purposes of gaining further input on the projects and soliciting interest in participating in the research. After these workshops, the Joint Utilities, in collaboration with LLNL, the Board of Directors and the Executive Director, will decide how to collaborate with third parties. The CRADA provides flexibility for either LLNL or the Joint Utilities to contract with third parties on the research.

4. Request for Commission Approval

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

a. Approves the research projects presented in this Advice filing and included in Attachment 2;
b. Approves a budget of $30 million for the first program period as presented in Table 1;
c. Authorizes that the first program period will be 18 months beginning on the effective date of the resolution approving this Advice filing, contingent upon approval of the Joint Utilities' Petition for Modification;
d. Authorizes the CES-21 Board of Directors to shift funds between expenditure categories equal to no more than 5% of the adopted annual budget or $1.5 million and the Executive Director to shift funds as needed between projects or activities within the expenditure categories; and
e. Approves the CRADA provided in Attachment 3 to 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 9, 2013** 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:

Brian K. Cherry
Vice President, Regulatory Relations
Pacific Gas and Electric Company
77 Beale Street, Mail Code B10C
P.O. Box 770000
San Francisco, California 94177
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c/o Karyn Gansecki
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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

PG&E requests that this Tier 3 advice filing become effective *upon approval by the CPUC*.

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

Vice President, Regulatory Relations

Attachment 1: CES-21 Workshop Presentation, February 20, 2013
Attachment 2: CES-21 Proposed Projects Business Cases – First Program Period
Attachment 3: 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 M)**

Utility type:	Contact Person: Kimberly Chang
☑ ELC ☑ GAS	Phone #: (415) 972-5472
☐ PLC ☐ HEAT ☐ WATER	E-mail: kwcc@pge.com and PGETariffs@pge.com

EXPLANATION OF UTILITY TYPE	(Date Filed/ Received Stamp by CPUC)
ELC = Electric GAS = Gas PLC = Pipeline HEAT = Heat WATER = Water	

Advice Letter (AL) #: **PG&E 3379-G/4215-E** **Tier: 3**
SCE 2887-E
SDG&E 2473-E

Subject of AL: **California Energy Systems for the 21st Century Proposed Year One Research 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

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:

Confidential information will be made available to those who have executed a nondisclosure agreement: ☐ Yes ☐ No

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
Attn: Brian Cherry
Vice President, Regulatory Relations
77 Beale Street, Mail Code B10C
P.O. Box 770000
San Francisco, CA 94177
E-mail: PGETariffs@pge.com

Attachment 1:

CES-21 Workshop Presentation, February 20, 2013

CES21

California Energy Systems for the 21^{st} Century

California Energy Systems for the 21^{st} Century Workshop

February 20, 2013

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California Energy Systems
for the 21st Century

CES-21 Workshop Agenda

- Welcome: Brian Cherry
- Introductions: Brian Cherry
  - CES-21 Board of Directors: Jane Yura, Doug Kim, Jeff Nichols, Dan Kammen, Mani Chandy, T.J. Glauthier
  - Liaison to Board of Directors: Ed Randolph
- Overview of Workshop Objectives: Erik Jacobson
  - Discussion of the proposed research and priorities
  - Review the business case for proposed research
- Research Area Presentations + Q&A
  - Cyber Security: Steve Knaebel (PG&E), Scott King (SDG&E), Efrain Gonzalez (SCE) & John Grosh (LLNL)
  - Electric Resource Planning: Antonio Alvarez (PG&E) & Tom Edmunds (LLNL)
  - Electric Operations: Robert Sherick (SCE) & Liang Min (LLNL)
  - Gas Operations: François Rongere (PG&E) & Lee Glascoe (LLNL)
- Next Steps: Erik Jacobson
  - Updates to CES-21 research projects and business cases
  - Next CES-21 Board Meeting
- Adjourn: Erik Jacobson

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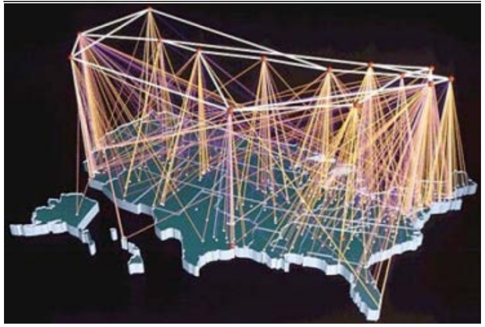
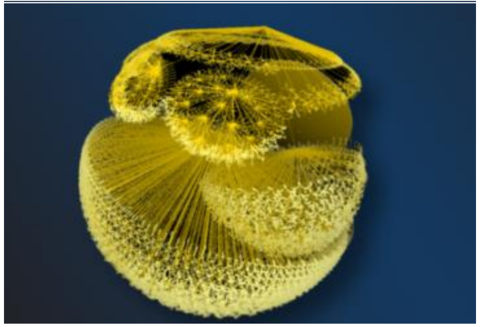
CES-21 is built around areas of collaboration

		
Electric Resource Planning	**Electric and Gas System Operations**	**Cyber Security**
▪ Planning (day to years ahead) simulations at scale ▪ Wind, hydro, and solar forecasting ▪ Impact of intermittency associated with renewables	▪ Operations (seconds to minutes ahead) simulation at scale ▪ Storage and demand response ▪ Real-time diagnostics and control	▪ Analytics and situational awareness of the grid ▪ Efficient algorithms to effectively capture, analyze, and share data on demand
Advanced Computing Services		

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CES-21 Potential Projects

CES-21 Potential Projects – Year 1	Estimated First Year Costs	Total Cost/Duration
Cyber Security		
• Advanced Threat Analysis Capability • Modeling and Simulation	\$8.3M \$2.8M	\$41M/5 years \$14M/5 years
Electric Resource Planning		
• Ensemble Weather Forecasting • Hydro Modeling and Simulation • Flexibility Metrics and Standards • Planning Engine	\$2.7M \$1.3M \$3.3M \$4.6M	\$9M/3 years \$9M/5 years \$9M/3 years \$21M/5 years
Electric System Operations		
• Distribution Modeling and Optimization • Real Time Hybrid Digital Simulation • Integrated Transmission and Distribution Model • Electric System Monitoring and Control	\$3.0M \$3.8M \$2.8M \$3.3M	\$6M/2 years \$15M/5 years \$9M/3 years \$14M/4 years
Gas System Operations		
• Geographic Data Integration for Risk Management • Advanced Modeling and Simulation Environment	\$1.7M \$2.2M	\$5M/3 years \$12M/5 years

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Cyber Security

"A cyber-attack perpetrated by nation states or violent extremist groups could be as destructive as the terrorist attack of 9/11. Such a destructive cyber-terrorist attack could virtually paralyze the nation. … We know of specific instances where intruders have successfully gained access to these control systems. We also know that they are seeking to create advanced tools to attack these systems and cause panic and destruction and even the loss of life."

- Secretary of Defense Leon Panetta

Steve Knaebel (PG&E)

John Grosh (LLNL)

Scott King (SDG&E)

Efrain Gonzalez (SCE)

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Cyber Security potential projects

- Advanced Threat Analysis Capability
  - Develop tools and algorithms to analyze large amounts of the IOU network data to detect advanced cyber attacks and improve situational awareness; develop tools to determine vulnerabilities in hardware, firmware, and software that support the operation of California's critical infrastructure.
- Modeling and Simulation
  - Build computational simulation codes that couple the industrial controls systems communication infrastructure with generation, transmission and distribution networks, storage, and loads to simulate cyber attack and defense.

President Obama's State of the Union address highlighted new efforts to improve cyber security for critical infrastructure.

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Cyber Security potential project
Advanced Threat Analysis Capability

Need:

A highly-coordinated cyber attack on CA power system could result in long-term, difficult-to-repair damage to key system components across the state. Existing tools lack the ability to detect new classes of advanced cyber attacks across industrial control systems (ICS) across the 3 IOUs. Identifying new vulnerabilities in ICS software and hardware is labor intensive and challenging. IOUs need new analytic technologies to address new threats and reduce impact of cyber attacks.

Objective:

This project includes two key components:

- **Situational Threat Awareness:** Develop tools and algorithms to mine and analyze large amounts of the IOU operational data over long periods of time to discover and implement corrective actions to reduce the impact of advanced threats on California's critical infrastructure.
- **Vulnerability Analysis:** Develop tools to determine the extent of cyber vulnerabilities in hardware, firmware, and software that support the operation of California's critical infrastructure.

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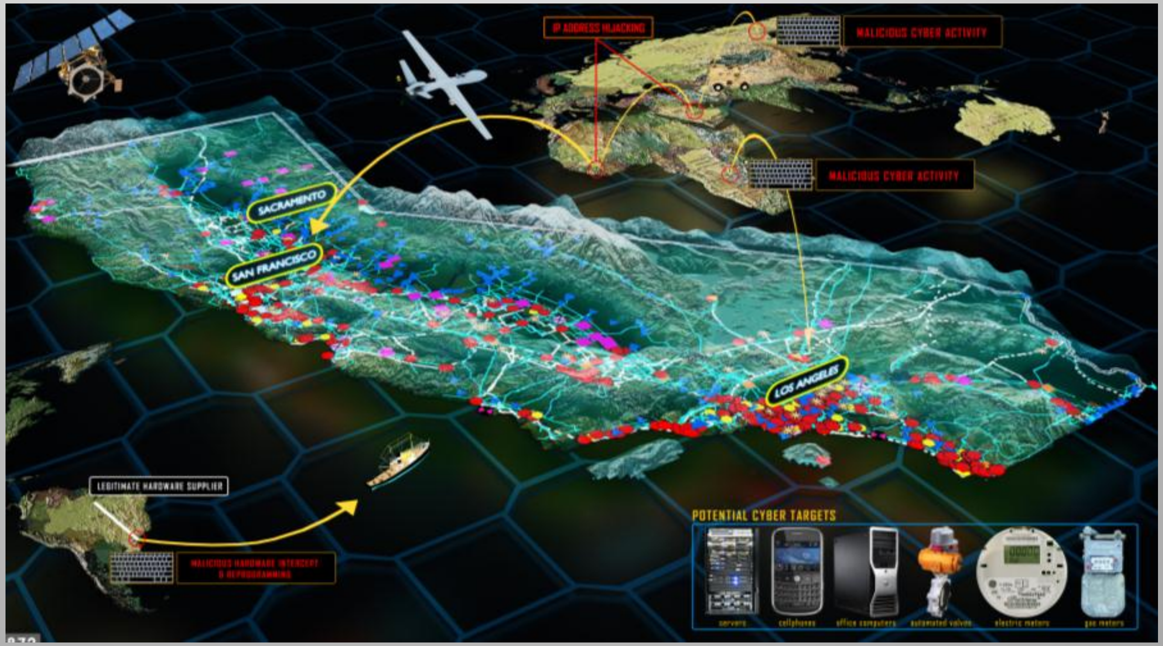
Cyber Security potential project
Advanced Threat Analysis Capability

Approach:

- Situational Threat Awareness (PM1-60)
- Vulnerability Analysis (PM9-60)
- Transition to IOUs (PM36-60)



Cyber Security potential project
Advanced Threat Analysis Capability

Research or service needed	Potential Collaborators
Device and control testing and evaluation and situational awareness tools	1. Sandia National Laboratories 2. Idaho National Laboratory 3. Pacific Northwest National Laboratory 4. EPRI 5. NERC 6. DHS

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Cyber Security potential project

Advanced Threat Analysis Capability

Potential customer benefits

1. Define and develop "forward looking" technology, strategies and tools that will further strengthen the grid against cyber based attacks.
2. Increase the security of California's critical infrastructure by creating new capabilities to prevent advanced attacks that existing technologies do not address.
3. Enable the California utilities to better understand the relationships between vulnerabilities in cyber systems and their impact to critical components within the electric grid.
4. Develop the capability to assess the likelihood of successful grid impacting cyber-attacks, determine the optimal placement of preventative security controls, and reduce the risk of a cyber-attack that would cause large scale grid impacts.

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Cyber Security potential project
Modeling and Simulation

Need:

Emerging cyber threats require detailed models to identify vulnerabilities and develop mitigation strategies. Because the grid is coupled at several levels, a comprehensive model has to be developed to a sufficient level of detail to identify vulnerabilities and paths across those levels. The increasing use of devices with two-way communication creates an emerging threat to grid control systems. These devices and their interaction with utility back office systems and control systems are growing in complexity. Detailed models identifying control characteristics and communication protocols have not been developed for a large-scale analysis across the State of California.

Objective:

We propose to build and successively refine a computational model that couples

- Communication infrastructure
- Primary electric generation and transmission behavior
- Utility distribution networks
- End-user loads and generation
- Utility ICS systems

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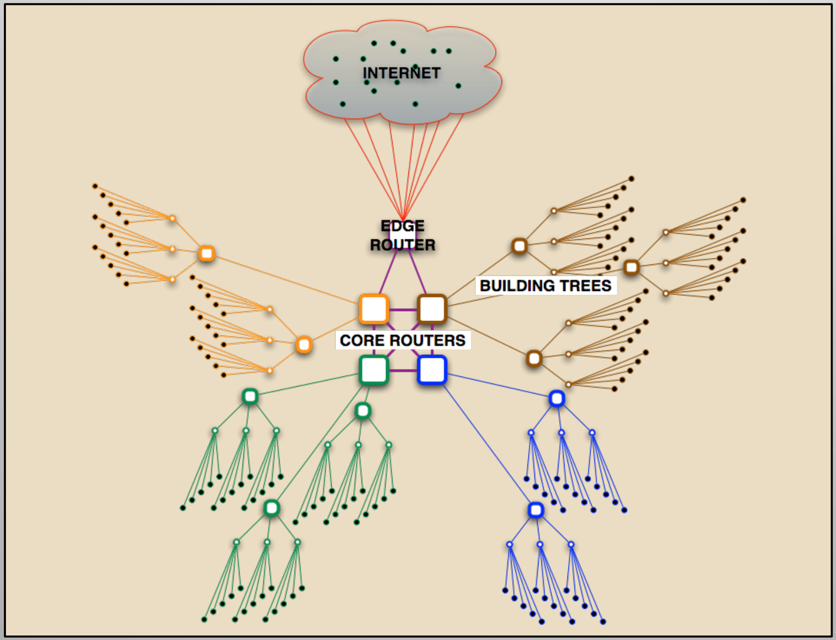
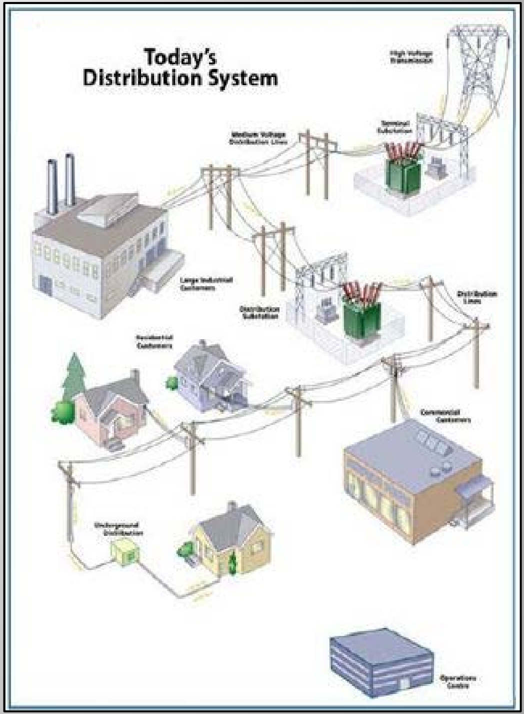
Cyber Security potential project
Modeling and Simulation

Approach:

- Baseline Device, Topology and Traffic (PM1-60)
- Coupled Model Development (PM6-44)
- Cyber Attack Scenarios and Modeling (PM18-60)





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Cyber Security potential project

Modeling and Simulation

Research or service needed	Potential Collaborators
Communication / Grid Modeling and Simulation Tools	1. University of Illinois 2. Pacific Northwest National Laboratory 3. Oak Ridge National Laboratory

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Cyber Security potential project
Modeling and Simulation

Potential customer benefits

1. As a planning tool in assessing operational benefits and risk reduction that could be realized by future grid improvement proposals. Such information would enable rapid quantitative assessment of potential benefits as part of developing future rate cases
2. Explore and evaluate incident response scenarios in advance of need, to improve the time to respond and recover
3. Capability to replay cyber incidents, with variations, to understand the range of risk exposures in similar situations, and the possible consequences of response strategies other those utilized at the time of incident

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Questions

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Electric Resource Planning

Integrate high resolution weather and electric resource models to improve accuracy and uncertainty definition of weather-based generation, reduce operating costs, and improve planning and investment decisions given RPS and other structural changes under way

Antonio Alvarez (PG&E)

Tom Edmunds (LLNL)

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Electric Resource Planning proposed projects

- Ensemble Weather Forecasting of Wind/Solar Generation
  - Develop an ensemble-based forecasting system to improve forecast accuracy and provide uncertainty bounds for wind and solar generation
- Hydro Modeling and Simulation
  - Develop hydrographic data network and predictive modeling toolbox to support hydropower planning and operations activities
- Flexibility Metrics and Standards
  - 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. Develop models to estimate flexibility deficiencies
- Planning Engine
  - Develop higher resolution, larger-scale models of transmission and alternatives to integrate renewable generation such as demand response, and energy storage

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Electric Resource Planning
Ensemble Weather Forecasting

Need:

New forecasting approaches are needed to integrate large amounts of weather-based electricity generation. New forecasts must improve the prediction and uncertainty measurement of weather parameters and renewable generation

Objective:

- Determine the optimal weather forecasting approach for renewable power generation
- Improve renewable generation predictions and uncertainty of weather and renewable generation for operation
- Deliver real-time ensemble-based forecasts for CAISO and utilities to compare the ensemble-based forecast to existing forecasts

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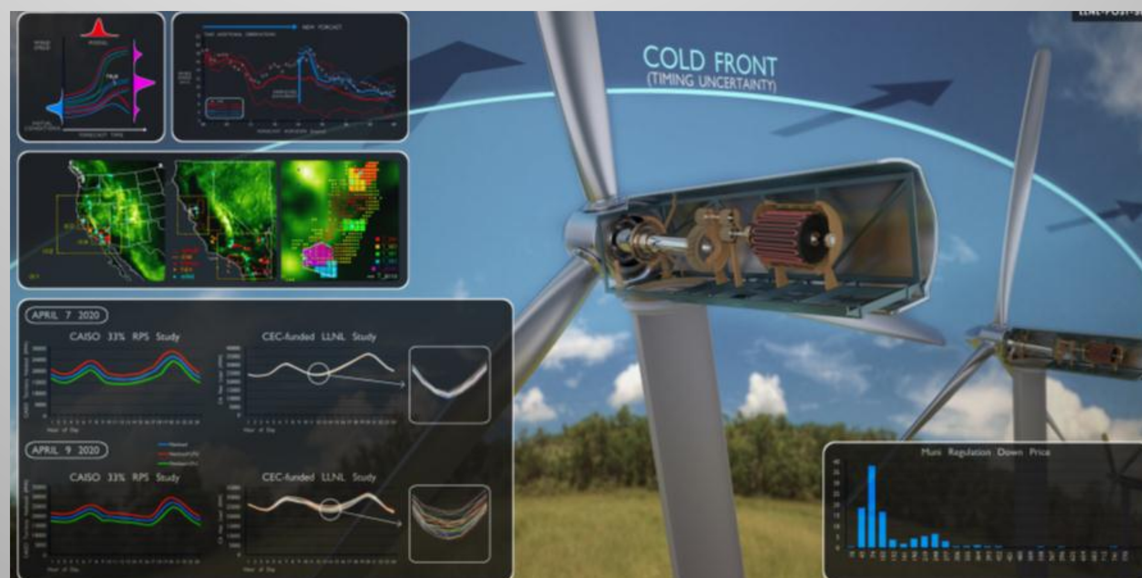
Electric Resource Planning

Ensemble Weather Forecasting

Approach:

- Build infrastructure for computations, data analysis, and data sharing (PM1 -12)
- Produce and provide ensemble forecasting to CAISO and IOUs (PM6-33)
- Evaluate statistical performance of forecasting methodology (PM30-36)
- Report benefits of approaches. Recommend how prototype operational forecasting tools can be implemented by vendors, CAISO or IOUs (PM36)



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Electric Resource Planning
Ensemble Weather Forecasting

Research or service needed	Potential Collaborators
Experience evaluating the use of ensemble forecasts in an operational setting	1. CAISO 2. Vendors of weather and generation forecasts
Extensive experience in ensemble forecasting, especially multi-analysis forecasting, developer of WRF	1. NCAR
Wind and solar resource data sets	1. CAISO 2. NREL 3. Vendors of weather and generation forecasts
End user of wind forecasts, experience in making weather-to-power conversions	1. Infigen 2. Cool Earth Solar
Expertise in solar tracking and short term prediction	1. UCSD

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Electric Resource Planning

Ensemble Weather Forecasting

Potential customer benefits

1. The CAISO can better predict net load, ramping and new flexibility reserves like load following requirements
   - Purchase the necessary reserves to account for the net load uncertainty faced on a daily basis.
   - Purchase additional reserves for days when the net load forecast is highly uncertain, thereby reducing the chance of over/underproduction and the expenses associated with them.
2. The IOUs and other wind/solar generation owners benefit from improvements in the overall accuracy and uncertainty of predicted generation
3. Customers ultimately benefit from lower cost of electricity and increased reliability ($30 million per year by reducing load following costs per CES-21 application)

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Electric Resource Planning

Hydro Modeling and Simulation

Need:

Better knowledge of snowpack, snow water content, runoff, and groundwater discharges to enhance use of hydro generation.

Prediction, planning, and management of hydropower resources relies on accurate and timely knowledge of water availability for generation stations.

Objective:

- Improve hydrologic data, modeling, and scheduling capabilities to more effectively manage limited hydro resources. (The initial research will be based on PG&E's East Branch of the upper North Fork Feather River hydroelectric system.)

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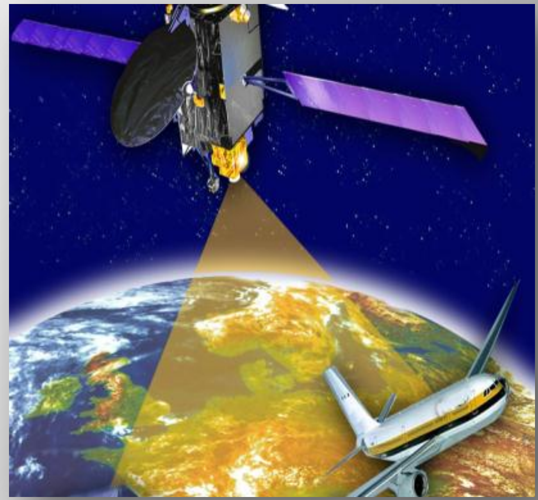
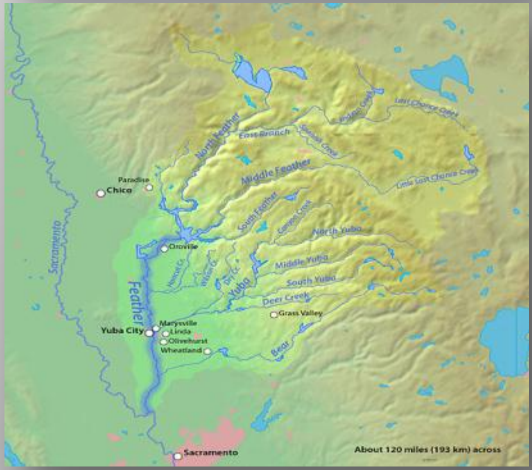
Electric Resource Planning
Hydro Modeling and Simulation

Approach:

- Develop Information Management System to retrieve data daily (PM1-8)
- Develop infrastructure for a network of ground-based sensors (PM12-36)
- Develop Modeling Toolbox for forecasting water availability (PM1-36)
- Improved decision making tools (PM30-60)





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Electric Resource Planning
Hydro Modeling and Simulation

Research or service needed	Potential Collaborators
Flexible information-management capabilities for hydrologic data	1. UC Merced (Sierra Nevada Res. Inst.) 2. UC Berkeley (CITRUS)
Satellite snow cover products	1. JPL/NASA
Expanded ground-based hydrologic sensor networks	1. State of California, DWR 2. State of California, CEC (EPIC)
Support for PRMS operational model used by PG&E	1. USGS 2. UC Merced (Sierra Nevada Res. Inst.)

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Electric Resource Planning
Hydro Modeling and Simulation

Potential customer benefits

1. Less lost water – Reduction in water spills
2. Higher value of hydro generation
3. New decision making tools – transferable to other watersheds
4. Non-quantifiable safety benefits, flood protection and management

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Electric Resource Planning

Flexibility Metrics and Standards

Need:

New operating flexibility metrics and targets are needed for long-term resource planning in California. Improvements to methodology and models are also needed to determine resource need for increased operating flexibility requirements

Objective:

- Review existing flexibility metrics and tools now in use and under development to identify resource needs
- Define flexibility metrics, such as insufficient ramping capacity
- Use high performance computing to operationalize flexibility metrics for planning purposes, as new flexibility metrics or modified reliability metrics
- Use LLNL's expertise to develop new or improved models that incorporate flexibility metrics with traditional production simulation and reliability models

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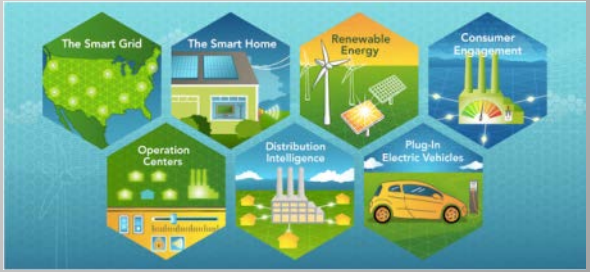
Electric Resource Planning
Flexibility Metrics and Standards

Approach:

- Define problem and characteristics of tools to needed to address the problem (PM1-3)
- Select base model (PM3-5)
- Develop the infrastructure to generate multiple weather dependent data (PM6-10)
- Develop the infrastructure to automate the running of many scenarios in batch mode through the optimizer (PM10-16)
- Develop Flexibility Metrics (PM16-20)
- Develop a prototype model to quantify flexibility metrics (PM20-30)
- Integrate the flexibility metric prototype with the base model (PM30-33)
- Document new or improved model (PM34-36)



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Electric Resource Planning

Flexibility Metrics and Standards

Research or service needed	Potential Collaborators
Simplified representation of weather uncertainty and its impact on load, wind and solar generation	1. CAISO 2. Consultants (Energy Exemplar, E3) 3. Vendors of weather and generation forecasts
Dynamic representation of flexibility requirements as weather uncertainty evolves during operating horizon	1. CAISO 2. Regulators (CPUC, FERC) 3. Research organizations (LBNL, EPRI, Dublin and other universities)
Ability to evaluate simplifications to representation of weather uncertainty and other inputs to production simulation models	1. CAISO 2. Consultants (Energy Exemplar, E3) 3. Research organizations (LBNL, EPRI, Dublin, other universities)
Ability to measure operating flexibility deficiencies, and contribution of resources to meet system needs	1. CAISO 2. CPUC 3. Parties to LTPP and RA proceedings

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California Energy Systems for the 21st Century

Electric Resource Planning

Flexibility Metrics and Standards

Potential customer benefits

1. More accurate estimate of flexibility requirements given a resource mix and operating policies for unit commitment and dispatch
2. Quantification of resource need
3. Identification of cost effective additions to provide flexibility
4. In CES-21 application these were estimated at a value of $552 million through improved resource planning

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Electric Resource Planning

Planning Engine

Need:

Higher resolution models with improved solution algorithms are needed to analyze systems with many intermittent generators and millions of distributed resources to improve generation and transmission investment decisions

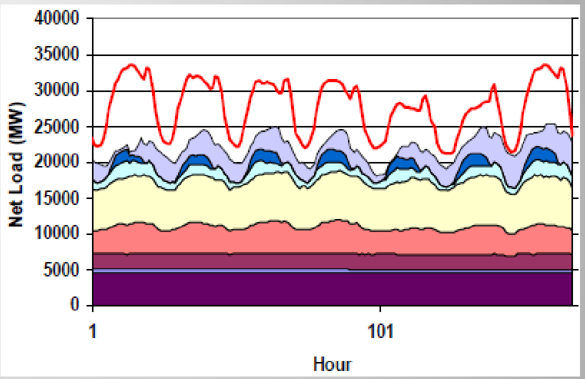
Objective:

- Better model resolution of transmission system to identify preferred location of resource additions and desired transmission reinforcements
- Inputs to transmission reliability models that incorporate the weather uncertainty associated with variable generation
- Close coupling of generation and transmission investment decisions
- Methodology and analytical tools to evaluate the feasibility and effectiveness of potential new demand response, energy storage, and other resource additions to satisfy operating flexibility metrics and standards

Electric Resource Planning
Planning Engine

Approach:

- Common building block and potential synergies from close coordination with other business cases (PM6)
- Enhanced representation of the transmission system in production simulation models (PM1-36)
- Enhanced inputs to transmission system planning models (PM12-48)
- Design and test tools for evaluation of demand response programs, energy storage and other alternatives for renewable integration (PM12-24)
- Investment and market analysis tools (PM12-24)
- IT infrastructure planning (PM24-45)



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Electric Resource Planning

Planning Engine

Research or service needed	Potential Collaborators
Better model resolution of transmission system to identify the preferred location of new resource additions and grid reinforcements	1. CAISO 2. Regulators (CPUC, FERC) 3. Vendors (Plexos, GE)
Inputs to transmission reliability models that incorporate the weather uncertainty associated with variable generation	1. CAISO 2. Research organizations (EPRI) 3. Software vendors
Methodology and analytical tools to evaluate the feasibility and effectiveness of demand side programs, energy storage and other alternatives for renewable integration	1. CAISO 2. Regulators (CPUC, FERC) 3. Consultants (Energy Exemplar, E3) 4. Demand response suppliers

Electric Resource Planning
Planning Engine

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California Energy Systems for the 21st Century

Potential customer benefits

1. Improved planning tools to identify cost effective generation and transmission additions
2. Lower operating costs and emissions with more effective algorithms for unit commitment and economic dispatch
3. Understanding how demand response, energy storage and other flexible resources can contribute to renewable integration
4. Improved reliability with better representation of weather uncertainties, transmission limitations

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Questions

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California Energy Systems for the 21^{st} Century

Electric System Operations

High fidelity models of multiple grid components will be developed, and then integrated to inform system-based simulations of grid operations. These simulations will inform operational decisions and shape the design of future monitoring and control systems.

Robert Sherick (SCE)

Liang Min (LLNL)

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Electric System Operation potential projects

- Distribution Modeling and Optimization
  - Develop a detailed model of the distribution grid, analyze various emerging technology adoption scenarios, determine market and control mechanisms that would optimize the balancing of resources and demand, and review the impacts on grid infrastructure
- Real Time Hybrid Digital Simulation
  - Develop high-performance hybrid digital simulator supporting integrated electromechanical and electromagnetic transient simulations to evaluate impacts from intermittent resources on system stability
- Integrated Transmission and Distribution Model
  - Develop an integrated transmission and distribution model to analyze reliability impacts of increased renewable penetration in the distribution network and identify restoration capabilities during large scale system outages
- Electric System Monitoring and Control
  - Develop tools and methods to analyze synchrophasor patterns and system events to improve transmission system monitoring; identify mitigation strategies to improve the stability of the transmission system during stress conditions

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Electric Operations potential project

Distribution Modeling and Optimization

Need:

Emerging technology devices (e.g. photovoltaic panels, controllable thermostats, plug-in electric vehicles, storage) are being interconnected to the distribution grid allowing new opportunities to balance resources and demands. These devices are presently encouraged through a series of incentive programs that are intended to increase the adoption of the technology, but there is no mechanism to optimize across the technologies.

Objective:

- Develop a detailed model of the distribution grid
- Build adoption scenarios for renewable generation, plug-in electric vehicles, demand response, and storage
- Analyze impacts to customers and the grid of different adoption scenarios
- Identify market mechanisms to enable interaction amongst devices to optimize resources and minimize consumption

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Electric Operations potential project
Distribution Modeling and Optimization

Approach:

- Modeling Framework and Model Development/Validation (PM1-12)
- Computational Runs, Analysis, Recommendations (PM13-24)

3

Electric Operations potential project
Distribution Modeling and Optimization

Research or service needed	Potential Collaborators
Distribution grid modeling tools	1. Pacific Northwest National Laboratory 2. EPRI 3. CYME 4. ETAP
Market Optimization	1. California Institute of Technology

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Electric Operations potential project

Distribution Modeling and Optimization

Potential customer benefits

1. Improved planning and reduced costs through improved understanding of technology adoption scenarios across the state
2. Identify Energy Efficiency and Demand Response opportunities across the state
3. Identify rate impacts to different customer classes and technology adopters
4. Evaluate voltage and VAR control and implementation strategies
5. Quantify the value derived from control of smart inverters
6. Identify market and control systems to optimize resources and demand within a region

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Electric Operations potential project

Real Time Hybrid Digital Simulation

Need:

The stability of the grid's frequency has traditionally relied on the mechanical inertia resulting from rotating machines. Recently, an increasing proportion of energy from PV and wind generation in California feeds the grid through solid-state, switch-controlled electronics which lack the mechanical inertia from rotating machines and whose dynamic behavior does not inherently stabilize the grid.

Objective:

- Develop high-performance hybrid digital simulator that integrates electromechanical and electromagnetic transient simulation
- Leverage existing tools and models developed on the real-time simulator at the California IOUs
- Leverage speed and memory available on a High Performance Computing platform

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Electric Operations potential project

Real Time Hybrid Digital Simulation

Approach:

- Prototype coupled software simulator (PM1-12)
- High Performance Dynamic Stability Assessment Tool (PM3-30)
- Hybrid Simulator Algorithms (PM12-54)
- Software Development and User Interface Development (PM30-54)

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Electric Operations potential project

Real Time Hybrid Digital Simulation

Research or service needed	Potential Collaborators
Modeling tools	1. GE 2. EPRI 3. PowerTech Lab 4. Manitoba HVDC Research Center
Real-time digital simulator	1. RTDS Technologies
Energy grid research	1. PSERC 2. University of Tennessee CURENT 3. Florida State University FREEDM

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California Energy Systems for the 21^{st} Century

Electric Operations potential project

Real Time Hybrid Digital Simulation

Potential customer benefits

1. Improved integration of renewable resources that are critical to meeting California' Renewables Portfolio Standard
2. Reduced customer costs from system outages through improved visibility of the health of the system
3. Improved ability to identify risks and reduce the incidence of blackouts and associated societal costs
4. Improved understanding of system stability to accurately identify necessary infrastructure

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Electric Operations potential project

Integrated Transmission and Distribution Model

Need:

The existing models used in transmission reliability assessment include models for the transmission network only. These models include an accurate representation of generation connected at the transmission level. However, the distributed generation is typically modeled as a reduction in load. With the increase in the distributed renewable penetration, there is a growing need to accurately capture the impact of the distributed generation on transmission reliability.

Objective:

- Develop an integrated transmission and distribution model
- Analyze interactions across the two systems
- Identify system restoration plans utilizing the integrated transmission and distribution system

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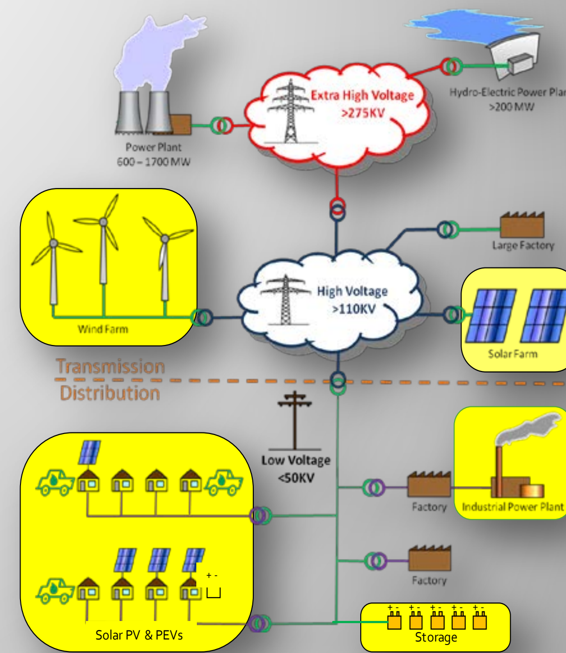
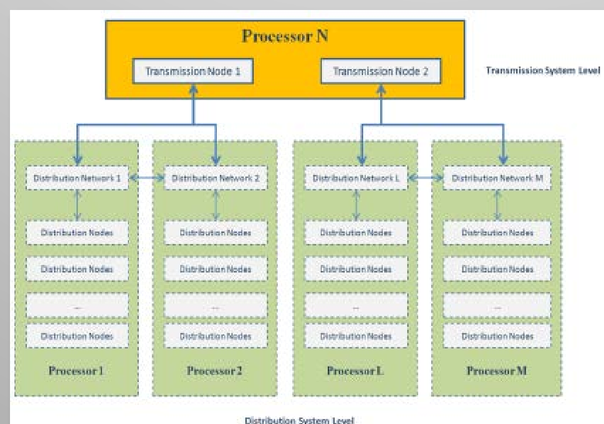
Electric Operations potential project

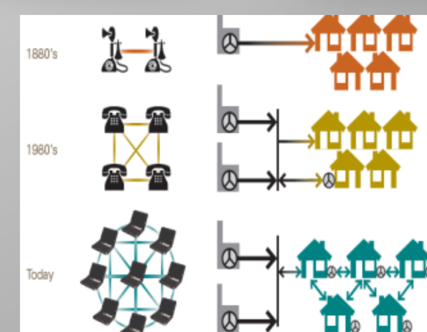
Integrated Transmission and Distribution Model

Approach:

- Integrated Transmission and Distribution Steady-state Model Development (PM1-15)
- Integrated Transmission and Distribution Dynamic Model (PM16-36)
- Restoration Capabilities in Extreme Scenarios Title (PM13-30)
- Integrated Electric Grid and Information Network Simulation (PM12-36)







Electric Operations potential project

Integrated Transmission and Distribution Model

Research or service needed	Potential Collaborators
Transmission modeling tools	1. GE 2. Powerworld
Distribution modeling tools	1. Pacific Northwest National Laboratory 2. EPRI 3. CYME 4. ETAP

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Electric Operations potential project

Integrated Transmission and Distribution Model

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Potential customer benefits

1. More comprehensive utilization of already purchased and deployed technology (i.e. Smart Meters)
2. Leverage the existence of data to reduce outage time and minimize costs
3. Enable integration of distributed energy resources restoration strategies
4. Avoid unnecessary capacity buildup through more accurate planning

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Electric Operations potential project

Electric System Monitoring and Control

Need:

One of key operational issues faced by California utilities is the ability to manage intermittent resources effectively while utilizing grid assets efficiently. With the increasing amounts of intermittent resources, stability analysis becomes more critical. Detailed system data (e.g. synchrophasors, digital fault recorders, SCADA) is collected and analyzed for discrete events, but large scale correlation and pattern recognition have not been employed due to the quantity of data.

Objective:

- Develop a predictive engine based on data mining and pattern recognition algorithms
- Develop system stability monitoring and mitigation system using predictive engine
- Increase transmission path capability through reliable use of actual system conditions

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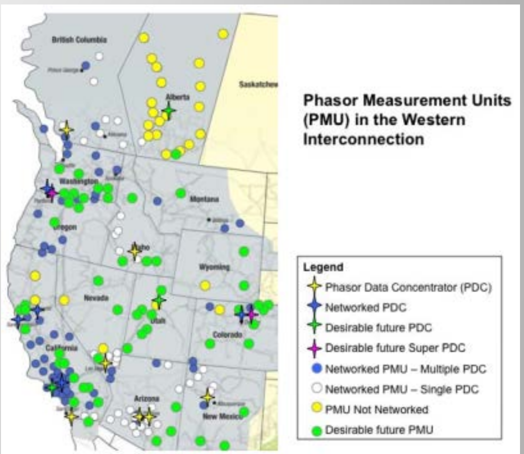
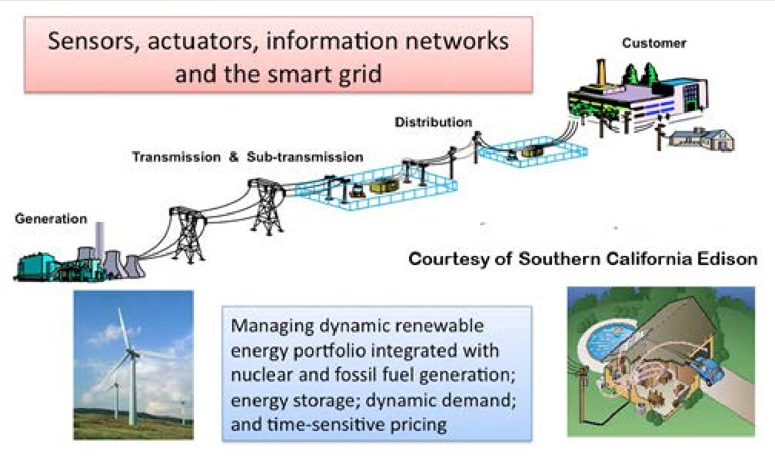
Electric Operations potential project

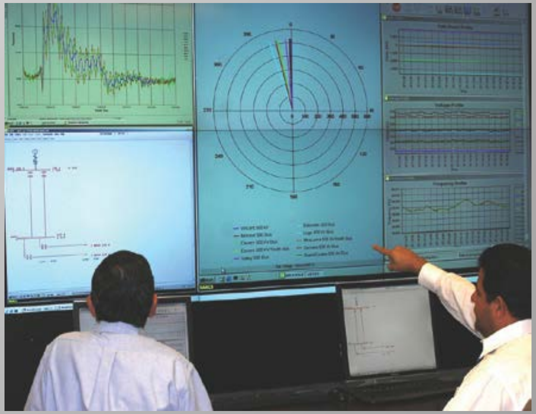
Electric System Monitoring and Control

Approach:

- Situational Awareness (PM1-PM39)
- Adaptive Protection and Control (PM16-27)
- Dynamic Transmission Paths Capability (PM28-39)
- Final Report, Documentation, and Technology Transfer (PM 40 - 45)







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Electric Operations potential project

Electric System Monitoring and Control

Research or service needed	**Potential Collaborators**
Monitoring and control tools	1. Grid Protection Alliance 2. Electric Power Group 3. GE Energy 4. Alstom
Data management	1. OSI Soft
Grid research	1. Power System Engineering Research Center 2. University of Tennessee's CURENT center

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Electric Operations potential project

Electric System Monitoring and Control

Potential customer benefits

1. Improved monitoring capability to reduce overall system outages through early warning and mitigation plans
2. Reduced generation and load dropping on special protection schemes
3. Increased wide area system awareness to increase transmission capacity and reduce costs

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Questions

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Gas System Operations

Advanced system modeling along with collection, extraction, fusion and analysis of multiple data sources that characterize the gas pipeline network and its operation will inform advanced risk analysis processes to ensure the safety and reliability of the gas pipeline system.

Francois Rongere (PG&E)

Lee Glascoe (LLNL)

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Gas System Operation potential projects

- Advanced Modeling and Simulation Environment
  - Develop and demonstrate tools to enable comprehensive parametric simulations of the transmission and distribution gas system including a quantified uncertainty framework to enhance modeling accuracy as well as the level of understanding and confidence in modeling results
- Geographic Data Integration for Risk Management
  - Develop and demonstrate tools that enable the integration of large amounts of both traditional (paper records) and non-traditional (electronic data and models) forms of gas infrastructure and environmental information to support comprehensive integrity assessments

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Gas System Operation potential project

Advanced Modeling and Simulation Environment

Need:

Natural Gas planning needs are evolving due to the integration of renewable energy sources and the availability of substantially more monitoring data on the transmission and distribution networks.

Enhanced system simulations have the potential to improve system operations by providing tools to guide complex real time decisions, provide insight into complex “what if” scenarios, and potentially to detect leaks or other equipment failures.

Objective:

- Automate the costly and time-consuming calibration process for pipeline models
- Increase the accuracy and robustness of calibrated models
- Develop a framework for reporting uncertainty in model predictions
- Provide visualization tools for complex simulations to improve gas system planning and operation

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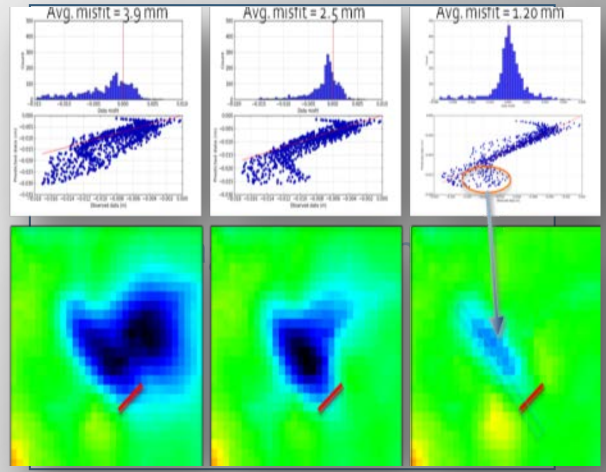
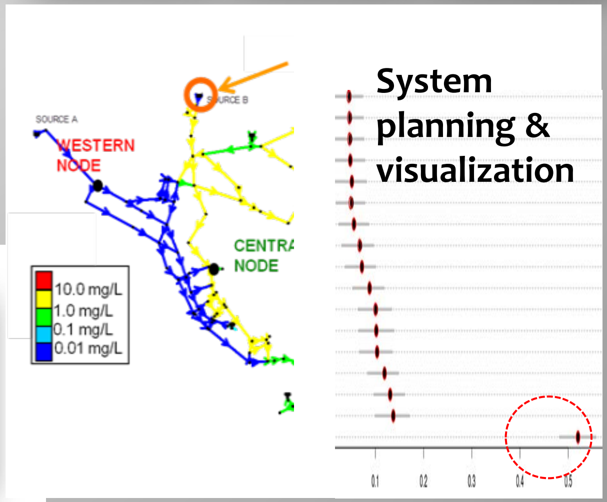
Gas System Operation potential project

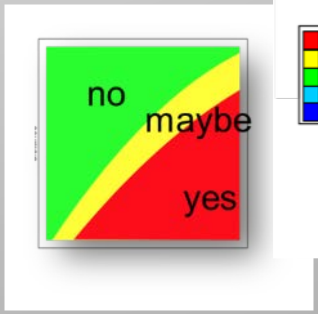
Advanced Modeling and Simulation Environment

Approach:

- Automate the calibration process for models in a way that is compatible with the IOU's existing modeling tools (PM1-24)
- Improve simulation performance and develop visualization tools that allow planners to leverage modeling results for complex decision making. (PM12-36)
- Address more complex networks and the integration of increasing amounts of available data (e.g. Smart Meters) (PM12-36)







Gas System Operation potential project

Advanced Modeling and Simulation Environment

Research or service needed	Potential Collaborators
Pipeline modeling tools	1. GL Noble Denton 2. Energy Solutions International 3. Gregg Engineering 4. ATMOS International 5. Simulation Software Limited 6. Eucalypt 7. Liwacom
Expertise in pipeline modeling	1. Sandia National Laboratories 2. Lawrence Berkeley National Laboratory 3. University of California, Santa Barbara
Research organization	1. Pipeline Research Council International 2. Pipeline Simulation Interest Group

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Gas System Operation potential project

Advanced Modeling and Simulation Environment

Potential customer benefits

1. Avoid unplanned disruption (curtailments) of gas service during a Cold Weather Day event or an Abnormal Peak Day event.
2. Diagnose system response to a gas leak with confidence and offer repair solutions that reduce system disruption.
3. Accurate knowledge of system capacity and customer usage to reduce the response time during emergency (such as a gas leak), thereby reducing natural gas emissions.
4. An effective simulation environment results in faster response to planning and operation requests. The benefits are multiplied during emergency scenarios to respond to a gas leak and implement repair alternatives.
5. Fully calibrated and validated high resolution models will allow planners to ensure that system investments are optimized, which will decrease costs.
6. Automate manual processes to increase the efficiency of the hydraulic simulation work, to lower costs and increase result resolution.

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Gas System Operation potential project

Geographic Data Integration

Need:

Risk assessment for Integrity Management requires historical and current information on the state of the natural gas system and its surroundings, including previous repairs and population distribution. All of this information must also be integrated into a single database for comprehensive risk assessments.

Objective:

- Transform the understanding and quantification of risk from and to natural gas infrastructure by using detailed information
- Implement population modeling tools with high~~er~~ time and spatial resolution
- Create digitization framework for historical (paper) records of pipeline maintenance activities to allow processing of millions of records
- Integrate both traditional (e.g. records) and non-traditional (e.g. population modeling) sources of information to Improve the understanding of risk from and to natural gas infrastructure

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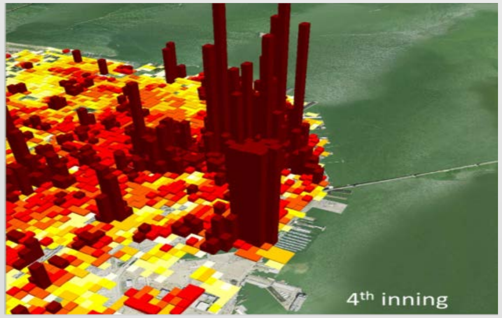
Gas System Operation potential project

Geographic Data Integration

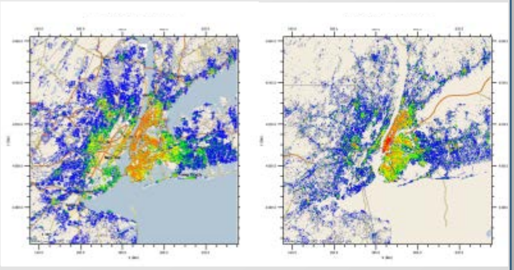
Approach:

- Spatially and temporally explicit assessment of risk associated with population distribution (PM1-36)
- Computer assisted extraction of geographical information from historical maintenance records (PM1-24)
- Methods for System-Wide Risk Assessment of PG&E's Natural Gas System (PM24-36)

RECORDS EXTRACTION



Dynamic population modeling in San Francisco



DAYTIME VERSUS NIGHTIME POPULATION

Gas System Operation potential project

Geographic Data Integration

Research or service needed	Potential Collaborators
Risk assessment	1. Lawrence Berkeley & Sandia National Laboratories 2. University of California, Berkeley, Santa Barbara, Los Angeles 3. Stanford University 4. EPRI 5. PRCI 6. Gas Technology Institute
Population dynamics	1. Oak Ridge National Laboratory 2. Sonoma State University
Energy informatics	1. University of Southern California
Optical character recognition	1. Technology providers
Document management	1. Technology providers

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Gas System Operation potential project

Geographic Data Integration

Potential customer benefits

1. A high resolution understanding of time dependent impact to the public in case of a potential pipeline failure that will support a cost effective risk-based assessment to prioritize system improvements such as shut-off valve installation, inspection and maintenance
2. Leveraging databases and models developed for a broad range of security and business applications by the National Laboratories provides a reliable solution at a minimal cost
3. Enabling new possibilities in operation and resource management to minimize response time, reduce costs, and improve safety
4. Exploring how population movement and density forecasts can be used to optimize work and investments on the pipeline network
5. Providing a reliable, fast and cost-effective method to process very large numbers of historical records of assets for pipeline maintenance and risk assessment
6. Accelerating the development of understanding quantitative comprehensive risk-based integrity management plans that are currently limited by the lack of accurate and reliable data

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Questions

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Next Steps

- Revisions will be made to CES-21 research projects and business cases
- Next CES-21 Board Meeting will be scheduled for late March or early April
- File Advice Letter by April 19, 2013
- Contact information

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Questions or Comments?

Attachment 2:

CES-21 Proposed Projects

Business Cases – First Program Period

California Energy Systems for the 21st Century

Advanced Threat Analysis Capability

Proposed Research Project: Business Case

1. Executive Summary

a) Research Project Opportunity Statement:

President Obama has declared that the "cyber threat is one of the most serious economic and national security challenges we face as a nation" and that "America's economic prosperity in the 21st century will depend on cyber security."

This proposal is to establish a relationship between the three California Investor Owned Utilities (IOU) and Lawrence Livermore National Laboratory (LLNL)[1] to develop advanced cyber technology and tools not currently commercially available. This relationship will enable the IOUs to utilize the super computing power and advanced data analysis capabilities of LLNL and the development of tools to improve the cyber resilience of the CA Utility Grid. The advancement in cyber security technology will enable the IOUs to identify and take action on advanced cyber threats before they impact California's critical infrastructure.

Proposed are two components that will enable the IOUs to identify stealthy advanced threats targeting critical infrastructure and reduce the impact and disruption of critical infrastructure services to California's residents and businesses.

This project includes two key components:

- Threat Modeling and Data Mining: Develop tools and algorithms to mine and analyze large amounts of the IOU operational data over long periods of time to discover and implement corrective actions to reduce the impact of advance persistent threats on California's critical infrastructure.
- Device and Vulnerability Analysis: Develop tools to determine the extent of cyber vulnerabilities in hardware, firmware, and software that support the operation of California's critical infrastructure.

This project aligns with the Whitehouse Comprehensive National Security Initiative to protect our nation's infrastructure.

[1] Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344.

b) Utility Sponsors:

☒ PG&E ☒ SCE ☒ SDG&E

c) This research focuses on the following area:

☒ Cyber Security ☐ Electric Resource Planning
☐ Electric System Operations ☐ Gas System Operations

d) This research maps to the following value chain categories:

☐ Grid operations/market design
☒ Generation
☒ Transmission
☒ Distribution
☐ Demand side management
☒ Cyber Security

e) This research supports one or more of the following objectives identified in Public Utilities Code §740.1:

☐ Environmental improvement
☒ Public and employee safety
☐ Conservation by efficient resource use or by reducing or shifting system load
☐ Development of new resources and processes, particularly renewable resources and processes which further supply technologies
☒ Improve operating efficiency and reliability or otherwise reduce operating costs

f) Potential Customer Benefits:

Identify and implement corrective actions to mitigate advanced cyber threats that pose a risk to public safety and reliability of gas and electric operations in California.

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. Tools developed through this process are not expected to be commercially available for up to 5 years. 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 Whitehouse Comprehensive National Security Initiative to protect our nation's infrastructure. *In July 2012 President Obama was published 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 exceptionally grave 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.	**Improves the responsiveness to cyber threats and reduces the disruption of critical infrastructure services in California**
Build California Talent in Cyber Defense	**Strengthen cyber security 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**

Benefit Category	Benefit Description	Customer Benefit
Develops Processes to Plan for Emerging Threats	**Define and develop enduring deterrence strategies and programs.** California Utilities have implemented traditional approaches to the cyber security 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**

g) Research Challenges and Hurdles to Overcome:

- Developing scalable and robust tools that accurately map entire computer / ICS networks
- Adapting / investing algorithms and tools to identify anomalous and malicious behavior on computer / ICS / power networks
- Developing scalable tools to identify exploitable vulnerabilities in hardware and software for binaries, source code, and firmware and techniques to mitigate such vulnerabilities
- Developing measurement and sensor strategies to sample across computer, ICS, and power networks
- Sharing system configuration, security incident, vulnerability and threat data to support tools research in the face of internal rules and legal hurdles

h) Unique Capabilities Offered by LLNL:

LLNL conducts leading research in machine learning and behavioral analysis applied to new domains such as cyber security. Additionally, LLNL has developed unique tools recognized throughout the federal government. LLNL's experience in setting up the Department of Energy's Computer Incident Advisory Center (CIAC) gives unique insight and will be leveraged in establishing the ATAC.

Alternatives	Assessment
Signature-based analysis tools	Signature-based tools are widely used but lack the ability to detect advanced threats where infrastructure knowledge is required.
ES-ISAC (Electricity Sector Information Sharing and Analysis Center)	Focused on topics affecting the electric infrastructure in the country as a whole and not specific to CA or threats to the gas infrastructure.

i) 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.

j) Duplication and synergies:

All project scope has been coordinated with other CES-21 projects, EPIC projects and other research efforts underway at the utilities and other research entities to ensure no duplication of effort. In addition, the CES-21 team will continue to monitor external RD&D projects to take advantage of synergies with external research and reduce the risk of future duplication.

2. Proposal Description

a) Background

A highly coordinated and structured cyber, physical, or blended attack on the bulk power system, could result in long-term, difficult to repair damage to key system components in multiple simultaneous or near-simultaneous strikes. Unlike “traditional,” probabilistic threats (i.e., severe weather, human error, and equipment failure), a coordinated attack would involve an intelligent adversary with the capability to bring down the system outside the protection provided by current planning and operating practices. An outage could result with the potential to affect a wide geographic area and cause large population centers to lose power for extended periods.[2]

According to Secretary of Defense Leon Panetta:

> *“A cyber-attack perpetrated by nation states or violent extremist groups could be as destructive as the terrorist attack of 9/11. Such a destructive cyber-terrorist attack could virtually paralyze the nation.”*
>
> *“We know that foreign cyber actors are probing America's critical infrastructure networks. They are targeting the computer control systems that operate chemical, electricity and water plants and those that guide transportation throughout this country. We know of specific instances where intruders have successfully gained access to these control systems. We also know that they are seeking to create advanced tools to attack these systems and cause panic and destruction and even the loss of life.”*

This is the threat environment that the California Investor-Owned Utilities (IOUs) face as they work to protect critical infrastructure from cyber based attacks. Each IOU dedicates significant resources to prevention, monitoring, and response capabilities in relation to these threats. However the California critical infrastructure remains at risk due to a lack of statewide visibility of advanced cyber threats and their impact to real-time gas and electric operations. Data analysis is necessary to profile normal behavior, overlaid with

[2] North American Reliability Corporation (NERC) Cyber Attack Task Force Final Report

operations data (voltage, phaser angles, circuit trips, and RTU status), to identify anomalies that would indicate a cyber-attack. Visibility into the operation of California's critical infrastructure must combine management of gas and electric load and frequency alongside cyber system monitoring to detect and respond to blended threats.
This project is proposing to develop the capabilities to enable the IOUs, in conjunction with Lawrence Livermore National Laboratory (LLNL), to blend security monitoring and better manage the ongoing security threats designed to cause physical world impacts. These tools need the capability to mine and analyze large amounts of data to identify stealthy advanced threats targeting critical infrastructure.

b) Objective

Build ATAC capabilities for IOUs that will enhance the traditional security event monitoring capabilities currently in place at the IOUs. Existing capabilities focus on real-time security monitoring based on known signatures. Implementation of ATAC competencies in the future can enable behavioral analysis of data for trends and patterns that will indicate the existence of advanced threats. Centralization of ATAC capabilities will improve the breadth of data and provide economies of scale by leveraging the LLNL computing power and advanced data analysis capabilities required to perform these functions. ATAC's mission statement supporting the IOUs is to:

> *Analyze large volumes of cyber activity data to look for trends that indicate the existence of advanced threats, collaborate with all the California IOUs when threats are identified, and find mitigation solutions to the threats.*

Additionally, the ATAC will provide software and hardware analysis of grid-connected cyber systems. This includes control system software, smart grid devices, networking equipment, and protocols. The ATAC will evaluate new and existing technologies through formal vulnerability analyses and help assess the impact of a compromise based on physical placement and electric peering points.

A key element in ATAC's success will be the collaborative relationships that are established with the IOUs, the CPUC, CAISO, DOE, DHS, and NERC. ATAC will work with these entities in a partnership role to help improve the overall security posture of the Bulk Electric System (BES) within the State of California.

c) Expected results

Provisioning ATAC competences can provide the following:

Threat Modeling and Data Mining

1) Establish policies and processes to share IOU security and system data between the IOUs and with LLNL
2) Develop technology to actively and passively identify industrial control systems, firmware versions, and computer systems for Integrated Control Systems (ICS) and computer networks.

3) Adapting / inventing algorithms and tools to identify anomalous and malicious behavior on computer / ICS / power networks
4) Developing measurement and sensor strategies to sample across computer, ICS, and power networks
5) Create a large scale pattern repository for individual ICS components and/or rapid changes in behavior of network communications
6) Develop secure collection, transfer, and storage capability to aggregate IOU cyber security data (IT, business system, ICS, etc.) at LLNL.
7) Create cutting edge tools to aid in analyzing IOU cyber data with the specific goal of identifying the presence of emerging threats on IOU networks and systems.
8) Seek innovative solutions to identified threats.

Device and Vulnerability Analysis

1) Develop scalable tools to identifying exploitable vulnerabilities in software for binaries, source code, and firmware and techniques
2) Select control system software, smart grid devices, embedded systems, field controllers, and firmware for analysis.
3) Perform hardware, firmware, and software vulnerability analysis using proprietary LLNL proof-based technologies.
4) Develop mitigations for vulnerabilities found; document best practices.
5) Build trusted firmware profiles for ICS and other cyber infrastructure devices.

3. Market Research

- NERC operates the ES-ISAC which is working to become a clearing house for threat, vulnerability, and security incident information. This effort is focused on the national perspective, and is not focusing specifically on California's critical infrastructure.
- DHS operates the US-CERT and the ICS-CERT. Both operational security organizations support security incident response, threat intelligence, and vulnerability awareness.
- Most utilities have very limited capabilities in advanced threat analysis and detection. What capabilities do exist typically revolve around information collected by 3rd party threat intelligence companies.
- Leveraging LLNL, DOE and other governmental agencies to gather threat and situational awareness information will enable the CA utilities to take meaningful action on the information to protect the IOUs.

4. Research Approach Assessment

Challenge	Assessment	Reason
Mapping an ICS network could have unknown consequences	Likely to succeed	LLNL has deep experience in network mapping. Additionally, other entities have been identified that may offer consultative subdomain knowledge.
Getting timely, reliable, and accurate cyber data from IOUs will be difficult	Likely to succeed	All parties are fully invested in this research partnership
Getting access to ICS component firmware for analysis could be technically difficult	Likely to succeed	The IOUs have long-standing relationships with their vendors and are willing to explain the importance of this security work to those vendors. Additionally, LLNL is fostering relationships with partners who may have access to this information.
Applying machine learning to ICS and other utility data is a new, unproven area	Likely to succeed	LLNL has expertise in machine learning and analysis of large volumes of data.

5. Partnership Opportunities

Potential Partner	Reason for Partnering
Sandia National Laboratories	Sandia has a proven tool, ANTFARM, for mapping industrial control system networks safely. This tool would fill gaps in LLNL's network mapping tool. Co-manager National SCADA Test Bed.
Idaho National Laboratory	Advanced control system security testing and data modeling Co-manager of National SCADA Test Bed
Internet Systems Consortium	ISC has developed a software platform for efficiently sharing cyber data from various sources
Invincea, Inc.	Visualization and machine learning expertise in diverse cyber datasets

6. Implementation Plan and Schedule

a) Work plan

For all related tasking a Milestone Memo (along with any associated deliverables) will be sent to the CES21 Management Team upon completion of a Milestone. Furthermore, Quarterly Progress Memos and an accompanying web conference will provide a forum for reviewing Milestones, identifying other accomplishments, reviewing challenges, and describing next steps. Comments and feedback will be documented after each web conference. Any changes will be handled according to the established operating procedures for CES-21. Presentations to the CES21 Board of Directors will be maintained in accordance with the CES21 governance guidelines as adopted by the Board.

Phase 1: Threat Modeling and Data Mining (PM1-60)

This phase will focus on the data that IOUs collect to monitor and maintain their networks, analyzing it for anomalies, emerging threats, and overall network health.

Major tasks:

1) (LLNL & IOUs) Gather and analyze the pertinent data. (PM1-2)
2) (LLNL & IOUs) Establish data transfer and storage policies and processes. (PM1-5)
3) (LLNL & IOUs) Design/build data warehouse infrastructure. (PM1-16)
4) (LLNL & IOUs) Identify and prioritize perimeters and sensor locations (network border, alternate entry points (WEC, Cal ISO, vendors), corporate to ICS points. (PM1-9)
    a. Assess data needs
    b. Analysis of network/system documents
    c. Gather/transfer data
5) (LLNL & IOUs) Build data analytics case studies (graph analytics, anomalous behavior, human vs. automated, etc.). (PM3-18)
    a. Mail gateways
    b. Firewall
    c. Web/proxy logs
    d. Network flow data
6) (LLNL & IOUs) Perform gap analysis for data acquisition - iterative step to look at adding further sensors and/or collecting additional data. (PM12-60)
    a. Define/identify necessary purchases for PY2
    b. Purchase equipment
7) (LLNL & IOUs) Build/verify device catalog. (PM1-36)
    a. Gather existing information from IOUs
    b. Deploy mapping tool
8) (LLNL & IOUs) Develop and deploy alerting and response framework. (PM18-36)
    a. Establish integrated collaborative work environment
    b. Convert analysis findings to packaged analytical products
    c. Implement analytical products for use in real-time IOU operations
9) (LLNL & IOUs) Refine data analytics case studies. (PM18-60)
    a. Expand to interior ICS networks
    b. Expand sensor footprint
    c. Develop new alerts and analytical products for framework
10) (LLNL & IOUs) Develop mitigation strategies and innovative solutions for attack vectors and potential threats. (PM18-60)

Phase 2: Device and Vulnerability Analysis (PM1-60)

This phase will analyze hardware, software, and protocols throughout the IOU cyber infrastructure for vulnerabilities.

Major tasks:

1) (LLNL & IOUs) Gather and analyze the pertinent data. (PM1-2)
2) (LLNL & IOUs) Identify critical devices, and required ISAs. (PM1-3)
   a. Each IOU identifies critical ICS device types and vendors
3) (LLNL & IOUs) Identify vulnerabilities to search for directly. (PM1-4)
   a. Look at ICS CERT vulnerability database
   b. Hire ICS security researcher/consultant to be a part of the team (contract).
4) (LLNL) Research feasibility of analysis for ICS protocols. (PM1-5)
   a. ICCP, DNP3, ModBus, 61850, 82351, GOOSE
5) (LLNL) Develop ISA specific analysis requirements and capabilities. (PM3-12)
6) (LLNL) Develop any required new program analysis. (PM4-60)
7) (LLNL & IOUs) Develop prototype tools for vulnerability analysis. (PM4-60)
8) (LLNL & IOUs) Develop initial work to identify vulnerabilities indirectly. (PM8-18)
9) (LLNL) Identify computing requirements for initial work. (PM4-14)
10) (LLNL & IOUs) Investigate new protocols and/or equipment based on findings from ATAC (Phase 1). (PM18-60)
11) (LLNL & IOUs) Test tools and refine. (PM18-60)
12) (LLNL & IOUs) Develop mitigation strategies for vulnerabilities found. (PM18-60)

Phase 3: Transition to IOUs (PM36-66)

(LLNL & IOUs) This phase will transition the tools, techniques, and data to the IOUs for continued support and development. (PM36-66)

b) Interdependency with other Business Cases

Business Case with Dependency (Phase)	Type of Dependency (provider, consumer, informational)	Required or Beneficial	Explanation
Cyber Mod/Sim: Baseline Device, Topology and Traffic	Provider	Required	This project will collect infrastructure data and topology information for use within and for the Cyber Mod/Sim project.
Cyber Mod/Sim: Cyber Attack Scenarios and Modeling	Consumer	Required	Collaborative environment for use in modeling various grid scenarios

Business Case with Dependency (Phase)	Type of Dependency (provider, consumer, informational)	Required or Beneficial	Explanation
Cyber Mod/Sim: Coupled Model Development	Provider	Required	Device models from vulnerability assessment tasks

c) Milestones/Deliverables

Phase	Type	Description	Due Date	Responsible
1	Deliverable	Data transfer and storage policies and processes	PM5	IOUs/LLNL
1	Deliverable	Data model, v1	PM6	IOUs/LLNL
1	Deliverable	Data warehouse infrastructure, v1	PM8	IOUs/LLNL
1	Deliverable	Prototype data analysis / techniques	PM12	LLNL
1	Deliverable	Data model, v2	PM14	IOUs/LLNL
1	Deliverable	Data warehouse infrastructure, v2	PM16	IOUs/LLNL
1	Deliverable	Best-effort maps and catalog of IOU infrastructure	PM3	IOUs
1	Deliverable	Network map complete for 1 network	PM12	IOUs/LLNL
1	Deliverable	Network map for all 3 IOUs	PM24	IOUs/LLNL
1	Deliverable	Prototype build of alerting and response framework, v1	PM24	IOUs/LLNL
1	Deliverable	Refined Data analysis / machine learning techniques	PM22	LLNL
1	Deliverable	End-to-end demonstration of data collection, aggregation, analysis and alerting	PM36	LLNL
2	Deliverable	Work plan	PM2	IOUs/LLNL
2	Deliverable	Candidate device list	PM3	IOUs/LLNL
2	Deliverable	Prioritized vulnerability list	PM4	IOUs/LLNL
2	Deliverable	New program analysis capability implemented in ROSE	PM12	LLNL
2	Deliverable	Prototype tools for analyzing ICS firmware, v1	PM18	LLNL
2	Deliverable	Tools for firmware analysis, v2	PM30	LLNL
2	Deliverable	Initial threat mitigation and best practices report, v1	PM30	LLNL
2	Deliverable	Threat mitigation and best practices report, v2	PM48	LLNL
2	Deliverable	Threat mitigation and best practices report, v3	PM60	LLNL

Phase	Type	Description	Due Date	Responsible
3	Deliverable	Draft transition plan	PM39	IOUs/LLNL
3	Deliverable	Revised transition plan	PM44	IOUs/LLNL
3	Milestone	ATAC transitioned to IOUs	PM66	IOUs/LLNL

d) Resource requirements

An average of 16 people per year will be required. This estimate includes LLNL, IOU, and potential partner resources in the following areas:

- System architecture
- Software development
- Cyber security analysis
- Network analysis
- Software reverse engineering
- Cyber security incident response

7. Cost Estimate and Allocation

Expense	PM1-18 ($K)	PM19-30 ($K)	PM31-42 ($K)	PM43-54 ($K)	PM55-66 ($K)
LLNL & Subcontract costs	3,900	3,900	3,900	3,900	3,900
IOU costs	1,500	1,500	1,500	1,500	1,500
TOTAL	**$5,400**	**$5,400**	**$5,400**	**$5,400**	**$5,400**

8. Benefits Estimate and Methodology

The utilities have a large investment in infrastructure across California. Though improving, the technologies for interconnectivity of control systems, still show vulnerabilities. Any extended threat that succeeds could cause and outage, locally, regionally or state wide. The research on outages on a regional scale shows millions of dollars in lost business revenues and productivity with a small to moderate outage. The 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 have other lasting effects on the California grid.

California Energy Systems for the 21st Century

Modeling and Simulation to Identify Cyber Security Vulnerabilities

Proposed Research Project: Business Case

1. Executive Summary

a) Research Project Opportunity Statement:

Emerging cyber threats require detailed models to identify vulnerabilities, develop mitigation strategies, and test/validate proposed security architectures. Having a simulator will allow us to model the effects of attacks and failures on the system in a structured lab environment. We will also be able to study the impact of future changes to the system to evaluate vulnerabilities in a variety of future scenarios.

This project relies on results from two other projects in the CES-21 portfolio: Advanced Threat Analysis Capability (ATAC) and Grid Operations Coupled Transmission-Distribution Model. This proposal is to establish a relationship between the three California Investor Owned Utilities (IOU) and Lawrence Livermore National Laboratory (LLNL)[1] to co-develop the device and topology catalogs for the electric grid and communication networks. These catalog development tasks are co-developed to ensure that the specific requirements of each project are met while eliminating duplication of effort for the common requirements.

The Grid Operations Coupled Transmission and Distribution project will develop computer models to enable study of the increasing level of interaction between the distribution system and the transmission system. The project will develop a static-coupled model first, then a dynamic-coupled model. This cyber modeling and simulation project will rely on those coupled T+D models as the grid side of a coupled T+D+C model. This project will be responsible for developing the coupling interface between the two modeling domains, using established techniques in the simulation literature.

This project also has a synergistic relationship with the ATAC project. Information developed by ATAC will be used as input in defining and assessing the cyber-attack scenarios used by this project. In turn, the models developed in this project will be key analysis tools for ATAC to assess the likely consequences of new threats as they emerge.

[1] Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344.

This project relies extensively on the high performance computing services made available by CES-21. In particular, this project will need nearly dedicated use of approximately 10K CPUs to run state-wide models. See section 6c below for details.

b) Utility Sponsors:

☒ PG&E ☒ SCE ☒ SDG&E

c) This research focuses on the following area:

☒ Cyber Security
☐ Electric Resource Planning
☐ Electric System Operations
☐ Gas System Operations

d) This research maps to the following value chain categories:

☐ Grid operations/market design
☐ Generation
☐ Transmission
☐ Distribution
☐ Demand side management
☒ Cyber Security

e) This research supports one or more of the following objectives identified in Public Utilities Code §740.1:

☐ Environmental improvement
☒ Public and employee safety
☐ Conservation by efficient resource use or by reducing or shifting system load
☐ Development of new resources and processes, particularly renewable resources and processes which further supply technologies
☒ Improve operating efficiency and reliability or otherwise reduce operating costs

f) Potential Customer Benefits:

Through modeling, we have the potential to develop methods to detect, diagnose and mitigate advanced threats that pose a future risk to safety and reliability of electric operations in California, in some cases even before the threats and vulnerabilities are actively exploited. This will ultimately enable improved resiliency and more efficient use of existing or planned recovery capacity.

Modeling is a key element in assessing the potential impacts and consequences of real and emerging vulnerabilities and weaknesses. This information is crucial in implementing a risk- and consequence-based prioritization process for addressing vulnerabilities and weaknesses in an optimal way.

In the long term the potential impact of large-scale models will be higher grid resilience, higher reliability, fewer and smaller-scale outages. These will ultimately have significant benefits for public safety, customer up time and reduced lost-revenue, and ultimately the entire state economy.

Specific operational benefits of large-scale predictive models could include:

- Ability to develop detection and mitigation strategies to emerging vulnerabilities before they can be exploited.
- Explore and evaluate incident response scenarios in advance of need, to improve the time to respond and recover.
- Capability to replay cyber incidents, with variations, to understand the range of risk exposures in similar situations, and the possible consequences of response strategies other those utilized at the time of incident.
- As a planning tool in assessing operational benefits and risk reduction that could be realized by future grid improvement proposals. Such information would enable rapid quantitative assessment of potential benefits as part of developing future rate cases.
- Provide training and exercise capability for incident detection and response.
- Evaluation of disaster response, recovery and restoration plans at the IOU and CAISO level, enabling all stakeholders to understand drivers and consequences outside their own domain.

Ultimately, predictive models that extend beyond the service area of one IOU will provide the IOUs, CAISO, and the CPUC with the necessary tools to be proactive in anticipating, assessing, and developing mitigations for emerging future threats, even before incidents occur.

California customers will benefit greatly from avoided (or, shortened outages) due to cyber-attacks. Modeling and simulation will enable development of improved security designs, tools, and methods. Improved grid security will reduce the number of outages, minimize their impact, and improve recovery times.

g) Research Challenges and Hurdles to Overcome:

The research challenges derive from the scope of the project, encompassing transmission, distribution, and communications networks, at statewide scale:

- Application of a coupled transmission-distribution model, at state-wide scale.
- Construction of a state-wide grid communications model.
- Coupling the T&D model with the communications model.
- Obtaining accurate infrastructure maps for grid systems across the state.

Simulation at this scale absolutely requires significant high performance computing. We anticipate utilizing a major 10K node parallel compute cluster full time by the end of the project, generating of order 1 PB/year of archived data.

h) Unique Capabilities Offered by LLNL:

Livermore has a nearly unique capability to model very large (1M node and larger) communication models on large high-performance parallel computer clusters, which is essential to modeling the entire CA grid communications in a timely manner.

Livermore is one of a handful of organizations with the skills to simulate large communications networks with realistic traffic at the required ~10M-node scale, and one of only two organizations to do so in parallel, enabling rapid time to decision and statistical quantification of results.

Alternatives	Assessment
OpNet	Parallelizable for statistical sampling only.

i) 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.

j) Duplication and synergies:

All project scope has been coordinated with other CES-21 projects, EPIC projects and other research efforts underway at the utilities and other research entities to ensure no duplication of effort. In addition, the CES-21 team will continue to monitor external RD&D projects to take advantage of synergies with external research and reduce the risk of future duplication.

2. Proposal Description

a) Background

Emerging cyber threats require detailed models to identify vulnerabilities and develop mitigation strategies. Having a simulator will allow us to model the effects of attacks and failures on the system in a structured lab environment. We will also be able to study the impact of future changes to the system to evaluate vulnerabilities in a variety of future scenarios.

Because the grid is coupled at several levels, a comprehensive model has to be developed to a sufficient level of detail to identify vulnerabilities and paths across those levels. The increasing use of edge devices (*e.g.*, distributed generation, smart meters, and home area networks) with two-way communication creates an emerging threat to grid control systems. These devices and their interaction with utility back office systems and control systems are growing in complexity. Detailed models identifying control characteristics and communication protocols have not been developed for a large-scale analysis across the State of California.

A comprehensive model would enable non-intrusive study of emerging issues and potential vulnerabilities, without impacting sensitive industrial control systems or current operations. Models are extensively used in other domains to plan and evaluate proposed evolutionary changes, particularly with respect to impacts on resilience.

Understanding emerging technology opens up the possibility to drive the technology development in favorable directions. Evaluating proposed changes in advance of implementation will maximize the utility of future investment, while minimizing the risk of stranded investment.

A statewide model would enable the incorporation of threat intelligence from multiple sources, assessment of the risks to operations across California Investor-Owned Utilities (IOUs), and enable enhanced design for security, safety, and reliability. While the current grid is designed for (*N*–1) resilience to random failures and natural causes, an attacker potentially can exploit a single vulnerability in a single widely deployed device model to effect widespread simultaneous failure. A communications-electric grid model will enable assessment of such impacts to reliability, and possible approaches to improving the resistance to cascades. Likely high priority assessments will understand the impact of attacks on the IOUs, the California Independent System Operator (CAISO), networked substation switches, and the emerging Advanced Metering Infrastructure (AMI).

b) Objective

We propose to build and successively refine a computational model that couples

- Communication infrastructure (wired and wireless networks and communication systems)
- Primary electric generation and transmission behavior
- Utility distribution networks
- Utility-operated energy storage, beyond hydro
- End-user loads and generation
- Utility ICS systems

This model will aim to be predictive across the entire state. We anticipate needing to model ~12,000 circuits, ~1,200 substations, with ~15M communication devices (*e.g.* smart meters, home area networks, distributed generation, relays). Initially we would use low-fidelity device models, but capture the diversity of as-deployed devices by the end of the project.

Simulation at this scale absolutely requires significant high performance computing. We anticipate utilizing a major ~10K node parallel compute cluster full time by the end of the project, generating of order 1 PB/year of archived data.

This project relies on results from two other projects in the CES-21 portfolio: ATAC and Grid Operations Coupled Transmission-Distribution Model. The ATAC Threat Modeling and Data Mining task will co-develop the device and topology catalogs for the electric grid and communication networks. These catalog development tasks are co-developed to ensure that the specific requirements of each project are met while eliminating duplication of effort for the common requirements.

The Grid Operations Coupled Transmission and Distribution project will develop computer models to enable study of the increasing level of interaction between the distribution system and the transmission system. The project will develop a static-coupled model first, then a dynamic-coupled model. This cyber modeling and simulation project will rely on those coupled T&D models as the grid side of a coupled T+D+C model. This project will be responsible for developing the coupling interface between the two modeling domains, using established techniques in the simulation literature.

This project also has a synergistic relationship with the ATAC project. Information developed by ATAC will be used as input in defining and assessing the cyber-attack scenarios used by this project. In turn, the models developed in this project will be key analysis tools for ATAC to assess the likely consequences of new threats as they emerge.

It may be desirable to integrate the communications model with a real time grid simulator, such as the Real Time Digital Simulator (RTDS), owned by all three major IOU's in California. The RTDS can model all of the major bulk system substations, and, where required, it may also include sub transmission and distribution circuits. The advantage of the RTDS is that it provides a platform for actual protection and control hardware to be connected as if it was actually on the grid. The RTDS also includes all major communication protocols used by electric utilities (e.g. IEC-61850, C37.118, DNP, Sample Value, *etc*.) An early task for this project is to assess the necessity and feasibility of integrating a communications model with a real-time hardware-in-the-loop electric grid simulator.

Potential simulation scenarios could include:

- Cyber-attack on substation intelligent electronic devices (IEDs) *via* wireless control interfaces;
- Cyber-attack on substation IEDs to alter protection settings, followed by cyber-attack on AMI to effect widespread simultaneous remote disconnect;
- Impact on grid stability and controllability of increased control system traffic during a significant incident.
- Simulate effects of proposed security architectures on stability and reliability of the grid.

The 5-year goal will be to simulate the entire state of California with enough temporal resolution to predict the onset and propagation of transients in the grid, due to a cyber intrusion and attack.

Technology represented in the model will include:

- Network communications model (including wired nodes, wireless nodes, routers, wireless access points)
- Utility control systems (e.g., supervisory control systems, relays, special protection schemes)

- Utility owned smart meters
- Customer devices connected with two-way communications (e.g., Home Area Networks, Distributed Generation)

c) Expected results

The model research project is scoped to run over a period of 60 months. Detailed work breakdown structure will be developed as part of the final project plan. Project deliverables will include:

- Coupled communication-electric grid simulation framework
- Grid+communication network model for the state. This model will be progressively refined throughout the project term.
- Feasibility study for coupling real-time and/or hardware-in-the-loop grid models with realistic communications models.
- Assessment of hypothetical cyber-attacks through the communications electric grid

3. Market Research

This effort would leverage and extend existing capabilities in:

- High fidelity communication models, including packet networks, real communication protocols, and IEC-61850.
- Coupled transmission-distribution grid models
- The Lawrence Livermore National Laboratory's (LLNL) high performance computing resources

This effort would be unique in several respects:

- Scale: encompass an entire state electric system, including controls
- Scope: span transmission and distribution for multiple utilities
- Depth: model individual control points, state-wide
- Resolution: capture end-point initiation of wide-scale transients

4. Research Approach Assessment

Challenge	Assessment	Reason
Construction and application of a coupled transmission-distribution model, at scale	Likely to succeed	Coupling transmission and distribution, with feedback, is the subject of a current LLNL research project
Construction of a state-wide grid communications model	Likely to succeed	Modeling of ~1M node communication systems has already been demonstrated by LLNL, and 300M node models by our collaborators.
Obtaining accurate infrastructure maps for grid systems across the state	Likely to succeed	ATAC and significant utility participation will be required

5. Partnership Opportunities

Potential Partner	Reason for Partnering
RTDS Technologies	RTDS is a real-time simulator in use by the IOUs
Oak Ridge National Laboratory	Experience coupling continuous time and discrete event simulation algorithms.
Pacific Northwest National Laboratory	Embedded and SCADA system cyber security analysis.

6. Implementation Plan and Schedule

a) Work plan

A Milestone Memo (along with any associated deliverables) will be sent to the IOUs upon completion of a Milestone. Furthermore, Quarterly Progress Memos and an accompanying web conference delivered from LLNL will provide a forum for reviewing Milestones, identifying other accomplishments, reviewing challenges, and describing next steps. Comments and feedback will be documented after each web conference. Any changes will be handled according to the established operating procedures for CES-21.

Phase 1: Baseline Device, Topology and Traffic (PM1-64)

Collect and archive baseline data on deployed grid and communication devices, and communication traffic traces. This task is in cooperation with the ATAC task. Elements specific to Modeling include: capturing device type, version, and firmware details; configuration information; capturing grid and communication network topology; capturing and analyzing network traffic traces to develop communication models.

Major tasks:

1) (IOUs & LLNL) Technical Scoping: gather and analyze the pertinent data. (PM1-6)
2) (LLNL) Catalog dB: design, deploy, and maintain a database for grid and communications device information, as well as topology information. (PM1-9)
3) (IOUs & LLNL) Device Catalogs: develop and successively refine catalogs of media and communication standards, grid and communication devices. (PM1-22)
4) (IOUs & LLNL) Communication Topologies: develop and successively refine descriptions of as-deployed grid and communication network topologies. (PM1-22)
5) (IOUs and LLNL) Communication Data: collect and analyze baseline communication network traces. (PM1-64)

Phase 2: Coupled Model Development (PM1-50)

Develop communications model coupled to transmission-distribution model. This task is in cooperation with the Integrated T+D model project. Specifically, T+D will be developing first static, then dynamic T+D models. This task is responsible for integrating those T+D models with a communications model.

Major tasks:

1) (LLNL) Protocol Model Development: extend the communications modeling framework to support relevant utility-specific protocols. (PM1-24)
2) (LLNL) Communication Models: develop and refine a statewide communications model, representing the current state of the Device, Topology, and Traffic database of Phase 1. (PM11-47)
3) (LLNL) Grid Models: develop and successively refine the grid representation within the communications model. (PM11-60)
4) (IOUs & LLNL) As-Deployed Devices: refine the communications and grid device models with as-deployed protocols, device configuration and behavior, and topology. (PM28-46)
5) (LLNL) Coupled T+D+C Model: design the interface and coupling between the communications model framework and first, the static T+D model framework, then the dynamic T+D model framework. (PM11-28)
6) (LLNL) Real-Time Feasibility Study: feasibility study for integrating real time grid models, such as RTDS, with a real time communications model. (PM11-28)
7) (LLNL) T+D Model Development: develop and refine the coupled communication-T+D model. (PM28-50)
8) (LLNL) T+D+C Coupling Development: refine the coupled communications-T+D model implementation with as-deployed device models. (PM28-50)

Phase 3: Cyber Attack Scenarios and Modeling (PM28-66)

Develop various cyber-attack scenarios. With the IOUs and ATAC perform joint assessment of likely risk and scale of consequences. For selected scenarios develop detailed attack, detection, response, and recovery models, and analyze and assess the model accuracy and performance. Demonstrate multiple response options for a given attack scenario.

Major tasks:

1) (IOUs & LLNL) Attack Scenarios Development: develop a set of conceivable attack scenarios. (PM28-42)
2) (IOUs & LLNL) Scenario Down Select: down select scenarios based on risk and consequence assessment. (PM42-50)
3) (LLNL) Modeling and Analysis: develop detailed attack, detection, response, and recovery models for selected scenarios. (PM50-60)
4) (LLNL) Model Assessment: assess model accuracy and performance. (PM60-63)

5) (IOUs & LLNL) Response Options: develop and model alternative response options for a given scenario. (PM63-66)

b) Interdependency with other Business Cases

Business Case with Dependency (Phase)	Type of Dependency (provider, consumer, informational)	Required or Beneficial	Explanation
ATAC	Consumer	Required	The ATAC project will co-develop the grid and communications device catalogs, as well as topology information.
ATAC	Provider	Required	The cyber modeling and simulation project will provide simulation output to the ATAC collaborative environment.
ATAC	Consumer	Required	The ATAC Device and Vulnerability Analysis task will provide behavioral device models to the simulation framework.
Grid Operations: Coupled Transmission & Distribution Model	Consumer	Required	The Grid T+D project will develop the baseline coupled transmission and distribution models. This project will develop the coupling to the communication model.
Grid Operations: Planning Engine: IT infrastructure planning	Provider	Required	The Grid Ops project will develop, simulate and evaluate alternative IT architectures using the communications models developed in this project.

c) Milestones/Deliverables

Phase	Type	Description	Due Date	Responsible
1	Deliverable	Catalog dB design document	PM9	LLNL
1	Deliverable	Media and standards catalog	PM9	IOUs & LLNL
1	Deliverable	Communications catalog, v1	PM11	IOUs & LLNL
1	Deliverable	Grid component catalog, v1	PM11	IOUs & LLNL
1	Deliverable	Grid & communications topology catalog, v1	PM11	IOUs & LLNL
1	Deliverable	Communications data catalog	PM11	IOUs & LLNL
1	Deliverable	Communications catalog, v2	PM23	IOUs & LLNL
1	Deliverable	Grid component catalog, v2	PM23	IOUs & LLNL
1	Deliverable	Grid & communications topology catalog, v2	PM23	IOUs & LLNL
1	Deliverable	Measurement campaign design document	PM23	IOUs & LLNL

Phase	Type	Description	Due Date	Responsible
1	Deliverable	Measurement campaign interim report	PM35	LLNL
1	Deliverable	Measurement campaign final report	PM47	IOUs & LLNL
1	Deliverable	Measurement analysis report	PM64	LLNL
2	Deliverable	Communication model, v1	PM28	LLNL
2	Deliverable	Grid model, v1	PM28	LLNL
2	Deliverable	Coupled T+D+C model design document	PM28	LLNL
2	Deliverable	As-deployed device models, v1	PM34	LLNL
2	Deliverable	As-deployed device models, v2	PM40	LLNL
2	Deliverable	T+D model development interim report	PM40	LLNL
2	Deliverable	T+D+C model interim report	PM40	LLNL
2	Deliverable	As-deployed device models, v3	PM46	LLNL
2	Deliverable	T+D model final report	PM49	LLNL
2	Deliverable	T+D+C model final report	PM49	LLNL
3	Deliverable	Cyber-attack scenarios, v1 report	PM42	IOUs & LLNL
3	Deliverable	Cyber-attack scenarios, v2 report	PM47	IOUs & LLNL
3	Deliverable	Cyber-attack model implementation report	PM60	LLNL
3	Deliverable	Cyber-attack model analysis report	PM63	IOUs & LLNL
3	Deliverable	Response options report	PM66	IOUs & LLNL

d) Resource requirements

An average of 4.5 people will be required. This estimate includes LLNL, IOU, and potential partner resources in the following areas:

- Modeling
- Programming
- Cyber security
- Grid infrastructure, controls and communications network

7. Cost Estimate and Allocation

Expense	PM1-18 ($K)	PM19-30 ($K)	PM31-42 ($K)	PM43-54 ($K)	PM55-66 ($K)
LLNL & Subcontract costs	1,326	1,366	1,407	1,455	1,486
IOU costs	375	375	375	375	375
TOTAL	**$1,701**	**$1,741**	**$1,782**	**$1,830**	**$1,861**

8. 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 some unknown. Any extended threat that succeeds could cause and 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. The 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

Ensemble Weather Forecasting for Wind and Solar Generation

Proposed Research Project: Business Case

1. Executive Summary

a) Research Project Opportunity Statement:

Optimizing short-term use of dispatchable resources to integrate purchases of new wind and solar generation presents a unique demand for accurate weather forecasts. Extending recent developments in high-resolution mesoscale weather forecasting are needed to resolve terrain-driven flows and intermittent wind ramp events as well as estimate hourly changes in incoming solar radiation due to clouds. New forecasting approaches must be developed to meet a new set of demands imposed by the integration of large amounts of weather-based electricity generation. These new forecasting tools must not only improve the prediction of relevant weather parameters, upon which renewable production and integration depend, but crucially must also provide a measure of the uncertainty associated with weather and renewable generation forecasts. Such uncertainties can be quantified using high performance computing and an ensemble weather forecasting approach. The ensemble methodology involves sampling known sources of forecast uncertainty to generate multiple forecasts over the same period (example shown in Figure 1) of weather, load and generation scenarios, to yield probabilistic distributions of likely generation and load outcomes. Estimates of uncertainties, for example in the timing and magnitude of wind/solar ramps, can assist in making unit commitment and reserve provision decisions.

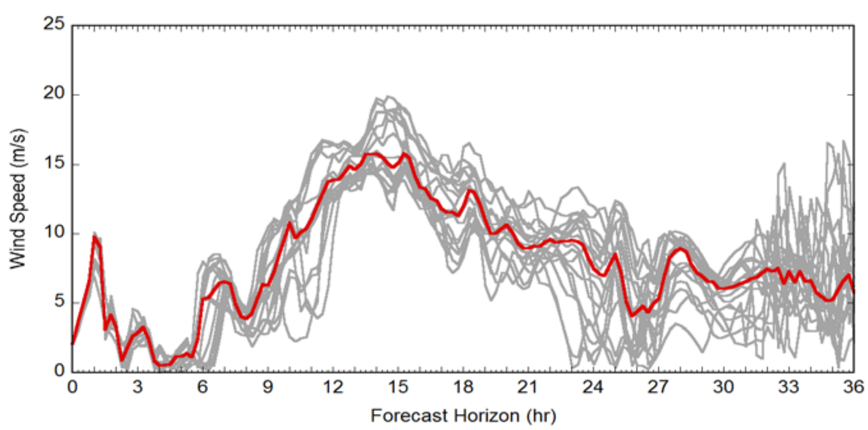

Figure 1: An example 20-forecast ensemble of wind speeds at the San Gorgonio wind park. Grey lines are forecast wind speed for each ensemble member and the red line is the ensemble mean. Note that all ensemble members predict wind speed ramp between hours 6 and 12, but timing and ramp rates vary. Ensemble forecasting captures the uncertainty in prediction, which is not provided by a single deterministic forecast.

Scientific literature currently does not provide specific guidance on the best ensemble forecasting methodology to generate wind and solar forecasts on time scales of a day ahead or less. In this project, we will investigate the renewable generation forecast skill associated with different ensemble weather forecasting methods over California. The goal is to determine the optimal ensemble forecasting strategy for targeting the unique demands of renewable power generation in California for the various time windows of interest to generation owners, utilities, and balancing authorities. This project will specifically investigate weather forecasting approaches that will improve renewable generation predictions for both 3-hour-ahead and day-ahead forecast horizons. In addition, we will investigate the accuracy and real-time applicability of several methods for estimating wind and solar generation from gridded weather forecast model output. As part of the process, LLNL will deliver ensemble-based forecast products to California Independent System Operator (CAISO) and the California Investor-Owned Utilities (IOU) in real time in order to compare the ensemble-based forecast methodology to existing approaches.

This proposal is to establish a relationship between the three California Investor Owned Utilities (IOU) and Lawrence Livermore National Laboratory (LLNL)[1] to develop visualization and decision tools tailored to their specific needs. These tools will be prototypes and at the end of the project may be transferred to the ISO, the IOUs, or a third party vendor for commercialization. The technical report delivered at the end of this project will contain the necessary level of scientific and operational detail for private vendors of weather forecast data to use the 'best practices' findings to improve their weather forecasting capabilities. In addition, the final report will provide guidance on how the IOUs and ISO could run a reduced order version of the developed forecasting tool in-house on a moderately sized Linux cluster or optionally take advantage of cloud computing resources to run the full version of the recommended forecast tool.

b) Utility Sponsors:

☒ PG&E ☒ SCE ☒ SDG&E

c) This research focuses on the following area:

☐ Cyber Security	☒ Electric Resource Planning
☐ Electric System Operations	☐ Gas System Operations

[1] Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344.

d) This research maps to the following value chain categories:

- ☒ Grid operations/market design
- ☒ Generation
- ☐ Transmission
- ☐ Distribution
- ☐ Demand side management
- ☐ Cyber Security

e) This research supports one or more of the following objectives identified in Public Utilities Code §740.1:

- ☒ Environmental improvement
- ☐ Public and employee safety
- ☒ Conservation by efficient resource use or by reducing or shifting system load
- ☒ Development of new resources and processes, particularly renewable resources and processes which further supply technologies
- ☒ Improve operating efficiency and reliability or otherwise reduce operating costs

f) Potential Customer Benefits:

This project is aimed at saving operational system costs, improving grid reliability, and giving generation owners information relevant to bidding decisions. System cost savings can be realized through improved forecasts as well as an understanding of the range of generation/load possible in the 3 hour-ahead to day-ahead time frames. Grid reliability can be bolstered on days when conditions are truly uncertain through the purchasing of additional reserves. Ensemble forecasting will also give generation owners probabilistic information about their potential generation scenarios in the day-ahead time frame, which can assist them in making bidding decisions.

Beneficiaries of the proposed ensemble-based forecasting system exist at multiple stages along the production and distribution chain, including:

- The CAISO, which can use these products to:
  - Make better net load predictions, allowing for more optimal unit commitment decisions and transmission line scheduling (for day-ahead forecasts).
  - Make better planning decisions related to the resources necessary for load following (for 3-hour ahead forecasts).
  - Purchase only the necessary quantity of reserves to account for the net load uncertainty faced on a daily basis.
  - Purchase additional reserves on days when the net load forecast is highly uncertain, thereby reducing the chance of over/underproduction and the expenses associated with them.

- The IOUs and other wind/solar generation owners, who will benefit from both improvements in the overall accuracy of forecasts of critical parameters, as well as uncertainty bounds in those predicted parameters. These improvements in renewable generation forecasting and associated quantification of uncertainty will better prepare them for the daily bidding of renewable resources as well as load affected by behind the meter or distributed renewable generation.

- The rate-payers, who will ultimately benefit by increased reliability and lower cost of electricity.

g) Research Challenges and Hurdles to Overcome:

The key research challenges underpinning the proposed research involve the statistical evaluation of prediction skill associated with state-of-the-art ensemble-based weather forecasting approaches, and the development of methodologies to incorporate probabilistic weather and renewable generation forecasts into CAISO and IOUs operational decision making.

Significant high-performance computing is critical to perform the tasks outlined in this proposal. Ensemble-based weather forecasting is inherently computationally intensive since numerous model configurations are run over the same period to generate a sufficient distribution of plausible forecast possibilities. The ensemble methodology replaces the single weather forecast approach typically used for load and generation scenarios for a given time period with multiple (~30) weather forecasts. An operational ensemble-based forecasting system is computationally expensive because the forecast simulations must be completed quickly enough to meet 'real-time' operational constraints. The research required to tailor the system to the unique requirements of renewable energy forecasting in California will also require large amounts of computing resources and storage. Thousands of simulations will be required for the systematic exploration of different sources of uncertainty in the modeling framework (e.g. initial conditions and model physics parameterizations), and their impact on weather forecast skill. These ensembles must also be executed over a range of weather conditions to sufficiently sample a variety of weather scenarios so that systematic biases in the model predictions can be removed. Finally, in order to mine the dataset, develop useful products to characterize forecast uncertainty, and provide actionable decision-making protocols, the results developed in the research phase must be archived. These efforts would not be possible without state-of-the-art computational resources.

h) Unique Capabilities Offered by LLNL:

There is an existent request to do a mesoscale project under EPIC which would address other pressing technical issues beyond wind power and solar power forecasting. The project proposed here addresses the issue of reliance on a single deterministic forecast which is the current industry approach.

The Lawrence Livermore National Laboratory (LLNL) possesses the unique combination of subject matter expertise and computational resources for constructing high-resolution ensemble based wind and solar forecast products for renewable electricity predictions in the geographically complex state of California. LLNL has demonstrated expertise in simulating complicated wind distributions at turbine rotor heights in complex terrain settings. LLNL also has extensive knowledge of detailed real-time meteorological observation data sets, experience assimilating a variety of meteorological data types into an sophisticated weather forecast system, and expertise in determining the accuracy of wind and solar forecasts. Through a previous research project with the California Energy Commission (CEC), LLNL developed specialized wind and solar production modules within the Weather Research and Forecasting (WRF) model for the Western Electricity Coordinating Council (WECC) (See Figure 2). While this model was developed for a future (2020) wind and solar build-out scenario, it can be reconfigured to reflect existing resources.

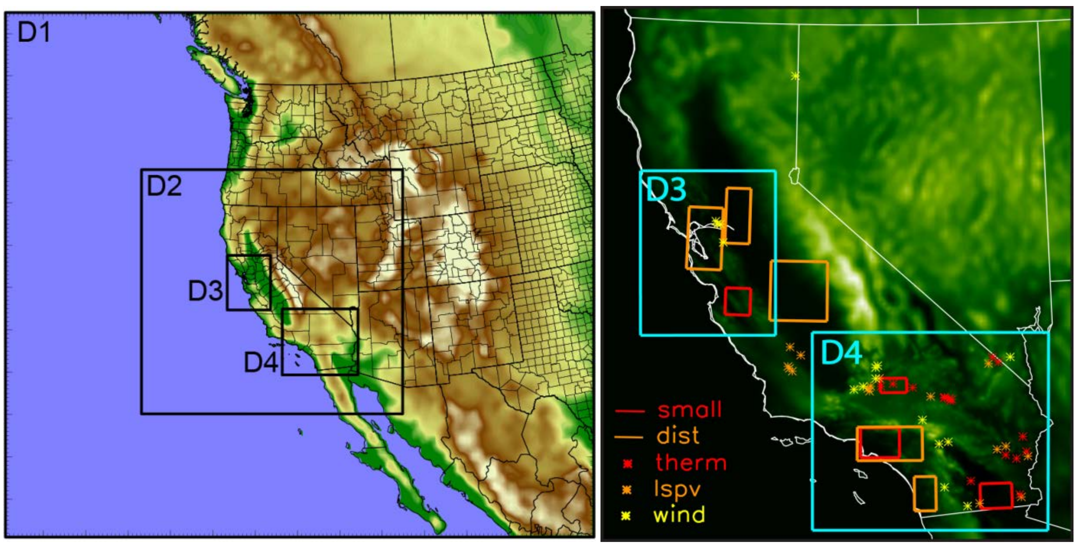

Figure 2: (Left) Domains of WRF-based multi-resolution model of WECC already in use at LLNL. Domains D3 and D4 are at 3 km resolution (nested within coarser resolution domains), and capture many of the wind and solar resources in California. (Right) Distribution of California proposed build-outs of solar and wind projects in the existing WECC model. Orange and Red rectangles encompass areas of small and distributed solar resources, while larger individual plants are indicated by asterisks.

Potential alternatives include the purchase of forecast products from existing governmental or commercial providers. However such products are typically deterministic and therefore do not provide probabilistic characterization of uncertainties. Some ensemble forecasts are available (e.g. NCEP, GFS, ECMWF), however these forecasts products do not have the time and space resolution necessary for alternative energy forecasts. They typically are updated every 6 hours making them less than ideal for providing forecasts a few hours into the future that need to include the most recent hourly weather observations. Also, these models are run on a course horizontal resolution that does not resolve wind flows in complex terrain prevalent in California. While they predict features of large-scale weather systems, they are not tailored to predict the specific parameters relevant to renewable generation such as surface solar insolation, low-level winds, and ramp events.

Alternatives	Assessment
Purchase existing forecast products through NCEP, GFS, ECMWF	Several day time horizon, not optimized for CA or for energy-related weather parameters, does not provide user guidelines
NCAR	NCAR has expertise in ensemble weather prediction, but the WRF-based model of the WECC that already exists at LLNL is not easily reproducible. NCAR is a potential partner.
NREL	NREL has weather modeling expertise with WRF and is a potential partner.

i) 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.

j) Duplication and synergies:

All project scope has been coordinated with other CES-21 projects, EPIC projects and other research efforts underway at the utilities and other research entities to ensure no duplication of effort. In addition, the CES-21 team will continue to monitor external RD&D projects to take advantage of synergies with external research and reduce the risk of future duplication.

2. Proposal Description

a) Background

Wind and solar power generators, the California Investor-Owned Utilities (IOU) and the California Independent System Operator (CAISO) all utilize meteorological forecast models to predict load and renewable power generation to schedule dispatchable generators and transmission. The inherent intermittency and uncertainty of these meteorological parameters are costly but manageable through effective use of ancillary services at small penetration levels. However, under the 33% RPS, simply increasing reserve provisions will be an exorbitantly expensive proposition.

An infrastructure for assessing the inherent uncertainties in forecasts and making sound decisions that incorporate these uncertainties will be required for the efficient, reliable and cost effective electricity generation and distribution with large inputs from weather-generated renewables. We propose to develop a forecasting framework to help generators and operators alike provide reliable and cost effective renewable power. This framework will produce ensembles of weather forecasts derived by sampling the sources of uncertainty in meteorological forecasts. The sampling method is developed so that the members of the ensemble will generally span the range of possible outcomes over the forecast period.

The proposed ensemble-based forecasting methodologies will provide the uncertainty information vital to the efficient and robust operation of the electrical grid under high renewable penetration scenarios. The ensemble-based system will replace the single forecast and uncertainty band that have been used for renewable integration studies (Figure 3). Our modeling will provide multiple forecast realizations that incorporate sources of uncertainty inherent in numerical weather prediction. Sources of uncertainty include both observations used to initialize weather forecast models, and the parameterizations of physical processes that govern the evolution of forecast quantities, including pressure, temperature, wind, cloud properties, and radiation. Since the atmosphere is a non-linear chaotic system, small differences in the initial conditions and physics parameterizations can lead to significantly different outcomes over various time horizons. The ensemble methodology systematically samples these uncertainties, generating multiple outcomes, resulting in probabilistic distributions of forecast conditions, from which uncertainty estimates and decision guidance can be obtained.

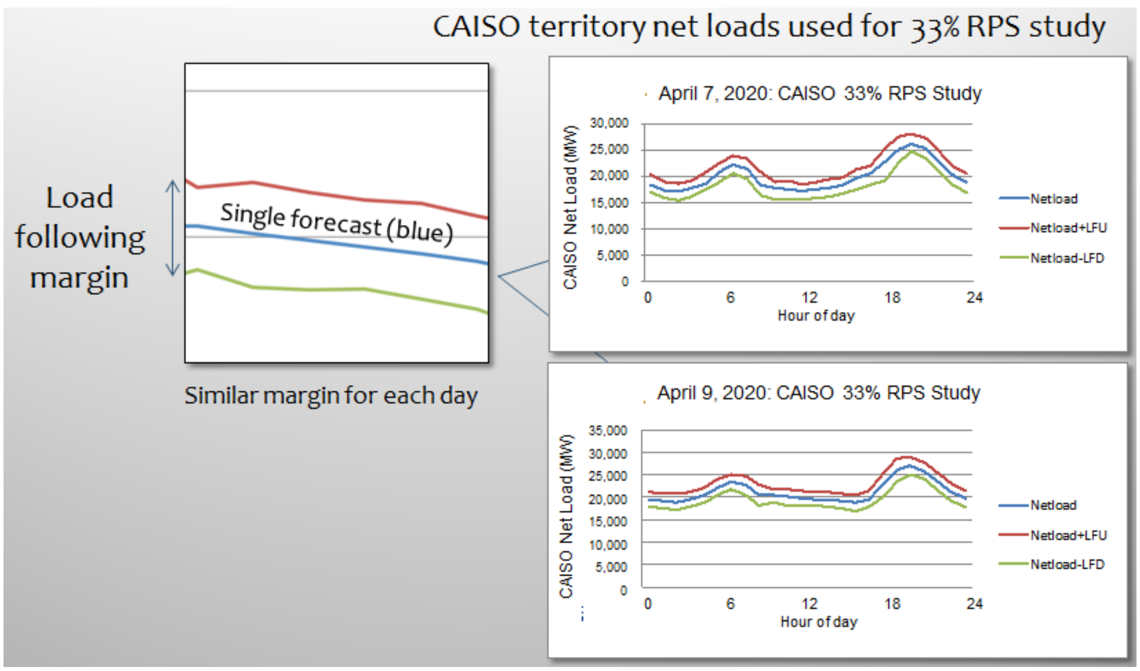

Figure 3: The CAISO net loads used for CAISO's 33% RPS study mimic the way that uncertainty in load and non-dispatchable generation is currently handled. A deterministic (single) forecast is used and a band of error around that forecast is used to define the reserve procurement. This band of error is nearly constant for a given season, since the uncertainty is based upon a single statistical model for that season. In this example, the reserves being carried on April 7th and April 9th are largely similar, even though the dominating weather patterns on those two days may dictate very different levels of uncertainty.

The ensemble mean has been shown to routinely outperform individual ensemble members over multiple scenarios[2] and consequently is frequently taken as the best estimate of the future state. Additionally, the spread of the ensemble members can be used to infer confidence in given outcomes. A close clustering of the ensembles can imply greater confidence in a given output, for example, while greater spread can alert the user to an increased likelihood of errors in the predictions, allowing for appropriate hedging strategies.

The ensemble forecasting methods we propose to evaluate will be based on the Weather Research and Forecasting (WRF) model. WRF is a state-of-the-art, full-physics atmospheric modeling system applicable to a variety of research and operational requirements. WRF is also open-source, and therefore benefits from continual improvement from a wide community of users spanning both atmospheric research and applied operations. LLNL is among the many institutions that have contributed physics modules into the WRF model that are now in the public WRF release. Due to the wide user group, WRF contains scripts that automatically configure the source code to run on a variety of computer systems, from single-processor laptops to Linux clusters with thousands of cores.

This project will implement and evaluate two basic approaches to developing ensembles of possible future weather conditions. One approach is referred to as the "Multi-Physics" approach. This recognizes the uncertainty regarding the physics processes that will dominate the evolution of the atmosphere over a span of one to a few days. These processes include the propagation of solar and terrestrial radiation between the top of the atmosphere and the surface, cloud microphysics, turbulent diffusion, land surface processes, and surface-atmosphere exchange. Various combinations of these physical process parameterizations can be used to generate multi-physics ensembles that characterize the uncertainties arising from the model physics.

The second approach is referred to as the "Multi-Analysis" approach. This accounts for the uncertainties in the initial conditions at the start of a forecast period. The WRF model can be used in conjunction with the Data Assimilation Research Testbed (DART)[3], which is housed at the National Center for Atmospheric Research (NCAR). DART uses the Ensemble Kalman Filter (EnKF) technique to assess a probability distribution over the true initial conditions at the start of a forecast. The approach samples different possible initial conditions from the probability distribution. Each of these initial

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[2] Hacker, J. P., S. Y. Ha, C. Snyder, J. Berner, F. A. Eckel, E. Kuchera, M. Pocernich, S. Rugg, J. Schramm, and X. Wang, The U.S. Air Force Weather Agency's mesoscale ensemble: Scientific description and performance results. Tellus, 63A,625-641, 2011.

[3] http://www.image.ucar.edu/DAReS/DART/

conditions is used in an independent WRF run to generate a possible trajectory over the conditions of the forecast period.

Both published research[4] and LLNL weather modeling experience indicate that different ensemble strategies are effective in different contexts. Multi-physics-based approaches are applicable to intermediate-length timeframes (several hours to days ahead), and are particularly important for the near surface winds and solar radiation, as these fields are highly sensitive to choice of cloud and boundary layer mixing parameterizations. For longer timescales (day-ahead or greater), multi-analysis approaches target modes of variability that influence dynamics that require longer timeframes to develop.

One should note that the Multi-Physics and the Multi-Analysis techniques are not mutually exclusive and can be used together to generate a more accurate forecast.

We propose to explore the benefits of both multi-physics and multi-analysis ensemble approaches to wind and solar energy prediction in California by generating a database of 3-hour and day-head forecasts for one month of each season. California possesses many characteristics that complicate regional-scale weather prediction applicable to solar and wind power production. These include marine influences on temperature and clouds near the coastlines, rapid transitions to arid desert conditions in the interior valleys, and complex terrain features that strongly influence wind fields in wind power production regions. We will investigate the behavior of different ensemble strategies in the unique microclimates of California over different weather scenarios and seasons to determine best practices for energy producers, IOUs and the CAISO. We will also explore the feasibility of using the generated forecast database to develop ensemble member specific weighting functions that can be used to improve unit commitment under uncertainty and to help establish dynamic reserve margins that depend upon weather conditions. In addition, the scenario with the highest probability, a weighted average of scenarios, or the most conservative estimate of generation can be used for deterministic planning calculations which require a single scenario, such as market clearing procedures.

As a practical matter producing and using ensemble forecasts requires that a substantial amount of data must be gathered each day (for daily forecasts) or each hour (for hourly updates). The data must be made available in time to assemble a model, execute it, and disseminate the results to users in time that they can use it in their planning processes. Part of this proposal will examine the practical issues in actually executing such real-time analyses. This will initially identify the data to be gathered each cycle, the sources

[4] Stensrud, D., J. W. Bao, and T. T. Warner, Using initial condition and model physics perturbations in short-range ensemble simulations of mesoscale convective systems. Mon. Wea. Rev. 128, 2077–2107, 2000.

of the data, and the schedules for compiling the data, delivering the data, and executing the runs. A real-time forecast delivery demonstration will then be undertaken to compile data, execute the models and deliver the results to the CAISO and IOUs in time for their planning processes. Visualization and decision-making tools will be delivered to the IOUs and CAISO along with the data.

To estimate the actual power produced from wind or solar resources, the predicted atmospheric conditions (wind speed, insolation) must be converted to power. We will investigate multiple approaches of converting weather data to power using state of the art methods. Evaluating the power conversion methods and the atmospheric forecast model will require access to site generation and meteorological data which may be proprietary. We will work CAISO and individual generators to obtain the necessary data to complete this task. Data security controls will be implemented to ensure that no external party will have access to proprietary data transferred from the IOUs or ISO to LLNL.

b) Objective

The overarching scope of the proposal is to develop an ensemble-based forecasting system to improve forecast accuracy and provide uncertainty bounds that reflect the inherent uncertainties in those predictions.

The power production models, combined with the ensemble forecasts, will result in a probabilistic power production model that can be used by power producers and the CAISO. The IOUs and other generation owners can use these probabilistic forecasts to inform their bids into the market. The IOUs can better forecast load affected by behind the meter or distributed renewable generation. The CAISO can use these forecasts to bracket their uncertainties, committing more ancillary services on days when the uncertainty is high and less on days when the forecasts are relatively more certain. This will have the net result of both lowering costs and ensuring reliability. Figure 4 shows an example of how the ensemble approach can provide uncertainty information that could be used to tailor the reserve provisions.

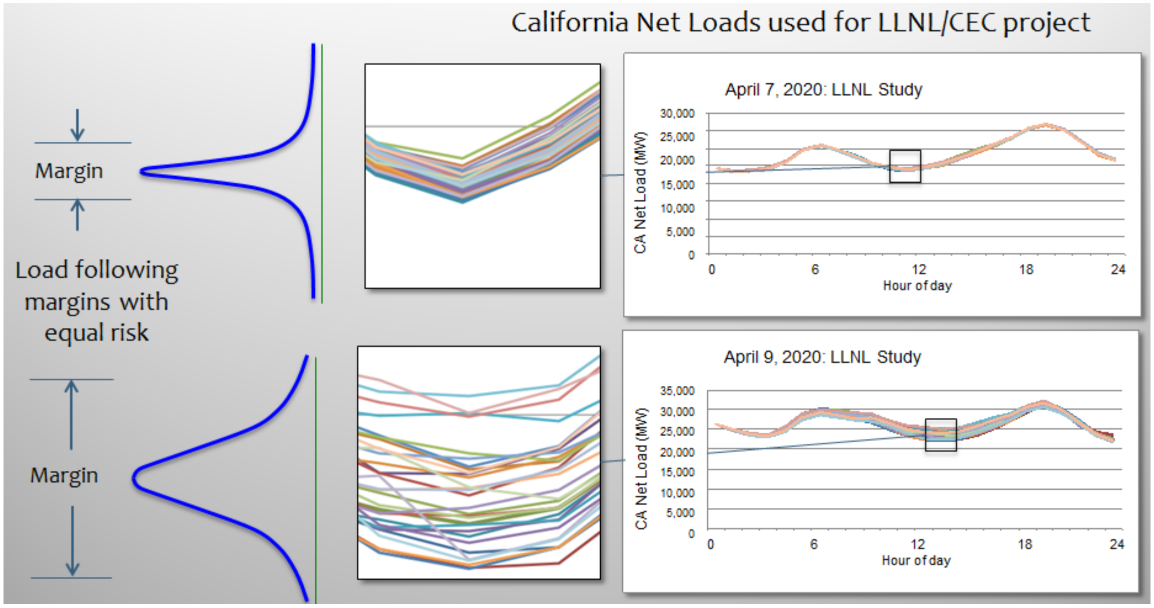

Figure 4: The California state net loads used in the CEC-funded LLNL study are based on 30 forecasts for each day, using a multi-physics ensemble approach. In this ensemble approach, the uncertainty is well defined and in fact varies daily and hourly. In this example, the uncertainty associated with the net load is much greater on April 9th than it is on April 7th. This could potentially allow operators to carry more reserves on days of high uncertainty and fewer reserves on days of low uncertainty, saving operational costs and boosting reliability.

The work will build on the forecasting system developed for the California Energy Commission (CEC) funded Lawrence Livermore National Laboratory (LLNL) study. That system utilized multi-physics ensemble-based weather forecasts to provide alternative weather, power generation, and load scenarios, along with their likelihoods to a production simulation (PLEXOS), which optimized unit commitment and economic dispatch based on those probabilistic scenarios.

This project will extend and improve several facets of the existing framework. We will perform the research required to develop more realistic weather-to-power production models, evaluate the merits of different ensemble approaches, and identify the best performing combinations of physics parameterizations. Statistical techniques will be applied to the dataset to extract useful relationships among system variables that can be used both to characterize uncertainties and to improve predictions. Finally, we will work closely with renewable energy providers, IOUs, and the CAISO to establish actionable decision guidelines tailored to the unique demands of disparate users.

The key activities for the project will include establishing an infrastructure for computations, data analysis, and data sharing with IOUs/CAISO, delivering forecast products and analysis tools, and evaluating and reporting on the potential cost savings.

The planned duration of the project is three years. The first year will establish computational and data sharing infrastructure and provide multi-physics ensemble forecast products, the second year will add the multi-analysis ensemble forecasts, and the third year will evaluate the benefits of each approach and determine best practices.

c) Expected results

At the conclusion of the project, we will have developed tools to improve the prediction of weather and renewable generation at forecast horizons of a few hours to day - ahead. Probabilistic information that characterizes system uncertainties will also be developed, and delivered to the IOUs and CAISO along with the data. LLNL will work with CAISO to develop decision-making tools that can effectively utilize this newly available data. This information is crucial to the efficient, reliable, and cost effective grid operations under a high renewable penetration scenario.

Renewable electricity generation, load forecasting, and unit commitment decisions all depend upon prediction of various weather parameters. Not only is the accuracy of these predictions important, but so too is the characterization of inherent uncertainties, which can lead to significantly different outcomes under certain conditions. With no a-priori way of knowing when the atmospheric state is highly sensitive to these uncertainties, ensemble-based weather forecast can provide estimates of these uncertainties, allowing generators, IOUs and the CAISO to bracket their expectations.

With an ensemble forecasting capability, the utilities and other renewable electricity producers can more accurately predict the power that can be produced, and can potentially avoid under-prediction scenarios which are costly and add stress to the system. They can also reduce the likelihood of having to spill renewable energy that could have been harvested.

The ISO can benefit by more efficient unit commitment decisions and a reduction in procurement of ancillary services when forecast confidence in particular outcomes is high. Rate payers benefit from the maintained reliability of the grid under reduced operating costs, which translate into lower electricity rates.

Although load forecasting is not included in the scope of this project, a probabilistic distribution of temperatures will be obtained from the ensemble weather forecasts. These temperature forecasts will be provided to CAISO to help bracket uncertainties in load forecasting. Load forecasting can also be improved with better prediction of behind the meter or distributed renewable generation.

3. Market Research

- Ensemble forecasts have not been widely adopted by CAISO, utilities, or small generation owners, likely due to lack of familiarity with the technique and lack of access to HPC. Until recently, these entities may also have had little incentive to develop better forecasts due to the relatively small amount of deployed wind/solar (in the case of the CAISO) and the compensation mechanisms for wind/solar generation (in the case of the generation providers).

- With the advent of ambitious RPS goals and compensation structures for wind/solar generators which penalize them for inaccurate day-ahead bids, there is and will continue to be an interest in improved forecasting methods.
- The California Energy Commission is currently funding a project with LLNL that uses ensemble forecasting techniques for future (projected for 2020) RPS build-outs and examines unit commitment and economic dispatch decisions with the ensemble approach. One finding of that work is that the spread in forecasted net load varies greatly from day to day, implying that there is an opportunity to save money by tailoring reserves to the specific daily uncertainty faced by the operators.
- This project will leverage the past work of the CEC-funded LLNL project in ensemble forecasting of the Western Electricity Coordinating Council (WECC) to provide this same type of forecast for the IOUs and CAISO in real time. This pilot project will demonstrate the potential value in incorporating ensemble forecasts into the daily decision-making of grid operators and generation providers.
- Just as California is leading the way in ambitious RPS goals, with this project, California will have the opportunity to lead the way in the forecasting tools of the future, to enable cost-effective and reliable integration of intermittent generation sources.

4. Research Approach Assessment

Challenge	Assessment	Reason
Implementation of DART multi-analysis procedures	Medium risk	DART multi-analysis procedures are very complex
Development of weather-to-power submodels	Low risk	Will require close collaboration with renewable forecasting to incorporate existing state-of-the-art techniques
Use of ensemble forecasts in an operational setting	Medium risk	Typical challenges incorporating new data into decision making processes

Key risk factor 1: Implementation of DART multi-analysis procedures. Mitigation strategy: If we are not able to implement the DART procedures by PM21, we will proceed using a simpler multi-analysis methodology. The simplified procedure will still provide sufficient data to evaluate the approach. Collaboration with NCAR, developer of DART software is a key component of the mitigation strategy.

Key risk factor 2: Development of weather-to-power submodels. If companies are unwilling to share key components of their weather-to-power models, we can construct our own based on published literature, including NREL's System Advisor Model. Alternatively, we may be able to provide forecast weather data for them to run through their models.

Key risk factor 3: Use of ensemble forecasts in an operational setting. In order to ensure that the IOUs and CAISO are comfortable viewing and using our ensemble forecasts in real time, we will need to work closely with key users to understand their requirements and beta test the forecast products before the production phase. We will also need to work with CAISO to develop visualization and decision-making tools that help the operators make use of this new type of data that has not been incorporated into the decision-making process previously.

5. Partnership Opportunities

Potential Partner	Reason for Partnering
CAISO	Needed for evaluating the use of ensemble forecasts in an operational setting
NCAR	Extensive experience in ensemble forecasting, especially multi-analysis forecasting, developer of WRF
NREL	Wind resource data sets
Infigen	End user of wind forecasts, experience in making weather-to-power conversions
Cool Earth Solar	End user of weather forecasts
UCSD	Expertise in solar tracking and short term prediction. In addition, UCSD has expertise in cloud assimilation and multi-physics ensembles, specializing in marine layer forecasting. UCSD is also doing extensive work in machine learning and solar forecast validation.

6. Implementation Plan and Schedule

a) Work plan

A Milestone Memo (along with any associated deliverables) will be sent to the IOUs upon completion of a Milestone. Furthermore, Quarterly Progress Memos and an accompanying web conference delivered from LLNL will provide a forum for reviewing Milestones, identifying other accomplishments, reviewing challenges, and describing next steps. Comments and feedback will be documented after each web conference. Any changes will be handled according to the established operating procedures for CES-21.

Phase 1: Build infrastructure for computations, data analysis, and data sharing (PM1 - 21)

We will begin this phase by identifying sources of weather and renewable generation data that are necessary to develop and validate the proposed ensemble based weather forecasting tool. An evaluation of current methodologies for calculating renewable generation from gridded weather forecast data will be performed. Working with our collaborators, we will build a data exchange infrastructure that includes an interface for sharing data between LLNL and the IOUs/CAISO, benchmarked wind and solar production models integrated with WRF output, and software tools to view the simulation results. We will also develop a set of forecast data visualization products that effectively communicate the probabilistic ensemble output, e.g. ensemble means and variance, confidence intervals, and ramp characteristics.

Major tasks:

1) (IOUs & LLNL) Establish an acceptable data format and sharing platform (PM1-9)
2) (IOUs & LLNL) Work with wind and solar producers to evaluate generation models that reflect common procedures (PM1-9)
3) (IOUs, CAISO, & LLNL) Identify wind and power data sources for benchmarking LLNL weather models and generation submodels and develop data safeguards to ensure the security of transferred propriety data (PM1-9)
4) (IOUs, CAISO, & LLNL) Develop preliminary specifications for a data visualization and decision making tool (PM1-13)
5) (LLNL) Integrate power generation submodels with WRF model output (PM10-18)
6) (LLNL) Benchmark wind and solar generation models against generation data (PM19-21)
7) (LLNL) Develop ensemble analysis products for operational use (PM10-21)

Phase 2: Multi-physics ensemble forecasting (PM9-21)

In this phase, we will modify the existing WRF multi-physics ensemble configuration developed for the CEC-funded LLNL study, to focus on existing wind and solar generation. The enhanced multi-physics weather prediction tool will provide improved uncertainty estimates of renewable generation forecasts for IOU grid operators. We will deliver a demonstration of a real-time multi-physics weather forecast to CAISO and the IOUs. We will also work with the IOUs and CAISO to develop additional methodologies for incorporating the weather forecast uncertainty estimates into operational decision making.

Major tasks:

1) (LLNL) Modify WRF post-processing scripts to reflect current CA wind and solar projects (PM1-13)

b) Interdependency with other Business Cases

Business Case with Dependency (WBS)	Type of Dependency (provider, consumer, informational)	Required or Beneficial	Explanation
Planning Engine	informational	beneficial	This planning engine project will benefit from ensemble forecast bias removal, benchmarking of weather-to-power models, and the capability of multi-analysis forecasting brought to LLNL.
Flexibility Metrics	Informational	Beneficial	The flexibility metrics project will benefit from a better characterization of wind/solar generation uncertainty, and a measure of that uncertainty on a daily basis rather than through a statistical model. It will also benefit from having some information on CAISO's operational experience using ensemble forecasts.

c) Milestones/Deliverables

Phase	Type	Description	Due Date	Responsible
1	Deliverable	Report describing sharing platform and data format agreed upon by IOUs/CAISO/LLNL. Report will also identify wind, solar, and power data sources to be used for benchmarking weather and generation models.	PM9	LLNL
1	Deliverable	Perform a multi-physics ensemble forecast software demonstration that assimilates available public and proprietary weather and utilizes a domain configuration based on IOU recommendations.	PM13	LLNL

Phase	Type	Description	Due Date	Responsible
1	Deliverable	Report describing the model specifications, the model domains used, the data sources assimilated, and the various weather-to-power generation models that are under consideration for the power benchmarking task.	PM18	LLNL
1	Deliverable	Report describing results of benchmarking wind and solar generation models against generation data and ensemble analysis products.	PM21	LLNL
2	Deliverable	Perform forecast software demonstration	PM14	LLNL

d) Resource requirements

An average of 2.7 people per year will be required. This estimate includes LLNL, IOU, and potential partner resources in the following areas.

- Modeling
- Atmospheric Science
- Programming
- Engineering
- Statistics
- Mathematics

7. Cost Estimate and Allocation

Expense	PM1-18 ($K)	PM19-30 ($K)	PM31-42 ($K)	PM43-54 ($K)	PM55-66 ($K)
LLNL & Subcontract Labor	1,561	337			
IOU labor	338	157			
TOTAL	**$1,899**	**$494**			

8. Benefits Estimate and Methodology

This business case is aimed at saving operational system costs and improving grid reliability with better renewable forecast tools. System cost savings can be realized with better net load predictions, which would lead to better unit commitment decisions for the day-ahead and to the purchase of only the necessary quantity of ancillary services such as load following to account for the net load uncertainty and volatility faced on that day. Reliability can also be improved with better forecasts that allow CAISO to purchase additional reserves on days when the net load forecast is highly uncertain, thereby reducing the chance of over/underproduction and the risk and expenses associated with them. The ratepayers will ultimately benefit by increased reliability and lower cost of electricity.

Utilizing a sophisticated ensemble-based forecasting approach versus a simplified deterministic forecast system has been shown to improve day-ahead wind power forecast accuracy by as much as 22%[5] . This magnitude of improvement in forecast accuracy can translate into significant operational cost savings. For example, Xcel Energy, which incorporates power from numerous wind parks over the Central United States, was able to save $6M a year in operational costs by implementing an advanced weather / power forecasting system[6]. NREL has investigated possible cost savings within the WECC from improved forecast skill and found that a 10%-20% increase in wind generation forecast skill would translate to operational savings of roughly $28M-$52M per year assuming a 14% wind energy penetration.[7] As wind energy penetration increases, the operational cost savings from improved forecasts goes up dramatically; for 24% wind penetration, cost savings are projected to be $100M and $195M for 10% and 20% improvements in forecast, respectively.

Illustrative examples provided by the utilities as part of the CES-21 application showed how new methodologies and tools such as improvements in renewable generation forecasts developed as part of this business case could provide benefits of $30 million per year by reducing load following costs.[8]

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[5] K. Parks, Y-H. Wan, G. Wiener, and Y. Liu, Wind Energy Forecasting: A Collaboration of the National Center for Atmospheric Research (NCAR) and Xcel Energy, NREL NREL/SR-5500-52233, Golden, CO: National Renewable Energy Laboratory, 2011.

[6] http://coloradoenergynews.com/2011/11/ncar-wind-forecasting-system-saves-millions-for-xcel-energy/

7 Lew, D., M. Milligan, D. Piwko, and G. Jordon, 2011: The value of wind power forecasting. Preprints, Second Conf. on Weather, Climate, and the New Energy Economy, Seattle, WA, Amer. Meteor. Soc., 2.1.

[8] D.12-12-031, p. 82.

California Energy Systems for the 21st Century

Flexibility Metrics and Standards

Proposed Research Project: Business Case

1. Executive Summary

a) Research Project Opportunity Statement:

New operating flexibility metrics and targets are needed for long-term resource planning in California. Improvements to methodology and existing models, or new models, are also needed to better estimate the system need for resources incorporating operating flexibility metrics, and to evaluate the effectiveness of resources with different operating attributes to meet those needs.

Traditional resource planning methods have used reserve margin metrics and targets, 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.

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 targets need to be updated to incorporate the increased need for operating flexibility with greater amounts of intermittent generation.

This proposal is to establish a relationship between the three California Investor Owned Utilities (IOU) and Lawrence Livermore National Laboratory (LLNL)[1] to:

- Review and critique existing flexibility metrics and tools now in use and under development by the utilities, CAISO, and others to identify flexibility needs.
- Define flexibility metrics, such as insufficient ramping capacity, that a system requires to balance loads and resources during different time intervals.
- Operationalize the flexibility metrics for long-term planning purposes, either as separate metrics or combined with existing reliability metrics, such loss of load expectation (LOLE) or planning reserve margin (PRM) requirement.

[1] Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344.

- Develop new or improved models that incorporate flexibility metrics with traditional production simulation and reliability models.
- Develop new or improved tools to measure the contribution of different types of resources toward the system's flexibility requirements, and determine system need.

The integrated optimization model will improve estimates of system need, incorporating operating flexibility metrics under a variety of weather scenarios, and provide new or improved tools to evaluate the effectiveness of resources with different operating attributes to meet those needs.

b) Utility Sponsors:

☒ PG&E ☒ SCE ☒ SDG&E

c) This research focuses on the following area:

☐ Cyber Security ☒ Electric Resource Planning
☐ Electric System Operations ☐ Gas System Operations

d) This research maps to the following value chain categories:

☐ Grid operations/market design
☒ Generation
☐ Transmission
☐ Distribution
☐ Demand side management
☐ Cyber Security

e) This research supports one or more of the following objectives identified in Public Utilities Code §740.1:

☐ Environmental improvement
☐ Public and employee safety
☐ Conservation by efficient resource use or by reducing or shifting system load
☒ Development of new resources and processes, particularly renewable resources and processes which further supply technologies
☒ Improve operating efficiency and reliability or otherwise reduce operating costs

f) Potential Customer Benefits:

This project will facilitate more accurate estimates of

- System flexibility requirements, such as net load following requirements, and ramping requirements
- System need for resources
- Effectiveness of different operating attributes to meet the system's need.

In regulatory proceedings before the California Public Utilities Commission, the CAISO has identified a need for 4,600 MW of new flexible generation need to reliably operate the generation system with 33% renewable generation. This estimate has not been supported by stakeholders due to perceived limitations in the analyses used by the CAISO, despite stakeholder input to the analysis methods. At a cost of perhaps $1 million per MW, improving the accuracy of flexible resource need determination could result in substantial benefit to California electricity consumers. In addition, under AB 2514, the CPUC is obligated to consider whether an energy storage mandate should be adopted. An improved understanding of flexibility needs may provide insight into the how to best take advantage of the flexible operating attributes that energy storage technologies can provide.

g) 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 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 targets used today.
- How to best determine resource need, or the effectiveness of resources with different operating attributes to meet those needs, considering the increased need for operating flexibility and traditional reliability requirements.

h) Unique Capabilities Offered by LLNL:

Developing a solution to this issue 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 testing 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. We have 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

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 we expect to partner for specific requirements
Other National Laboratories	Do not have the combination of a wide range of atmospheric modeling, high performance computing, and experience in decision and operational modeling

i) 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.

j) Duplication and synergies:

All project scope has been coordinated with other CES-21 projects, EPIC projects and other research efforts underway at the utilities and other research entities to ensure no duplication of effort. In addition, the CES-21 team will continue to monitor external RD&D projects to take advantage of synergies with external research and reduce the risk of future duplication.

2. Proposal Description

a) Background

Today, California's electric grid uses loss of load expectation (LOLE), planning reserve margin (PRM) and operating reserve margin (ORM) as reliability metrics. These metrics have corresponding targets or standards that serve as guidelines for electric resource planning.

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.

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 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

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 the CPUC 2010 long-term procurement plan proceeding, utilities and the CAISO investigated flexibility needs, and the CAISO estimated a need for 4,600 MW of new flexibility need in 2020, using conventional natural gas fired generation to manage net load (customer demand less intermittent generation sources). Most stakeholders agreed the results were inconclusive, and the CAISO has initiated a new modeling effort in the 2012 LTPP which will go forward during 2013. There remain substantial modeling limitations, and success of these efforts remains uncertain.

b) Objective

This project 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 tested 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.

The ability to meet ramping requirements depends on the state of the generators at the time the ramp occurs (ie, generator is on line or committed and likely to be on line 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. Depending on the outcome of the initial stages of the project, the work may be extended to study the benefits of improved quality of the forecasts and decision procedures used to operate the system.

c) Expected results

This project will develop new metrics to measure the probability that the system will be unable to ramp quickly enough to meet the ramping events that are possible with high levels of renewables. If properly constructed and employed, such a metric can 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 identify flexibility needs.
- Define flexibility metrics, such as unserved ramping capacity, that a system requires to balance loads and resources during different time intervals.
- Operationalize the flexibility metrics, either as separate metrics or combined with existing reliability metrics, such loss of load expectation (LOLE) or planning reserve margin (PRM) requirement.
- Develop new or improved models that incorporate flexibility metrics with traditional unit commitment and economic dispatch models, and can inform the selection of operating flexibility standards.
- Estimate the need for resources considering operating flexibility metrics.
- Develop new or improved tools to measure the contribution of different types of resources toward the system's flexibility requirements, and determine system need.

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 sinks 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

We are also aware of E3's effort to develop a new model where the flexibility constraints or costs are considered in commitment decisions. E3 proposes an "endogenous2" design that allows the model to consistently operate the controllable generation to explicitly react to intermittency. This is in contrast to an "exogenous3" modeling of ramping proposed by the Dublin group. E3 only models California and 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.

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[2] 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.

[3] An exogenous approach would separate the fine detail of the unit commitment and dispatch from the finest level of the flexibility metric. In this case, you have two or more models for two or more aspects of the system and you must make them work together in some way that approximates the solution of the whole. Decomposition methods from optimization theory could make an exogenous approach practical.

To simulate load, wind and solar and model the coupling between them, E3 buckets the historical data into months, and then into low and high load days. Load is further bucketed 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.

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

5. Partnership Opportunities

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
University College, Dublin	They have conducted research on similar problems.

6. Implementation Plan and Schedule

a) Work plan

A Milestone Memo (along with any associated deliverables) will be sent to the IOUs upon completion of a Milestone. Furthermore, Quarterly Progress Memos and an accompanying web conference delivered from LLNL, will provide a forum for reviewing Milestones, identifying other accomplishments, reviewing challenges, and describing next steps. Comments and feedback will be documented after each web conference. Any changes will be handled according to the established operating procedures for CES-21.

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 to needed to address the problem (PM1-7)

In this first phase, we 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 of what is 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 addresses 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. 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.

Major tasks:

1) (IOUs, LLNL) Gather and Analyze pertinent data. (PM1)
2) (IOUs, LLNL) Decide characteristics methodology and analytical tools needed to solve the problem. (PM2-3)
3) (IOUs, LLNL) Determine if and how to incorporate findings from current efforts in Flexibility (SCE study, CAISO/E3, and others as applicable). (PM4-7)

Phase 2: Select a base model (PM7-9)

Based on the characteristics identified in the prior phase, select a base model. In this phase we 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. For purposes of providing a cost estimate, we will assume Plexos is the base model given CAISO and IOUs experience with the model and LLNL's on-going use of Plexos for its probabilistic analysis of demand response and storage for the CEC (CEC Project).

Major tasks:

1) (IOUs, LLNL, CAISO, consultant) Review and critique existing flexibility metrics and tools now in use and under development in consultation with CAISO and model vendors. (PM7-9)

Phase 3: Develop the infrastructure to generate multiple weather dependent data (load, hydro, wind, solar) (PM9-15)

Initial experiments will be conducted to understand what modeling approach and computational resources will be required to do develop possible flexibility metrics. For purposes of estimating the cost of this project, we will assume, similar to the approach LLNL is using for its CEC Project, that the Weather Research and Forecasting (WRF) model will be used to reproduce a range of temperature, wind and solar conditions prevailing in California and the Western Electricity Coordinating Council (WECC) for 30 scenarios for each of four different weather years. 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 to generate multiple weather dependent data for or 30 scenarios for each of four different weather years. (PM9-15)

Phase 4: Develop the infrastructure to automate the running of many scenarios in batch mode through the optimizer (PM15-21)

Set up model so it can be run in batch mode with many predefined scenarios. Use this to produce a reasonable list of scenarios of output that can be analyzed by hand, and later with the use of the prototype code developed in later phases of the project, and used to begin gaining insight into what the filing should look like. Automate storage of the results into a database or other convenient form for subsequent analysis. For purposes of estimating the cost for this project, we will assume that the weather scenarios will be run in Plexos in weekly batches, and 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. (PM15-16)
2) (LLNL) Develop code to speed up run time and manage storage inputs/output. (PM16-21)

Phase 5: Develop Flexibility Metrics (PM9-20)

Based on the previous phase's results, the appropriate models and simulation codes will be developed or extended – leveraging existing products whenever possible. New tools developed 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, we 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. For purposes of developing a cost estimate for the project, we will assume three flexibility metrics will be used and tracked: Regulation, Net Load Following and Net Load Ramping, as explained below.

Major tasks:

1) (IOUs, LLNL) Develop a prototype Regulation metric in consultation with CAISO. This metric would define the flexible capacity on automatic generation control (AGC) that the system needs to respond to the intra-5 minute variability and forecast uncertainty of net load. Net load is the residual load left after subtracting intermittent wind, solar and other variable and uncontrollable generation. This regulation metric would most likely apply at 5 minute intervals, and would help identify AGC responsive capacity, supply or demand-side capacity, to meet a selected regulation standard. (PM9-14)
2) (IOUs, 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. (PM14-20)

3) (IOUs, 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. (PM14-20)

Phase 6: Develop a prototype model to quantify flexibility metrics (PM14-20)

The metric 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 (say, 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). (PM14-20)

Phase 7: Integrate the flexibility metric prototype with the base model (P21-26)

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 targets given the marginal cost of flexibility. The following diagram illustrates the three components of the optimization.

The ultimate goal is to integrate the selected flexibility targets into a larger optimization which can be solved in workstations used by the utilities, CAISO and other parties in 4 hours per weather year. We will look for ways to reduce run time by: 1) clustering the 30 weather scenarios into 6 scenarios, as LLNL is currently doing for the CEC Project, and 2) simplifying the representation of the system without losing significant accuracy. We will validate those simplifications with higher resolution simulations using LLNL's HPC.

Major tasks:

1) (LLNL, consultant or model vendor) Integrate the flexibility metric prototype. (PM21-26)

Phase 8: Test and evaluate the results from the three-model integrated optimization (PM26-32)

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 with any research project, it is difficult to predict all obstacles or difficulties that we may find, and therefore the precise completion time and cost of the project.

Major tasks:

1) (IOUs, LLNL, consultant or model vendor) Test and evaluate the results. (PM26-32)

Phase 9: Document the model (PM26-36)

Major tasks:

1) (IOUs, LLNL, consultant or model vendor) Document new or improved model. (PM26-32)

b) Interdependency with other Business Cases

Business Case with Dependency (Phase)	Type of Dependency (provider, consumer, informational)	Required or Beneficial	Explanation
Planning Engine	Provider	Beneficial	Planning engine will improve performance of production simulation models and the supporting optimization codes, will adapt codes to HPC environment
Planning Engine	Consumer	Beneficial	Flexibility metrics and constraints will be incorporated in production simulation models developed and used in Planning Engine

c) Milestones/Deliverables

Phase	Type	Description	Due Date	Responsible
1	Milestone	Definition of problem and characteristics of needed tools	PM7	IOUs, LLNL
2	Milestone	Base model selected	PM9	IOUs, LLNL
3	Deliverable	Software infrastructure to generate multiple weather dependent data (load, hydro, wind, solar) to input into selected base model	PM24	IOUs, LLNL
4	Deliverable	Software infrastructure to automate the running of many scenarios in selected model	PM21	LLNL
5	Deliverable	Report on flexibility metrics	PM18	LLNL
6	Deliverable	Prototype model to calculate the expected amounts and probability of flexibility deficiencies	PM18	LLNL
7	Deliverable	Prototype code to optimize commitment and dispatch that integrates the flexibility metrics [run iteratively; may need manual interphase]	PM26	LLNL
8	Deliverable	Report on test results	PM36	LLNL
9	Deliverable	Model documentation	PM36	LLNL

d) Resource requirements

2 people will be required in Project Year 1 months 1-6, and 4 people months 6-12. 6 people per Projects Years 2 and 3 will be needed. This estimate includes LLNL, IOU, and potential partner resources in the following areas.

- Weather modeling
- Production simulation modeling
- Computer scientist
- Statistician

7. Cost Estimate and Allocation

Expense	PM1-18 ($K)	PM19-30 ($K)	PM31-42 ($K)	PM43-54 ($K)	PM55-66 ($K)
LLNL & Subcontract	1,325	1,825	1,825		
IOU labor	75	75	75		
TOTAL	**$1,400**	**$1,900**	**$1,900**		

8. Benefits Estimate and Methodology

This project will facilitate more accurate estimates of:

- System flexibility requirements, such as load following requirements, and ramping requirements for different operating flexibility policies or standards
- System need for resources
- Effectiveness of different operating attributes to meet the system's need.

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. They included $552 million in savings from improved resource planning.[4]

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

California Energy Systems for the 21st Century

Planning Engine

Proposed Research Project: Business Case

1. Executive Summary

a) Opportunity Statement:

This proposal is to establish a relationship between the three California Investor Owned Utilities (IOU) and Lawrence Livermore National Laboratory (LLNL)[1] to provide utilities with the modeling ability and knowledge to ensure that they can provide safe, reliable, and affordable power to their customers. Specifically, this project aims to provide utilities with a modeling tool that will enable system planners to evaluate the cost and reliability impacts of various transmission and/or generation capacity expansions, as well as to help them seek optimal solutions to existing or potential grid reliability issues.

Existing modeling tools are insufficient for co-optimization of resource and transmission resources, and will only become more deficient as California's electrical system undergoes radical changes in the upcoming years. Planning tools and methods currently used by utilities do not have the capability to dynamically vary generation and load to model the impacts on the transmission system and the implications for transmission reliability. They cannot effectively evaluate distributed grid impacts such as renewable generation, demand-side resources including demand response and distributed generation, the addition of plug-in electric vehicles (PEVs), and other factors that will make the electrical grid even more dynamic and uncertain. Recent research by the CAISO and IOUs have shown sizable swings in net load resulting from wind and solar generation shapes may exacerbate the effects of other distributed generation or high load draw technologies that are on the cusp of widespread deployment. Moreover, with highly variable generation coming on line, traditional thermal generation will have to react in new and possibly unexpected ways in order to close the gap between must-take generation and load.

This research seeks to develop a tool that will be able to optimize generation dispatch and test power flow over transmission lines. A tool that would be able to both dispatch generation assets and model the power flow over transmission lines resulting from that generation dispatch would allow system planners to model and quantify the trade-offs they face as they weigh different transmission and generation solutions. By necessity, this tool will require the development of a higher resolution model than normally used in production simulation and a more comprehensive model than normally used in power

[1] Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344.

flow analysis. To enable a solution of higher resolution models, we will engage commercial software and hardware vendors to develop improved solution algorithms. As part of this effort, high performance computing (HPC) platforms will be used to solve problems more rapidly. The solutions to these large scale problems will be used to develop and validate simpler reduced-order models that can be solved on more conventional computing platforms by a range of stakeholders.

b) Utility Sponsors:

☒ PG&E ☒ SCE ☒ SDG&E

c) This research focuses on the following area:

☐ Cyber Security ☒ Electric Resource Planning
☐ Electric System Operations ☐ Gas System Operations

d) This research maps to the following value chain categories:

- ☐ Grid operations/market design
- ☒ Generation
- ☒ Transmission
- ☐ Distribution
- ☐ Demand side management
- ☐ Cyber Security

e) This research supports one or more of the following objectives identified in Public Utilities Code §740.1:

- ☐ Environmental improvement
- ☐ Public and employee safety
- ☐ Conservation by efficient resource use or by reducing or shifting system load
- ☒ Development of new resources and processes, particularly renewable resources and processes which further supply technologies
- ☒ Improve operating efficiency and reliability or otherwise reduce operating costs

f) Potential Customer Benefits:

Without the tools to identify an optimal solution, it is difficult to quantify the excessive costs imposed by current generation and transmission planning methods. However, costs of individual generation and transmission assets are large ($500 million to $2 billion) for moderate sized project, so even minor improvements would have significant value. Also, some categories of transmission security violations can be met by implementing a load reduction scheme in which blocks of firm customer load are dropped during a loss of two or more transmission elements to prevent widespread blackouts. The frequency with which such schemes are operated is not well understood, and it may be beneficial to make wider use of such schemes to protect against unlikely contingencies, thereby eliminating the need for transmission upgrades.

Improved planning tools can lead to improved capital utilization and consequent reduction of the fixed cost of the grid by guiding policy initiatives and design of preferred resource programs. The tools can also help reduce operating costs and emissions by providing more effective algorithms for unit commitment and economic dispatch. Finally, the tools can assist in determining the operating attributes of new resource additions needed to maintain reliability in face of increased system variability and uncertainty.

The enhanced planning tools will help reduce costs and improve reliability of the grid by:

- Optimizing the use of existing capital equipment given the large variability and uncertainty introduced by intermittent generation and customer demand
- Identifying the most cost effective generation and transmission additions
- Facilitating the evaluation and design of effective demand response resources
- Ensuring a reliable power grid under extreme weather conditions and component failures

g) Research Challenges and Hurdles to Overcome:

Currently, it is unclear whether it is possible to develop a tool that can optimize generation and transmission in the manner outlined in the previous section. There are no pre-existing tools that can perform this task, particularly for a system as large and complicated as the WECC. The first task of this project is to evaluate current power flow and production simulation tools to determine the ability of these tools to perform the analyses required or the potential to modify pre-existing tools to suit the purpose of this research.

The second primary challenge of this research will be to develop new algorithms that can better utilize pre-existing optimization methods. There are several possible approaches to addressing the computational limits of existing power flow models. More efficient solution algorithms could be beneficial at reducing computational limits. For instance, early production simulation models used a Balreaux-Booth algorithm to reduce the number of calculations required to assess reliability, but this algorithm has not been extended to multi-area models nor integrated with power flow methods. Alternatively, solution methods could be efficiently organized into parallel streams, allowing for simpler application of distributed processing across multiple computers or processing cores. In either case, integration of current generation and transmission planning models into a single modeling tool would need to occur simultaneously with improvements to algorithms currently employed by these models in order to incorporate the quantity of data analysis that will be necessary for a unified model.

In the event that such a tool could be produced, it will require very high fidelity modeling of the California electrical grid and necessitate serious computing power. A co-optimized model would need to produce the following information in a computationally efficient manner:

- Identify the stochastic range of exposure to transmission grid overload or failures under major contingent events, incorporating uncertainties due to weather and generating plant performance.
- Identify necessary generation reserve margin standards regionally, in an analytical framework in which transmission power flow constraints and the stochastic potential for transmission outages are considered.
- Perform scenario analysis of different generation development alternatives (including both conventional and renewable/alternative resources) in a manner that fully reflects locational value and is suitable to identify total system production costs and environmental impacts (related to power plant emissions).

h) Unique Capabilities Offered by LLNL:

LLNL research relationships with the Power Systems Engineering Research Consortium (PSERC), IBM, Energy Exemplar (Plexos developers), UC Berkeley, Princeton, and others 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.

Alternatives	Assessment
Private sector consulting firms	Short-term focus, use of existing tools, no access to HPC, will engage consulting firms as needed
Power system software vendors	Short-term focus on incremental improvement to existing software, will engage vendors as needed
Universities	Long term focus with less emphasis on deployment of solutions, will engage universities as needed
Other national laboratories	Lawrence Berkeley Laboratory – focus on data resources and pilots rather than modeling Other laboratories – limited relationships with California IOUs, smaller high performance computing programs Will engage other laboratories as needed

i) 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.

j) Duplication and synergies:

All project scope has been coordinated with other CES-21 projects, EPIC projects and other research efforts underway at the utilities and other research entities to ensure no duplication of effort. In addition, the CES-21 team will continue to monitor external RD&D projects to take advantage of synergies with external research and reduce the risk of future duplication.

2. Proposal Description

a) Background

Current Modeling Solutions

In cases where there is potentially the need for major system upgrades in the form of generation or transmission, system planners seek solutions that will provide the most system reliability at the lowest cost. However, because there are no models that simultaneously determine system reliability (power flow modeling) and generation cost (production simulation modeling) in a stochastic manner, it becomes difficult for system planners to jointly model and quantify the trade-offs they face as they weigh different transmission and generation solutions. As a result, often conservative or incomplete analyses are performed, resulting in non-optimal solutions that can raise costs by overinvesting in physical generation and transmission assets.

Utilities currently use commercial off-the-shelf (e.g. PLEXOS, MAPS) and in-house developed modeling tools for planning. Generation planning employs production simulation models, which dispatch system generation resources on an hourly or sub-hourly basis to optimize system costs while meeting various system constraints, such as hourly load, generator ramping capabilities, or import limitations. Along with generator dispatch decisions, production simulation models will also have associated data such as total production cost, tons of pollutant emissions, and reliability statistics (expected unserved energy or reserve shortfall). In order to model an entire electrical interconnection system, current production simulation models commonly employ a highly simplified representation of the transmission system in which regions or load serving entities are modeled as “bubbles” with aggregated regional load and transmission lines are modeled as power flow constraints between bubbles.

There are also some models that use nodal transmission representations, but these models are most often used for market analysis and do not represent transmission planning activities well. Generation reliability models use probability based a “one-in-ten” loss of load standard, i.e. generation should be sufficient so as to have one loss of load event in ten years. In order to model this, production simulation models commonly allow for model inputs like peak load or generator forced outages to be varied using Monte Carlo techniques to address whether there is a sufficient reserve margin (generation in excess of expected peak load) to assure adequate reliability. Scenario analysis commonly varies exogenous factors (such as peak load or policy directives) to identify a particular mix of future resource types that satisfy cost, reliability and economic criteria.

Also because of computational challenges, production simulation models typically do not incorporate power flow representations, or do so only in a deterministic modeling environment. As a result, there is limited locational information available in production simulation modeling to incorporate locational preferences for new generation that can reduce the impact of contingencies on transmission grid security.

In transmission planning, power flow models are used to assess the robustness of a transmission grid under specific stress conditions, to ensure that the specified contingencies (such as generator or transmission line outages) do not cause overloaded transmission components or voltage disturbances leading to regional blackouts. Typically, such models are performed deterministically, simulating a particular high load scenario (one-in-ten year load) which is generally up to 10% higher than the expected load, and then selectively testing grid conditions with one and two major system components out of service. Transmission system security violations are remedied by upgrading the transmission grid or adding new generation in specific locations.

Transmission power flow analyses are computationally demanding, and so to make analysis more manageable for only one contingency scenario, transmission models are only run for the one hour of the year of peak load, with the assumption that the system is under the most stress at the time of peak load. However, there is some concern that this will no longer be a sufficient means to test the potential stresses on the transmission system in light of increased renewable penetration. As must-take generation becomes a greater percentage of load, high ramping needs to meet net load are expected to place the transmission system under new and different stresses, which will not be captured by this type of modeling.

Another effect of the computational limitations of transmission modeling is that transmission planners test potential system security risks only under extreme stress conditions, rather than under a range of stochastic events. While the specific conditions tested are typically very low probability there is little understanding of whether system security violations are also prevalent under less stressful, higher probability conditions. As a result, there is no clear understanding of the transmission reliability benefits that are associated with identified transmission system upgrades or generation additions. Also, it is difficult to assess the value of use-limited resources such as demand response to meeting transmission security violations.

Transmission and generation reliability are two sides of the same coin in that they are different reasons for a loss of load event—a generation insufficiency is a loss of load event due to load exceeding generation capabilities; a transmission insufficiency is a loss of load event or excedance of thermal, voltage or other criteria due to lack of transmission capability while trying to move power from generation centers to load centers. Note that a system reliability issue, either from generation or transmission insufficiency, can often be solved with either a generation or transmission solution, in that a generation asset may be a solution to a transmission insufficiency and vice versa. Because of this, it is important to consider the solution space of all potential solutions, be they generation or transmission, when trying to solve a system reliability issue of either type.

Co-optimization Model

The motivation for this research is twofold. First and foremost, current tools are not sufficient to meet modeling needs. As previously discussed, generation and transmission expansion plans are developed in largely separate processes that use different types of computer models and have substantially different performance criteria. However, because generation and transmission systems are innately interdependent, truly optimal system dispatch of resources may not be captured by one tool. In fact, some research has shown that considering both transmission and generation topology can change the optimal unit commitment schedule.[2] It may be that a better understanding of the holistic generation and transmission system may allow for the avoidance of millions of dollars of investment in physical generation assets.

Secondly, new and upcoming developments in California's electric system, particularly increased must-take and variable generation, will require new tools to fully understand the impact on the electrical grid. Increasing quantities of renewable resources has resulted in an increasing need to performing generation and transmission planning with higher time granularity (for renewable resource integration studies) and including lower voltage components (distribution-level generation assets). Other research efforts are addressing these challenges, but successfully addressing computational challenges in this initiative could allow increased capability to address renewable resource related planning issues as part of a co-optimized model. This tool will provide a means to perform more complex and in depth analysis on many of the challenges facing California's electric system, including growing fleet of renewable and demand-side resources, demand-side and distributed generation, energy efficiency and new technologies, and changes in electricity demand due to electrification, plug-in load, and dynamic pricing.

An optimal outcome of this research is a tool that can simulate generation and power flow from generators in the WECC to load centers in a high resolution manner that will simultaneously optimize production costs and reveal the impacts on transmission reliability. Such a tool will need to be able to simulate a year's worth of generation and transmission in a reasonable amount of time (hours or days) and produce useful, comprehensible output that will allow system planners to make informed decisions about the reliability of California's electrical grid and the potential costs of various scenarios. Specifically, this tool will need to be able to model GHG produced in California and the WECC, as well as hourly power prices, ancillary services and reliability statistics.

Potential Applications

It is hoped that when this tool is fully functional, it can be used for a number of applications, most specifically, as a capacity expansion tool to evaluate the potential of physical asset investments. In this case, the tool will be used to evaluate a spectrum of potential solutions to determine the optimal solution to capacity expansion need. In

[2] http://pages.cs.wisc.edu/~ferris/papers/Hedman_GenUC.pdf

other words, the tool would have to search some solution space, which is composed of various transmission and generation solutions and evaluate a potential solution's ability to resolve reliability issues and then quantify the capital and operational costs or benefits of the solution. Optimally, as this tool becomes more completely developed the set of potential solutions would include not only generation and transmission expansions, but also alternative energy solutions such as energy efficiency, distributed generation, demand response, or even implementation of time of use rates for peak load shifting.

b) Objective

The objective of this research is to develop a tool that can model both transmission and generation to analyze more complex grid planning problems at larger scale. The added complexity introduced by intermittent renewable generation and demand response will be key areas of focus. Topical studies that are required to support large scale models (e.g., generate input parameters or assess viability of solutions generated) will also be performed.

Although the proposal outlined here may represent years of work, due to the uncertain nature of this project, the work proposed in this business case covers only:

(1) An initial six-month phase intended to better assess the potential of this project. In this first six-month phase there are two primary goals: (1) evaluation of pre-existing production simulation and power flow modeling tools for incorporation into the model and (2) evaluation of programming and algorithm development needs resulting from results of task (1).

(2) Development of an enhanced representation of the transmission and generation system in for a co-optimization production simulation and power flow model.

After Part 1, there will be an evaluation of the potential and feasibility of the research. If it is felt that this project is still possible and can be completed within the timeframe and budget outlined, then it will move forward to Part 2. The budget for subsequent years of the project will be updated to reflect the priorities and the detailed work plan developed in the first year.

c) Expected results

The enhanced, higher resolution planning tools will help reduce costs and improve reliability of the grid by:

- Optimizing the use of existing capital equipment given the large variability and uncertainty introduced by intermittent generation
- Identifying the most cost effective generation and transmission additions
- Created a model that can be used in the future to improve understanding of how demand response, energy storage and other flexible resources can contribute to renewable integration.

- Considering the computational requirements of this model, develop potential implementation plans for utilities (with a particular focus on implementation costs) with possibilities such as
  - Mini supercomputer clusters
  - Parallel processing
  - Outsourced computing
  - Cloud computing

3. Market Research

Commercial production simulation codes commonly used by the industry include PROMOD IV, MAPS, and Plexos. Other codes developed by utilities, software vendors, consulting firms and academic researchers are also used. Aggregation of busses, generators, demand and other system components is typically used to allow modeling of larger systems. None of the commercial codes have been deployed and demonstrated on high performance computing systems at the scale envisioned by this research. All of them were originally developed for deployment on single-CPU systems.

The work here would leverage LLNL-funded work with Energy Exemplar (developer of Plexos production simulation software) and IBM (developer of CPLEX solver used by Plexos) to demonstrate formulation and solution of large scale grid planning models. This initial research indicated that the models and algorithms for formulation and solution of production simulation models under uncertainty did not exploit high performance computing resources.

4. Research Approach Assessment

Challenge	Assessment	Reason
Reformulation of problems to exploit HPC architectures	Medium level risk	• Availability of decomposition methods that can represent problem as a collection of related smaller subproblems • Software infrastructure at LLNL to facilitate development of parallel code • LLNL's and collaborators' experience with reformulating problems to exploit HPC systems
Data sets to support model development and analysis	Medium level risk	• Availability of data sets from IOUs and CAISO • Data can be anonymized or non-disclosure agreements can be executed

5. Partnership Opportunities

Potential Partner	Reason for Partnering
Energy Exemplar	Plexos grid modeling software
IBM	CPLEX optimization software
GE	Developer of MARS & MAPS
Ventyx	Developer of PROMOD
UC Berkeley	Stochastic optimization software, power markets
Princeton	Approximate dynamic programming software

6. Implementation Plan and Schedule

a) Work plan

A Milestone Memo (along with any associated deliverables) will be sent to the IOUs upon completion of a Milestone. Furthermore, Quarterly Progress Memos and an accompanying web conference delivered from LLNL will provide a forum for reviewing Milestones, identifying other accomplishments, reviewing challenges, and describing next steps. Comments and feedback will be documented after each web conference. Any changes will be handled according to the established operating procedures for CES-21.

Phase 1: Evaluate pre-existing modeling tools (PM1-6)

To better leverage pre-existing modeling tools for both generation and transmission, the first phase of the project is to identify and research the tools and algorithms currently used by industry or researchers to simulate electrical systems.

Major Tasks:

1) (LLNL, IOU) Compile comprehensive list of modeling tools. (PM1-2)
2) (LLNL) Research and understand the optimization methods and algorithms underlying tools. (PM1-4)
3) (LLNL) Identify which tools or algorithms have potential to be used in co-optimization model. (PM4-6)

Phase 2: Evaluate model development need (PM1-6)

Identify the gaps in existing knowledge and capabilities, and develop an understanding of the type of work needed to fill those gaps.

Major Tasks:

1) (LLNL) Identify limitations and algorithm needs of current models. (PM1-3)
2) (LLNL) Identify potential for calculation time improvements through algorithm improvements. (PM4-6)

3) (LLNL) Determine if goals of the research project are feasible given the limitations of current tools, and if so evaluate the time and cost requirements to complete research. (PM6)

Phase 3: Enhanced representation of the transmission system in production simulation models (PM 7-21)

Develop a high fidelity representation of the California or WECC existing electrical system and a tool that can to perform production simulation and power flow analysis over that system. The tool should also be able to evaluate additional resource expansions and their impact on transmission reliability and power prices.

Major Tasks:

1) (LLNL, IOUs) Identify alternatives to improve the representation of transmission constraints in production simulation models. (PM7)
2) (LLNL, IOUs) Test the feasibility and accuracy of alternatives, and recommend best alternatives to improved transmission constraints representation. (PM8)
3) (LLNL, IOUs) Develop production simulation model with improved representation of transmission system. (PM9-12)
    a. Develop transmission model
    b. Develop simulation with constraints
4) (LLNL, IOUs) Conduct studies with improved model. (PM12-21)

b) Interdependency with other Business Cases

Business Case with Dependency (Phase)	Type of Dependency (provider, consumer, informational)	Required or Beneficial	Explanation
Flexibility Metrics and Standards	Informational	Beneficial	Assessment of ability of system to ramp to accommodate variability in renewable generation or contingencies

c) Milestones/Deliverables

Phase	Type	Description	Due Date	Responsible
1	Deliverable	Report detailing findings and feasibility of research	PM6	LLNL, IOUs
2	Deliverable	Software demonstration of enhanced transmission in production simulation models	PM12	LLNL
2	Deliverable	Report on enhanced transmission modeling and analysis	PM21	LLNL

d) Resource requirements

An average of 6 people per year will be required. This estimate includes LLNL, IOU, and potential partner resources in the following areas.

- Production simulation modeling
- Optimization
- Economics
- Computer science
- Statistics
- Electrical engineering

7. Cost Estimate and Allocation

Expense	PM1-18 ($K)	PM19-30 ($K)	PM31-42 ($K)	PM43-54 ($K)	PM55-66 ($K)
LLNL & Subcontract costs	1,825	225			
IOU costs	175	175			
TOTAL	**$2,000**	**$400**			

8. Benefits Estimate and Methodology

The utilities periodically make large investments in new infrastructure. For example, the CPUC's recent 2012 Long-term Procurement Plan decision in its Track 1 proceeding authorized SCE to procure approximately 2,000 MW of a combination of demand response, energy storage, and gas-fired generation to meet local reliability needs. Assuming a capital cost of approximately $1,000/kW, this authorization has an initial cost about $2 billion. With respect to transmission investment, as part of its 2012-2013 transmission plan CAISO identified 36 transmission projects with an estimated cost of $1.3 billion, as needed to maintain reliability.

The analysis of common planning tools proposed in Phase 1 of this business case will identify areas for improvements in planning processes and potential savings. The production simulation model with enhanced representation of the transmission system proposed in Phase 2 in this business case will likely reduce customer costs by enabling CAISO, and the utilities to make better decisions regarding future investment in new transmission, demand response programs, or generation, including energy storage. Given the large capital investment required by the industry, the potential for even a 1% savings in cost from better decisions could save about $30 million in capital cost for investments currently under consideration. Hence, the potential savings are over ten times the $2.4M cost of this project.

Finally, the simulation models will help identify generation and transmission system configurations that enable deployments of wind and solar generation resources sufficient to meet California's goal of 33% renewable generation by the year 2020.

California Energy Systems for the 21st Century

Distribution Modeling and Optimization

Proposed Research Project: Business Case

1. Executive Summary

a) Research Project Opportunity Statement:

Many pre-commercial and emerging technology devices (e.g. photovoltaic panels, controllable thermostats, plug-in electric vehicles, storage) are being interconnected to the distribution grid allowing new opportunities to manage localized balancing requirements between resources, grid support systems, and demands. Ideally, a distribution system would optimize voltage and VAR control, maintain a safe and reliable distribution grid, and provide a secure control infrastructure that would enable active and reactive power control and balancing services similar to a centralized wholesale market.

Technologies such as residential and small commercial/industrial Solar Photovoltaic, Fuel Cells, Plug-in Electric Vehicles, Home Area Networks (which govern appliance operation), and Energy Storage Systems are presently encouraged through a series of incentive programs that are intended to increase the adoption of the technologies. However, there is limited means to optimize across the technologies. This proposal is to establish a relationship between the three California Investor Owned Utilities (IOU) and Lawrence Livermore National Laboratory (LLNL)[1] to develop a modeling and analysis tool that identifies the value of this optimization. The assumed optimization would require some type of mechanism to identify resources and loads, incentivize the resource/load based on the operating characteristics of the resource/load, and a control mechanism to utilize the resource/load based on the operating characteristics. Possible systems identified through this analysis would include state estimation to monitor power flow, volt/VAR control to reduce power consumption, self-healing circuits to reduce outages, load balancing mechanism to coordinate distributed resources and loads, and micro-grid enablement to exploit and optimize their effectiveness.

The specific regional characteristics of the area may require individualized control systems to optimize a particular region's distributed resources and loads. The research initiative would build a model and analysis tool to evaluate these dimensions and identify the opportunities and benefits of improving regional optimization of the distribution grid.

[1] Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344.

b) Utility Sponsors:

☒ PG&E ☒ SCE ☒ SDG&E

c) This research focuses on the following area:

☐ Cyber Security ☐ Electric Resource Planning
☒ Electric System Operations ☐ Gas System Operations

d) This research maps to the following value chain categories:

☐ Grid operations/market design
☐ Generation
☐ Transmission
☒ Distribution
☐ Demand side management
☐ Cyber Security

e) This research supports one or more of the following objectives identified in Public Utilities Code §740.1:

☒ Environmental improvement
☐ Public and employee safety
☒ Conservation by efficient resource use or by reducing or shifting system load
☒ Development of new resources and processes, particularly renewable resources and processes which further supply technologies
☒ Improve operating efficiency and reliability or otherwise reduce operating costs

f) Potential Customer Benefits:

Having a representative model would allow for:

- Improved design of voltage and VAR control systems that if implemented would reduce electricity losses and improve power quality
- Improved planning and consequently reduced costs through better understanding of technology adoption scenarios across the state
- More accurately identified Energy Efficiency and Demand Response opportunities across the State
- Increased ability to identify rate impacts to different customer classes and technology adopters
- More accurate quantification of the value from control of smart inverters
- Improved ability to identify market and control systems to optimize resources and demand within a region

For instance, from the benefit of reduced electricity losses perspective, this project will identify:

- Peak feeder loads;
- Opportunities to locate electricity production closer to the load;
- Customer voltages within service tolerances; and

- Opportunities to minimize the amount of reactive power provided.

Identifying these opportunities, targeted locations and prioritized applications will inform operational and planning decisions to support and implement control systems (as approved by the CES-21 board of directors) to improve the power factor and reduce line losses for a given load served. In 2010, a total of $33.5 billion was spent on electricity in California. The average transmission and distribution loss is around 6% in California[2], which results in equivalently proximate $2 billion each year. The objective of this project is to improve power factor and reduce line losses.

Furthermore, the development of this model will inform the development of state-wide policies addressing de-carbonization and economic development goals.

g) Research Challenges and Hurdles to Overcome:

Development of a representative model will require detailed emulation of not only the transformers, tap changers, conductors, and capacitors normally modeled for distribution planning purposes, but would also include a representation of behind-the-meter devices and systems (e.g. PV; HAN and associated load – AC, Pool Pumps; PEV load, Energy Storage) as well as the thermal characteristics of residential houses, apartments, condominiums, and commercial buildings. The model would be representative of the State's IOU service areas and allow for adoption scenarios to be applied across the applicable technologies to determine and advise growth and therefore optimization opportunity over time. The complexity of a detailed model for the IOUs' service areas is significant, but less representative models will result in sub-optimal solutions. The model would also capture the control characteristics of the resources and loads and define the necessary communication systems required to optimize the devices across an optimal regional area (e.g. Micro-grid, Distribution Feeder, Distribution Substation, and Cluster of Substations).

Existing systems have the following limitations and each of these would need to be addressed in this research initiative:

- Limited SCADA penetration beyond the distribution substation
- Limited scan rates on SCADA systems to manage real-time, dynamic control systems
- Large data input from multiple devices and systems required to optimize control systems
- Limited telecommunications paths, monitoring capabilities, and control of of end use devices

1. "A Review of Transmission Loss in Planning Studies", California Energy Commision Report # CEC-200-2011-009, August 2011. [Online]. Available: http://www.energy.ca.gov/2011publications/CEC-200-2011-009/CEC-200-2011-009.pdf

- Significant integration issues with existing SCADA control systems and self-healing schemes
- Complex wholesale market structure interacting with a regional, distribution market structure
- Ongoing changes to inverter device interconnection and control standards (IEEE 1547)

h) Unique Capabilities Offered by LLNL:

There are several research initiatives in this area:

Alternatives	Assessment
SCE Irvine Smart Grid Demonstration	See below
SDG&E Borrego Springs Microgrid	See below
AEP Ohio gridSMART Demonstration	See below
PNNL Pacific Northwest Smart Grid Demonstration	See below

This effort would leverage these initiatives to incorporate their learning to the broader view of what are the impacts to emerging distribution technology within the California regulatory structure. The scale of a representative model and analysis tool would require the collective information from the IOUs as well as a high performance computing environment to analyze the optimization opportunities.

i) 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.

j) Duplication and synergies:

There is significant work in this area but a comprehensive model detailing the California distribution grid that takes into account the specific California programs that drive much of the adoption behavior in the State is not available. The research initiative would leverage ongoing work that is related and supportive of this effort and partner with research entities that would provide value to the effort. For example, the California Energy Commission (CEC) is proposing to conduct applied research in:

- Energy Efficiency and Demand Response
- Smart Grid-Enabling Clean Energy
- Cross-Cutting

This research, if it goes forward, would be informative to this Distribution Modeling and Optimization initiative. The CEC administered research is investigating individual energy efficient opportunities (S1.1 Lighting Systems; S1.2 Heating, Ventilation, Air-Conditioning, and Refrigeration Systems; S1.3 Envelop Systems, Materials, and Components; S1.4 Occupant Behavior; S1.5 Retrofit Strategies; S1.6 Consumer Behavior with Plug-Load Devices; S1.8 Zero Net Energy Buildings) and Customer-Side-of-the-Meter technologies (S2.1 Metering and Telemetry; S2.2 Ancillary Services; S2.3 Distributed Resources; S2.4 Dispatchable Distributed Resources and Demand Response). This Distribution Modeling and Optimization initiative is anticipating an optimization analysis that would include these emerging opportunities and a market mechanism that would enable these technologies to interact and operate in a particular region. Additionally, the proposed research in Smart Grid Enabling Clean Energy (S6.1 Bi-Directional Power Flow; S6.2 Controls for Distribution Automation; S6.3 Smart Grid Equipment; S6.4 Renewable Availability Data; S6.5 Smart Grid Communication Systems) would be very informative to the control systems described in this Distribution Modeling and Optimization proposal.

All of these individual components on the Distribution Grid require additional research and the CES-21 team would monitor progress and incorporate findings on periodic basis. The fundamental difference in research approaches is that the Distribution Modeling and Optimization research is working to scale the model across the state and analyze the interactions amongst these emerging technologies to determine optimization opportunities and identify impacts to improve overall planning for the distribution system of the future.

There are additional opportunities to leverage research within the CES-21 portfolio of projects. Through coordination with the cyber security modeling being developed within the cyber security research, this team will be able to identify how the control system would interact with existing systems (e.g. Supervisory Control and Data Acquisition – SCADA systems, Volt-VAR control systems within Distribution Management Systems, and "Self-Healing" for fault isolation) and emerging systems (e.g. Solar PV inverters, Storage, Home Area Networks).

This research initiative will also coordinate with the Transmission/Generation model being advanced within the Resource Planning research and the Transmission/Distribution model being built within the Electric Operations research to identify opportunities for the Distribution grid to interact with the Transmission system to both optimize voltage and VAR but also transfer (export or import) active power across the two systems.

2. Proposal Description

a) Background

Pre-commercial and emerging technology devices (e.g. photovoltaic panels, fuel cells, controllable thermostats, plug-in electric vehicles, energy storage) are being interconnected to the distribution grid allowing new opportunities to balance resource and demand. Adoptions of these devices are encouraged through a series of incentive programs that are intended to increase the adoption of the technology. There is no mechanism to optimize across the technologies as control systems and aggregation methods are still evolving. This project proposes to create a representative model that would allow for the analysis of multiple adoption scenarios to determine an optimized method to manage the distribution grid. These scenarios would be based on assumptions for technology adoption supported and driven by regulatory direction and incentives. This will enable the project to determine the value of an optimized distribution market and guide in developing a conceptual framework for a distribution market.

Existing control of the distribution system is managed through Distribution Management Systems and Outage Management Systems that have some monitoring and control capability through the SCADA system. Additionally, smart meter information is now available to utilities that will allow more refined load information on a near real-time basis.

The control system or systems for additional monitoring and control of the emerging devices being connected to the grid needs to be meaningfully advanced. To develop these systems, a representative model of the distribution grid is necessary with insight into the adoption rates of the devices being connected. Only with a detailed representative model will there be clarity on the appropriate control systems and the optimization path for these devices. The assumption is that market incentives would optimize customer decisions rather than regulatory policy and programs. But neither the market structure nor the corresponding control infrastructure are well understood. This initiative would work to identify opportunities to create a price based distribution market that would also be able to operate the distribution grid in a safe, reliable, efficient and secure manner.

b) Objective

This research effort would develop a detailed representative model of the distribution grid, analyze various adoption scenarios, determine market and control mechanisms that would optimize the balancing of resources (both traditional and local) and demand, review the impacts on grid and communications network infrastructures, and evaluate methods to encourage optimized distributed generation and demand response.

Detailed Model of Distribution Grid: The distribution model would be developed to capture the current distribution grid in the State of California. This would require creating a collection of distribution feeder circuits that sufficiently captures the major differences amongst feeder circuits (e.g. voltage level, climate zone, distributed generation adoption, load characteristics behind-the-meter). This collection of representative distribution feeder circuits would be applied to each feeder circuit in each of the three utility services areas to arrive at a representative model of the Investor Owned Utility distribution grids.

Adoption Scenarios: The team would explore various adoption models for pre-commercial and emerging technologies including Solar PV, Fuel Cells, Plug-in Electric Vehicles, Programmable Thermostats, and Storage Devices. These adoption scenarios would be applied to the distribution model to analyze impacts and trends.

As an example, for Plug-in Electric Vehicle adoption the team would create scenarios based on historical information, technology assumptions, accurate vehicle production forecasts from Automotive OEMs and consumer adoption behavior. These scenarios would range from slow to fast adoption to provide a range of scenarios that would assist in identifying possible outcomes on the State's distribution grid.
Additionally the team would use census data, other data resources (for example CSI and SGIP), and geospatial statistical techniques to estimate PEV purchase, adoption and use patterns on the grid. Transportation models will be utilized to help estimate energy demand patterns at locations on the grid. Rooftop solar photovoltaic deployment patterns that could mitigate PV charging during midafternoon hours will be included to generate net load patterns that will be experienced by the local distribution transformers.

Consideration for vehicle charging coordination at the feeder level would be investigated including decentralized market-based models in which a real time price or price proxy is communicated or manipulated in order to balance supply with demand and direct load control. The real time price approach would involve simple feedback control algorithms, while the direct load control approach would take into account requirements of customers to compute a vehicle charge episode that would attempt to meet all constraints (optimal kWh capacity delivered, not to exceed pricing, minimum kWh required by what time, etc.).

Control Optimization: The team would identify high potential control strategies to optimize the scenarios identified. For example, to create an optimized volt/VAR control system the team would run simulations for the variety of scenarios and analyze the performance for various circuit characteristics and system conditions. These results would be synthesized into benefits and design criteria for a volt/VAR control system. Both deterministic and stochastic simulations would be run to test specific conditions and analyze the natural uncertainty of weather on both resources and demand. Weather forecast data, asset dispatch state-of-readiness and contingency planning must all be incorporated for the system be optimized and to operate effectively in the dynamic scenarios present.

Market Concept: The team would review the opportunities through the control optimization analysis to propose possible control systems to enable a market mechanism. The market mechanism would provide a platform for resources and demand to participate in a market based incentive program rather than the traditional regulatory based incentive program. The team would also develop a high-level approach of interacting with the wholesale market to optimize balancing across the transmission and distribution systems.

c) Expected results

This model will enable the following:

- Analysis of technology adoption scenarios
- Identify Energy Efficiency and Demand Response opportunities across the State
- Indicate rate impacts to different customer classes and technology adopters
- Evaluate the benefits and implementation strategies for voltage and VAR control systems
- Evaluate the value of active power control of inverters
- Identify impacts on distribution infrastructure and determine future requirements
- Analyze market and control concepts to optimize resources and demand within a region

Milestones and Deliverables:

- Milestone 1: Develop Modeling Framework (components, data structure, software and hardware platform)
- Milestone 2: Design and Validate Model
- Deliverable 1: Report specifying model approach, assumptions, capabilities, validation results
- Milestone 3: Scenario runs and analysis
- Deliverable 2: Report results, benefits and recommendations
- In addition the deliverables, the framework and models developed during this project can be reused, extended, and leveraged for similar problems, new data, etc.

3. Market Research

There are several research initiatives in this area:

- SCE Irvine Smart Grid Demonstration
- SDG&E Borrego Springs Microgrid
- AEP Ohio gridSMART Demonstration
- PNNL Pacific Northwest Smart Grid Demonstration

Currently, no resolute models or analytical tools are available that represent the California distribution system at the detailed level required to assure reliable operation. This effort would leverage existing initiatives to incorporate their learning. As such, the project goals provide a holistic view of what the application-specific impacts are and how best to exploit opportunities from emerging distribution technology within the California regulatory structure, and how changes to the structure could benefit local and wide-scale operations. Increasing the capabilities of the detailed model of the State's distribution grid with the rational scenario-based assumptions for technology adoption based on regulatory direction and incentives will allow the project to advance a conceptual framework for an optimized distribution market.

4. Research Approach Assessment

Challenge	Assessment	Reason
The suitability of the HPC architecture for large-scale distribution modeling and simulation	Medium Level Risk	After the team ports the distribution simulation software codes to one of the LLNL HPC machines, the team will conduct detailed performance studies to identify computational bottlenecks. Based on that, the team will utilize state-of-art parallel algorithms as needed to minimize bottlenecks and exploit parallel computer architectures. This will likely involve efforts to investigate data ingestion/analysis and generate sub-problems that can be solved in approximately the same amount of time in order to facilitate load balancing of the processors.
The fidelity of distribution models for the IOUs' service areas	Medium Level Risk	The complexity of having a detailed model that is representative of the IOUs' service areas is significant, but less accurate models will result in sub-optimal solutions.

5. Partnership Opportunities

Potential Partner	Reason for Partnering
ETAP	Distribution simulation software vendor
PNNL	Gridlab-D– open source distribution simulation software developer
EPRI	OpenDSS – open source distribution simulation software developer. Collaborate with other utility members outside California who are EPRI members.
California Institute of Technology	Market Optimization

6. Implementation Plan and Schedule

a) Work plan

A Milestone Memo (along with any associated deliverables) will be sent to the IOUs upon completion of a Milestone. Furthermore, Quarterly Progress Memos and an accompanying web conference delivered from LLNL will provide a forum for reviewing Milestones, identifying other accomplishments, reviewing challenges, and describing next steps. Comments and feedback will be documented after each web conference.

Any changes will be handled according to the established operating procedures for CES-21.

Phase 1: Modeling Framework and Model Development/Validation (PM1-18)

This phase will develop a detailed representative model of the distribution grid for the state of California. The model will be validated against actual feeder data collected by three IOUs. Changes and refinements to the model will be developed as needed.

Major tasks:

1) (IOUs & LLNL) Identify model components and level of detail. (PM1-3)
2) (LLNL) Design data structure and computational platform. (PM4-6)
3) (IOUs & LLNL) Develop adoption scenario models. (PM7-9)
4) (IOUs & LLNL) Develop customer segment and behavior models. (PM10-12)
5) Apply framework to IOU service area model and develop code. (PM13-15)
6) (IOUs & LLNL) Validate model against actual feeder data and adjust code and models. (PM15-18)

Phase 2: Computational Runs and Analysis (PM19-30)

This phase will use the model developed through the previous phase to analyze various adoption scenarios, determine market and control mechanisms that would optimize the balancing of resources and demand, and review the impacts on grid infrastructure, customer rates, and incentive programs.

Major tasks:

1) (IOUs & LLNL) Run technology adoption scenarios using adoption scenario framework and modify model and code as necessary. (PM19-21)
2) (IOUs & LLNL) Analyze optimization of volt/VAR control and modify model and code as necessary. (PM22)
3) (IOUs & LLNL) Analyze methods to control active power and optimize balancing load and resources within region and modify model and code as necessary. (PM23)
4) (IOUs & LLNL) Analyze rate impacts on various customer segments and modify model and code as necessary. (PM24-25)
5) (IOUs & LLNL) Analyze market incentives to optimize customer behavior and impacts on existing incentive programs and modify model and code as necessary. (PM26)
6) (IOUs & LLNL) Develop conceptual framework for a regional distribution market. (PM27-28)
7) (IOUs & LLNL) Analyze regional distribution market relationship to statewide market. (PM29-30)
8) (IOUs & LLNL) Develop demonstration project plan. (PM27-30)

b) Interdependency with other Business Cases

Business Case with Dependency (Phase)	Type of Dependency (provider, consumer, informational)	Required or Beneficial	Explanation
Integrated Transmission and Distribution Model	Provider	Required	The integrated T&D project will use the distribution models developed in this project.

c) Milestones/Deliverables

Phase	Type	Description	Due Date	Responsible
1	Milestone	Complete Model and Computational Engine	PM18	LLNL & IOUs
1.3	Deliverable	Design document of the computational platform	PM9	LLNL
1.6	Deliverable	Technical report	PM18	LLNL & IOUs
2	Deliverable	Run Scenarios and Develop Demonstration Project Plan	PM30	LLNL & IOUs

d) Resource requirements

An average of 6 people/year will be required. This estimate includes LLNL, IOU, and potential partner resources in the following areas.

- Modeling
- Programming
- Engineering
- Statistics
- Mathematics
- Energy Markets
- Regulatory and Rate Design

7. Cost Estimate and Allocation

Expense	PM1-18 ($K)	PM19-30 ($K)	PM31-42 ($K)	PM43-54 ($K)	PM55-66 ($K)
LLNL & subcontractor costs	1,916	1,930			
IOU costs	610	610			
TOTAL	**$2,526**	**$2,540**			

8. Benefits Estimate and Methodology

Having a representative model would allow for:

- Improved design of voltage and VAR control systems that if implemented would reduce electricity losses and improve power quality

- Improved planning and consequently reduced costs through better understanding of technology adoption scenarios across the state
- More accurately identified Energy Efficiency and Demand Response opportunities across the State
- Increased ability to identify rate impacts to different customer classes and technology adopters
- More accurate quantification of the value from control of smart inverters
- Improved ability to identify market and control systems to optimize resources and demand within a region

For instance, from the benefit of reduced electricity losses perspective, this project will identify:

- Peak feeder loads;
- Opportunities to locate electricity production closer to the load;
- Customer voltages within service tolerances; and
- Opportunities to minimize the amount of reactive power provided.

Identifying these opportunities, targeted locations and prioritized applications will inform the decision to support and implement control systems (as approved by the CES-21 board of director) to improve the power factor and reduce line losses for a given load served. In 2010, a total of $33.5 billion was spent on electricity in California. The average transmission and distribution loss is around 6% in California[3], which results in equivalently proximate $2 billion each year. The objective of this project is to improve power factor and reduce line losses.

This project will provide an overall framework to determine optimization of the next generation distribution system. Each utility spends billions of dollars on infrastructure replacement and upgrades and significant investment in incentive programs to drive customer behavior to fulfill State policy goals.

This project provides a platform to determine investment outcomes based on different adoption scenarios for emerging technology in the State. This project will also work to develop a distribution market concept that would progress regulatory incentive programs to market driven incentives. The project will works towards the development of a plan to demonstrate this distribution market structure in a region or multiple regions within the State.

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2. "A Review of Transmission Loss in Planning Studies", California Energy Commision Report # CEC-200-2011-009, August 2011. [Online]. Available: http://www.energy.ca.gov/2011publications/CEC-200-2011-009/CEC-200-2011-009.pdf

The project supports current policy objectives including:

- **Order Instituting Rulemaking on Residential Rate Structures**: "Smart Grid" investments will support the growth in distributed generation technologies, increased penetration of electric vehicles, and growth in third party offerings for demand response, energy efficiency and other energy management services by providing the utility with greater visibility into the distribution grid in real-time and near-real-time." This research initiative will assist in identifying the growth opportunities of emerging technologies and increased understanding of the opportunities to incorporate and optimally manage these technologies.
- **Order Instituting Rulemaking on Storage**: "Due to the variety of applications for storage and the lack of a cohesive regulatory framework, it would be difficult if not impossible to develop a single unifying policy for energy storage. However, the proposed scenarios in the Final Proposal would allow focused analysis of barriers and policy options. This approach will also allow us to consider whether one ownership model (i.e., ownership of the ESS by utility, end-use customer, third-party entity or some combination via joint ownership) is more beneficial in certain situations than others." This research initiative will assist in the understanding of optimal control systems and usage of storage within the distribution grid.
- **Decision Adopting Demand Response**: "In particular, we recognize with the implementation of a 33 percent renewables portfolio standard (RPS), we may need additional flexibility from the grid to integrate intermittent renewable resources.12 The need for this flexibility is not fully determined, but we can easily envision a scenario in which DR can complement renewable integration" This research initiative will assist in the deployment of more active demand response to balance renewable energy integration into the distribution grid.

California Energy Systems for the 21st Century

Real Time Electromagnetic and Electromechnical Hybrid Transient Simulation

Proposed Research Project: Business Case

1. Executive Summary

a) Research Project Opportunity Statement:

The stability of the grid's frequency has traditionally relied on the mechanical inertia resulting from rotating machines, which represent the majority of conventional generation serving California. Consistent with efforts to meet the state's Renewable Portfolio Standard, the California Solar Initiative, California's Self Generation Incentive Program and cost contraction of the relevant technologies, an increasing amount of PV and wind generation in California feed the grid through solid-state, switch-controlled electronics (inverters). Fundamentally, these systems lack the mechanical inertia associated with traditional generation from rotating machines and have a different dynamic behavior, which detracts from the stability of the grid. At high levels of PV penetration, the capacity of a conventional synchronous (rotating) generator may have to be reduced to maintain the power supply and demand in balance, further lowering system inertia and decreasing stability. Decreased stability could be further impacted when many PV systems disconnect during voltage sag. In order to prevent potential cascading failures and to minimize outages, operators increasingly need visibility and control of the operation of the system.

This proposal is to establish a relationship between the three California Investor Owned Utilities (IOU) and Lawrence Livermore National Laboratory (LLNL)[1] to develop a hybrid simulator that will enable the analysis of electromagnetic and electromagnetic characteristics of the system. Electromagnetic transient impacts can result from the effects of small and medium sized generators, associated with power electronic devices, such as power electronics used in integrating renewables to the grid. Electromechanical procedures simulate the other AC systems. The proposed hybrid would be the first simulator to integrate both protocols to enable operators with increased visibility.

In addition, the Hybrid simulator may to be used as a Dynamic Stability Assessment (DSA) tool. The DSA will enable evaluation of simultaneous contingencies in the medium term (5 seconds to 5 minutes) and long term (longer than 5 minutes). Presently, these dynamic effects are not adequately assessed by existing transient

[1] Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344.

stability analysis simulators, primarily due to the time requirements to run those simulations among existing platforms. The intent of this work is to expand capabilities of these kinds of analytical tools to accommodate the levels of data intensity and computational capacity required to develop effective solutions.

b) Utility Sponsors:

☒ PG&E ☒ SCE ☒ SDG&E

c) This research focuses on the following area:

☐ Cyber Security
☐ Electric Resource Planning
☒ Electric System Operations
☐ Gas System Operations

d) This research maps to the following value chain categories:

☒ Grid operations/market design
☐ Generation
☒ Transmission
☐ Distribution
☐ Demand side management
☐ Cyber Security

e) This research supports one or more of the following objectives identified in Public Utilities Code §740.1:

☐ Environmental improvement
☐ Public and employee safety
☒ Conservation by efficient resource use or by reducing or shifting system load
☒ Development of new resources and processes, particularly renewable resources and processes which further supply technologies
☒ Improve operating efficiency and reliability or otherwise reduce operating costs

f) Potential Customer Benefits:

The potential benefits from the Hybrid Simulator project may include:

- Improved real time simulation capability related to integration of renewable resources that are critical to meeting California' Renewables Portfolio Standard. The complexities and more accurate simulation of inverter based renewable resources (e.g. wind generators and Solar PV) may be address by the Hybrid Simulator tool.
- Reduced wide-scale brown/black-outs and avoided customer costs of outage through real-time simulation capability by having a tool that can run to a large number of scenarios at a much higher speed that the existing power system simulators. The speed and higher accuracy of the simulation allows operator to make better and faster decisions especially during stress system conditions.
- Improved visibility of the health of the system and ability to locate risks which may reduce the incidence of brown/black-outs, and hence avoid customer outage costs. The Hybrid Simulator will improve the accuracy and speed of the

results in a highly interconnected system where disturbance are easily spread around the system and having the ability to simulate these effects and reducing computation time to and make operating from a wider system prospective.
- The ability to evaluate equipment (e.g. wide area protection and controls, special protection schemes) by including the actual devices into the simulation before these are actually install may reduce the uncertainty and potential mis-operation that can result in wide-scale brown/black-outs.

These benefits could help reduce some of the cost related to the following areas. It is also important to point out that as the work progresses the cost will be better quantified. As an example we could site:
- The Real Time Hybrid Digital Simulation may offer system operators insights into the potential impacts of variable generation on frequency control as well as new methods for minimizing any negative impacts on system frequency performance. It is possible that ancillary service levels could be reduced, decreasing the cost of energy for market participants and utilities. Total ancillary service costs totaled $84 million in 2010[2]. Assuming that this project has a 10% positive contribution to the ancillary service cost reduction, the benefits would amount to $8.4 million each year.
- Reduced Congestion Cost – With California's goal of 33% Renewal Portfolio by 2020, the volatility of congestion due to wind generation will be magnified. The total import congestion charge in 2010 was around $73 million; and will likely increase even more with the higher penetration of wind power, so improvements in congestion management could yield significant cost savings and help achieve the State's public goals. The Real Time Hybrid Digital Simulation can provide grid operators a high resolution view of the power system and its stability
- Reduced wide-scale blackouts and avoid customer costs of outage – this project could help improve grid stability, and help grid operators avoid conditions that could lead to generator tripping or other results that could cause outages. A report[3] prepared for the California State Legislature and the Electricity Oversight Board estimated that California customer losses during an 8-hour workday outage ranged between $95 to $200 per kW of load[4]. The study projected that 3600 MW of load in WSCC could be shed following the loss of the California-Oregon Interties. Of that amount, half would be in California, giving a cost to California of $170 to $360 million. With the frequency of these cascading

[2] 2010 Market Issues & Performance Annual Report, CAISO, available online: http://www.caiso.com/2b66/2b66baa562860.pdf
[3] "A Survey of the Implications to California of the August 10, 1996 Western States Power Outage," California Energy Commission, Report P700-97-003, June 1997.
[4] "1998 Transmission Reliability Report," prepared by the California Independent System Operator in consultation with The AB 1890 Report Steering Committee.

outages occurring about once every two years in the last ten years, the average cost

g) Research Challenges and Hurdles to Overcome:

- The Electromagnetic Transient Program (EMTP) solves the network in very small time intervals (micro-seconds in many cases) for all three phases There are tools such as real time digital simulators which address the problem of speed and solve the EMTP algorithm, but due to the amount of nodes (thousands of nodes) large networks where hundreds of thousands of buses are required can become a time-consuming and expensive task.
- The Electromechnical Transient Stability (TS) assessment involves the solution of thousands of stiff system of differential and algebraic equations (DAE), is computationally intensive and extremely challenging even for a short amount of simulated time such as 10 seconds, even for few limited number of contingencies. On-line simulation of minutes to hours for a very large number of contingencies requires computational efficiency several orders of magnitude greater than today's state-of-the-art.
- The proposed project will leverage the recent advances in high performance computing at LLNL as a platform to enable real time simulation of large-scale power system dynamic models efficiently and affordably
- Once computational efficiency is achieved at the lab, the framework and tools developed still face the challenge of being transferred back to the utilities, operating in a computationally limited environment

h) Unique Capabilities Offered by LLNL:

This project will fully leverage products and existing research work on both electromagnetic transient simulation and electromechnical transient simulation. The unique capability at LLNL, High Performance Computing, will be utilized to develop the hybrid digital simulation, which integrates electromagnetic and electromechncial transient simulations into one integration tool with the unique capability of simulating larger power systems.

Alternatives	Assessment
Real Time Digital Simulator – RTDS OPAL-RT (real-time simulation of power electronics)	The RTDS and Opal-RT are two popular system simulators that solve electromagnetic transient simulations in real time. Both of them can provide accurate and detailed resolution of all types of temporary changes at relatively small scale.

Alternatives	Assessment
GE's Postive Sequence Load Flow (PSLF) Siemens's PSS/E Power Tech Lab's Transient Security Assessment Tool EPRI's Extended Transient Midterm Stability Program (ETMSP)	These electromechnical transient stability programs are based on fundamental frequency phasor models. They can quickly simulate the behavior of system after disturbances; but they cannot provide detailed dynamic responses of highly nonlinear components such as HVDC links and FACTS devices especially under asymmetrical faults.

i) 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.

j) Duplication and synergies:

All project scope has been coordinated with other CES-21 projects, EPIC projects and other research efforts underway at the utilities and other research entities to ensure no duplication of effort. In addition, the CES-21 team will continue to monitor external RD&D projects to take advantage of synergies with external research and reduce the risk of future duplication.

2. Proposal Description

a) Background

The increasing complexity of power system networks require the use of tools that conduct simulations with a higher level of detail than the classical existing power flow and dynamic tools. Another important requirement is the speed of the simulations which in many cases might be required to be real time or faster than real time (real time means that one micro second of simulation is one microsecond on the actual time clock).

In order to capture the fast dynamic changes coming from solid state devices, an essential part of modern wind turbines, generator controls, solar PV plants among others, power system simulation tools that can provide with a more accurate solution (simulation) to the real power system behavior are necessary. As an example we could name electromagnetic transient programs (EMTP-type) simulation tools. The EMTP programs simulate the network voltages and current waveforms (as the actual system) which differ from other types of power systems simulator that only simulates average values at longer time intervals (seconds). The challenges in solving EMTP-type simulation are that due to the short time interval (micro seconds) and depending on the total length of the simulation, it can be time and computer-memory consuming making the simulation extremely slow and in some cases impossible. In the case of very large networks (WECC system) the EMTP simulation approach may not be viable since a single simulation can take several hours or days. There are tools such as real time digital simulators (parallel computer technology) which address the problem of speed in solving the EMTP algorithm by distributing the computation jobs among many computer processors, but due to the amount of nodes (tens of thousands of nodes) in very large power system networks this may become a time-consuming and expensive task.

In the case of large network solutions, transient stability (TS) programs have been used successfully for many years. The TS programs can capture the system electromechanical dynamics (interactions between conventional (synchronous) generators); however, due to their long time interval (seconds) it is difficult to capture dynamic responses coming from solid state devices; whose technology requires a very short time interval.
A Hybrid tool will consist of combining programs, transient stability and electromagnetic transient, to simulate large power system networks at very high speed. Another important area that the Hybrid simulator will address is the proper modeling of large scale wind generation especially the type 3 and type 4 turbines. The Hybrid simulator will capture the dynamic behavior of wind generation and its impact to the grid.

Both the 2003 Northeast blackout and the recent Arizona-Southern California Outage show the need for much faster and more accurate tools that can be used by operators and operation engineers to deal with the increasing number of contingencies as the system is driven closer to its margins. The lack of protection system coordination was also stated as an issue on the September 8, 2011 Arizona-Southern California Outage report by NERC and FERC. Performing these type of studies with existing tools is very difficult and in some cases impossible task. The industry needs Dynamic Stability Assessment (DSA) tools that can quickly evaluate a large number of potential system harmful events and determine which ones could cause unacceptable grid instabilities, and thus give grid operators an opportunity to figure out appropriate remedial actions that could prevent a cascading blackout.

b) Objective

A hybrid simulator system will:

- Combine a small time step solution (EMTP-type solution) with a longer and average time step solution (transient stability) allowing the simulation of very large power system network in real time by taking advantage of the speed of High Performance computing (HPC).
- Provide planning and operations engineers with an accessible tool to perform contingency analysis in real time
- The real time stability assessment capability will provide system operators and operation engineers the capability to evaluate a large number of potential system harmful events and determine which one could cause unacceptable grid instabilities, and thus give grid operators an opportunity to determine which could cause unacceptable grid instabilities. It will also include large scale wind farms.

- Give grid operators an opportunity to establish appropriate remedial actions that could prevent cascading. Provide the ability to incorporate protection devices, special protection schemes, remedial action schemes which can be simulated as closed loop system[5] .
- Run "what-if" simulations involving system dynamic phenomena.

c) Expected results

This project proposes to develop the high-performance hybrid digital simulator supporting integrated electromechanical and electromagnetic transient simulation. The hybrid simulator will leverage existing tools and models developed on the EMTP-type simulator at California IOUs and combine the speed and memory available on a High Performance Computing platform at LLNL.

3. Market Research

Alternatives	Assessment
Real Time Digital Simulator – RTDS OPAL-RT (real-time simulation of power electronics)	All three IOUs in California use RTDS system. The RTDS and Opal-RT are two popular system simulators that solve electromagnetic transient simulations in real time. Both of them can provide accurate and detailed resolution of all types of temporary changes at relatively small scale.
GE's Positive Sequence Load Flow (PSLF) Siemens's PSS/E Power Tech Lab's Transient Security Assessment Tool EPRI's Extended Transient Midterm Stability Program (ETMSP)	All three IOUs in California and California ISO use PSLF for electromechnical transient stability assessment. All of these electromechnical transient stability programs are based on fundamental frequency phasor model. They can quickly simulate the behavior of system after disturbance; but it cannot provide detailed dynamic responses of highly nonlinear components such as HVDC links and FACTS devices especially under asymmetrical faults.

4. Research Approach Assessment

This project will fully leverage products and existing research work on both electromagnetic transient simulation and electromechnical transient simulation. Some of the existing research work focus on improving the performance of either electromagnetic

[5] The actual device protecting the grid can be integrated to the simulator to evaluate their performance under disturbance conditions. This process is also known as Hardware-in-The-Loop.

transient simulation programs or electromechnical transient simulation programs. None of them proposed to develop a hybrid simulator.

The unique capability at LLNL, High Performance Computing, will be utilized to develop the hybrid digital simulation, which integrates electromagnetic and electromechncial transient simulations into one hybrid simulator with the unique capability of simulating lager power systems. The proposed project is unique and not duplicative of other research funded by California utilities, CEC, EPRI or the U.S. DOE. Some of work proposed here builds on previous LLNL work:

- HPC4Energy Incubator project with GE Energy- Improving PSLF Simulation Performance and Capability using LLNL's High Performance Computing capability.
- Advanced Computational and Modeling Research for the Electric Power System – a collaborative project with the Electric Power Research Institution under the Department of Energy's Advanced Modeling Grid research program. At this project, LLNL's team uses its high performance computing to help EPRI improve the computational speed of the Extended Transient Midterm Stability Program (ETMSP).

Challenge	**Assessment**	**Reason**
The suitability of the HPC architecture for solving this hybrid digital simulation problem	Medium level risk	After the team ports software codes to one of the LLNL HPC machines, the team will conduct detailed performance studies to identify computational bottlenecks. Based on that, the team will utilize state-of-art parallel algorithms as needed to minimize bottlenecks and exploit parallel computer architectures. This will likely involve efforts to investigate data ingestion/analysis and generate sub-problems that can be solved in approximately the same amount of time in order to facilitate load balancing of the processors.
Accuracy of the hybrid digital simulation tool	Medium level risk	The project team will empirically measure the computational complexity of the algorithms and models for this class of problems. Verification will then be performed on a series of simplified physics test problems where correctness of the mathematical algorithms can be measured. We will also evaluate the parallel scaling performance of the hybrid digital simulator using the full California system model.

Challenge	Assessment	Reason
Data sets to support model development and analysis	Low level risk	This is a collaborative research project between LLNL and IOUs. Three IOUs and CAISO will fully support this project and provide available data sets. Non-disclosure agreements will be executed for the Critical Energy Infrastructure Information (CEII).

5. Partnership Opportunities

Potential Partner	Reason for Partnering
GE	Developer of PSLF
EPRI	Developer of ETMSP. Collaborate with other utility members outside California who are EPRI members.
PowerTech Lab	Developer of the TSAT software program
Manitoba HVDC Research Center	Developer of EMTDC/PSCAD
RTDS Technologies	Developer of the RTDS system. These systems have been installed at three IOUs
OPAL-RT Technologies	Developer of OPAL-RT eMEGAsim
Power System Engineering Research Center	Power Systems Engineering Research Center (PSERC) draws on university capabilities to creatively address the challenges facing the electric power industry
University of Tennessee's CURENT center	CURENT is a National Science Foundation Engineering Research Center. Jointly supported by NSF and the Department of Energy, the Center is led by the University of Tennessee, Knoxville.
The Center for Advanced Power Systems at Florida State University / FREEDM	The 40,000 square foot research, development, test, and demonstration facility is located in Innovation Park, adjacent to the National High Magnetic Field Laboratory (NHMFL), the Applied Superconductivity Center, and the FAMU-FSU College of Engineering. It has 14 RTDS racks.

6. Implementation Plan and Schedule

a) Work plan

A Milestone Memo (along with any associated deliverables) will be sent to the IOUs upon completion of a Milestone. Furthermore, Quarterly Progress Memos and an accompanying web conference delivered from LLNL, will provide a forum for reviewing Milestones, identifying other accomplishments, reviewing challenges, and describing next steps. Comments and feedback will be documented after each web conference. Any changes will be handled according to the established operating procedures for CES-21.

Phase 1: Prototype coupled software simulator (PM1-24)

Develop a prototype software simulator to evaluate algorithms and coupling capabilities for hybrid Dynamic Stability Assessment (DSA) and EMTP-Type applications.

Major tasks:

1) (IOUs and LLNL) Identify potential dynamic stability assessment (DSA) tools and EMTP-type tools that can be incorporated to develop this high performance hybrid simulator and establish any needed collaborations and IP agreements. (PM1-6)
2) (LLNL) Investigate algorithms for stable coupling of the DSA and EMTP-type codes. (PM6-12)
3) (LLNL) Verify the prototype simulator on a small test case. (PM13-24)

Phase 2: High Performance Dynamic Stability Assessment Tool (PM3-42)

Develop the high-performance dynamic stability assessment tool.

Major tasks:

1) (LLNL) Porting the codes to HPC: LLNL will port the DSA software codes from the chosen tool on task #1.1 to one of LLNL HPC machines at LLNL and conduct detailed performance studies to identify computational bottlenecks. (PM3-9)
2) (LLNL) Parallel contingency analysis: Based on the results of #2.1, LLNL will utilize state-of-art parallel algorithms as needed to minimize bottlenecks and exploit parallel computer architectures for contingency analysis. (PM9-13)
3) (IOUs & LLNL) Demonstration for massive contingency analysis using an industry-scale system. (PM13-18)
4) (LLNL) Parallel solvers: LLNL will investigate different parallel nonlinear/linear algorithms to exploit parallel computer architectures. (PM18-31)
5) (IOUs & LLNL) Demonstration for parallel solver using an industry-scale system Benchmarking. (PM31-36)
6) (LLNL) Software Release Review: High Performance DSA tool software release review and release. (PM36-42)

Phase 3: Hybrid Simulator Algorithms (PM25-60)

Investigate and develop efficient algorithms for the parallel solution of coupled TS and EMTP-Type applications.

Major tasks:

1) (LLNL) Investigate and develop parallel solution strategies for EMTP-type codes from the identified tools of Task 1.1. (PM25-36)
2) (LLNL) Verify the initial simulator based on the tools identified in Task 1.1. (PM27-36)

3) (LLNL) Refine the coupling algorithms and software between the transient stability and EMTP-type codes. (PM36-48))
4) Develop adequate model that can properly capture the dynamics introduce by large scale wind generation. (PM48-54)
5) (IOUs and LLNL) Complete performance profiles and address performance bottlenecks in large, parallel contingency analyses. (PM54-60)
6) (IOUs and LLNL) Complete performance tests on a large contingency coupled system. (PM60-66)

Phase 4: Software Development and User Interface Development (PM42-66)

Develop the software and user interface.

Major tasks:

1) (IOUs and LLNL) Design user interface. (PM42-47)
2) (LLNL) Develop user interface to conduct model management and perform studies. (PM48-60)
3) (LLNL) Documentation. (PM60-66)

b) Interdependency with other Business Cases

Business Case with Dependency (Phase)	Type of Dependency (provider, consumer, informational)	Required or Beneficial	Explanation
Integrated Transmission & Distribution Model	Provider	Beneficial	The integrated T&D project may use the transmission models developed in this project.

c) Milestones/Deliverables

Phase	Type	Description	Due Date	Responsible
1.1	Deliverable	Technical report documenting choice of the transient stability and EMTP-type tools to be used for final simulator development	PM6	IOUs & LLNL
1.2	Deliverable	Design document for initial prototype simulator	PM12	LLNL
1.3	Deliverable	Executable Prototype software of hybrid simulator	PM24	LLNL
2.3	Deliverable	Technical report on performance of initial parallelization of the electromechanical stability codes for massive contingency analysis	PM18	IOUs & LLNL

Phase	Type	Description	Due Date	Responsible
2.4	Deliverable	Technical report on performance of initial parallelization of linear solvers	PM30	LLNL
2.5	Deliverable	Technical report on demo results	PM36	IOUs & LLNL
2.6	Deliverable	Release 1.0 of high performance DSA tool (Executable file)	PM42	LLNL
3.1a	Deliverable	Initial design document for final simulator software	PM27	LLNL
3.2	Deliverable	Release 1.0 (Executable file) of hybrid simulator using tools identified in Task 1.1	PM36	LLNL
3.1b	Deliverable	Final design document for simulator software	PM42	LLNL
3.3	Deliverable	Release 2.0 (Executable file) of hybrid simulator using enhanced algorithms	PM48	LLNL
3.4	Deliverable	Technical report documenting further performance modifications and release 3.0 of software	PM54	IOUs &LLNL
3.5	Deliverable	Technical report on testing results	PM60	IOUs &LLNL
4.1	Deliverable	Design document of the GUI	PM48	IOUs &LLNL
4.2	Deliverable	Software tool ((Executable file)) with the GUI	PM60	LLNL
4.3	Deliverable	Software Manual and Report	PM66	LLNL

d) Resource requirements

An average of 4 people/year will be required. This estimate includes LLNL, IOU, and potential partner resources in the following areas.

- Modeling
- Programming
- Power System Engineering
- Mathematics

7. Cost Estimate and Allocation

Expense	PM1-18 ($K)	PM19-30 ($K)	PM31-42 ($K)	PM43-54 ($K)	PM55-66 ($K)
LLNL & subcontract costs	1,486	1,843	1,902	1,843	1,843
IOU costs	450	515	515	515	515
TOTAL	**$1,936**	**$2,358**	**$2,417**	**$2,358**	**$2,358**

8. Benefits Estimate and Methodology

The California grid becomes is becoming complex due to the increase in renewable generation, increase in distributed energy resources, and as conventional generation is retired. The operation of the grid requires newer tools that are faster with higher accuracy to help system operations and planning and assure that the grid remains reliable, secure and economical. The main intent of the Hybrid Simulation is to boost simulations capabilities and increase the speed at which different system contingencies are solved with a high degree of accuracy, which may reduce the impact of the cost identified below:

- The Real Time Hybrid Digital Simulation may offer system operators insights into the potential impacts of variable generation on frequency control as well as new methods for minimizing any negative impacts on system frequency performance. It is possible that ancillary service levels could be reduced, decreasing the cost of energy for market participants and utilities. Total ancillary service costs totaled $84 million in 2010[6]. Assuming that this project has a 10% positive contribution to the ancillary service cost reduction, the benefits would amount to $8.4 million each year.
- Reduced Congestion Cost – With California's goal of 33% Renewable Portfolio by 2020, the volatility of congestion due to wind generation will be magnified. The total import congestion charge in 2010 was around $73 million ; itwill likely increase even more with the higher penetration of wind power, so improvements in congestion management could yield significant cost savings and help achieve the State's public policy goals. The Real Time Hybrid Digital Simulation can provide grid operators a high resolution view of the power system and its stability

Reduced wide-scale blackouts and avoided customer outage costs – this project could help improve grid stability, and help grid operators avoid conditions that could lead to generator tripping or other results that could cause outages. A report[7] prepared for the California State Legislature and the Electricity Oversight Board estimated that California customer losses during an 8-hour workday outage ranged between $95 to $200 per kW of load[8]. The study projected that 3600 MW of load in WSCC could be shed following the loss of the California-Oregon Interties. Of that amount, half would be in California, giving a cost to California of $170 to $360 million.

[6] 2010 Market Issues & Performance Annual Report, CAISO, available online: http://www.caiso.com/2b66/2b66baa562860.pdf
[7] "A Survey of the Implications to California of the August 10, 1996 Western States Power Outage," California Energy Commission, Report P700-97-003, June 1997.
[8] "1998 Transmission Reliability Report," prepared by the California Independent System Operator in consultation with The AB 1890 Report Steering Committee.

California Energy Systems for the 21st Century

Integrated Transmission and Distribution Model

Proposed Research Project: Business Case

1. Executive Summary

a) Research Project Opportunity Statement:

Traditionally, the Transmission and Distribution systems have been modeled and solved separately. Neither has traditionally addressed combinations of large scale renewables integration or the effects of distributed energy or energy storage systems. There is little understanding about how they influence each other. In practice, distribution operators observe significant shifts in load, both seasonally and throughout the day, which may not be adequately captured by transmission planning tools. The existing models used in transmission reliability assessment include a discrete representation of generation connected at the transmission level only. Distributed generation is typically modeled as a reduction in load; effectively limiting it's potential to serve as supply. Given the increase in distributed renewable energy penetration, there is a growing need to understand its impact on transmission reliability. Equally important is the need to understand the value of technologies and processes that may enhance the potential synergies between transmission and distribution.

This proposal is to establish a relationship between the three California Investor Owned Utilities (IOU) and Lawrence Livermore National Laboratory (LLNL)[1] to develop integrated transmission and distribution model will be used to better understand critical scenarios where resources and loads are affected by unprecedented levels of intermittency, from both large and small scale renewable generation. Of particular interest is the circumstance of a cyber-attack or a major cascading outage, where utilities could face significant challenges to restore power to the backbone of the system. The model can be used as a tool to model the true capabilities to restore the system with current black-start resources. As more renewable generation comes online, utilities will increasingly have portfolios of resources lacking dynamic reactive power, essential to control voltage and frequency during grid restart and restoration. Other related scenarios will simulate the value of integrating larger amounts of distributed resources, injection of reactive power and energy storage to inform decisions before making large capital investments for reliability. Using the proposed integrated transmission and distribution model is also essential for adequate operation of the grid within a cost-effective range, while enabling emerging and pre-commercial resources and technologies.

[1] Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344.

b) Utility Sponsors:

☒ PG&E ☒ SCE ☒ SDG&E

c) This research focuses on the following area:

- ☐ Cyber Security
- ☐ Electric Resource Planning
- ☒ Electric System Operations
- ☐ Gas System Operations

d) This research maps to the following value chain categories:

- ☒ Grid operations/market design
- ☐ Generation
- ☒ Transmission
- ☒ Distribution
- ☒ Demand side management
- ☐ Cyber Security

e) This research supports one or more of the following objectives identified in Public Utilities Code §740.1:

- ☐ Environmental improvement
- ☐ Public and employee safety
- ☒ Conservation by efficient resource use or by reducing or shifting system load
- ☒ Development of new resources and processes, particularly renewable resources and processes which further supply technologies
- ☒ Improve operating efficiency and reliability or otherwise reduce operating costs

f) Potential Customer Benefits:

A representative Integrated Transmission & Distribution model will identify opportunities, target locations and prioritize applications to inform decisions to support and influence policy, implement procedures, control systems and the deployment of technology to ultimately:

- Avoid high customer costs due to unlikely, but potentially impactful outages
- Improve strategies to upgrade/ invest in, procure, build and replace infrastructure with the goal of evaluating service, reliability, as well as carbon reduction goals
- Improve planning and reduce costs through improved understanding of technology adoption scenarios
- Anticipate challenges in a controlled simulated environment to avoid “near-crisis-level” experiences
- Increase the utilization of already purchased and deployed technology
- Reduce line losses
- Quantify the operational value of energy storage and distributed resources on reliability
- Improve customer satisfaction by reducing the time to restore service

The quantification of benefits is challenging. It depends more upon how utilities utilize the developed algorithms and tools to inform operational and planning decisions to avoid major blackouts, reduce line losses, and defer transmission and distribution capital investment. For example, in PG&E's Smart Grid Deployment Plan[2], it is estimated that avoided or deferred future capital costs are between $240 million and $360 million. This project may help avoid unnecessary capacity buildup through more representative modeling and simulation and through better understanding of technology adoption scenarios across the state.

More broadly, this project will provide a platform to validate the benefits of transmission and distribution networks operated and planned together. Each utility spends billions of dollars on infrastructure replacement and upgrades and significant investment in reliability and to fulfill State policy goals. This project will provide parameters for the investment outcomes based on different network configurations and the observation of interactions across systems. Finally, the tested scenarios may also be used to understand the costs and benefits of implementing current and new energy policies.

g) Research Challenges and Hurdles to Overcome:

The research challenges to overcome are:

- Although several commercial or research modeling and simulation software packages are used widely in the electric power industry, there is no single tool to model the system at the transmission and distribution levels with adequate focus on renewables integration, VAR injection, various forms of energy storage and management algorithms needed to align the operation of these systems with traditional grid systems. From the viewpoint of modeling and simulation, it is important to evaluate, develop and validate methods which fortify the strength and clarify the impacts of the variation of proximity of couplings of transmission and distribution models. Then, based on those findings, refine the parallel approach and develop effective solution methods for the lower level use cases. The development approach to delivering a robust computing architecture will be an evolving process based on the results obtained during each phase.

- One of the challenges of restoring a system from a fully blacked-out state is the ability to control voltage and frequency. As generation sources with the ability to provide frequency control and dynamic reactive control for voltage support are being replaced by environmental friendly resources with limited management of voltage or frequency regulation, the ability to mitigate erratic voltage and frequency swings from a blacked-out state will be difficult and inevitably increase restoration time. The proposed model and simulations will capture these scenarios and provide the ability to develop, test and validate tools, technologies and algorithms which address these problems.

[2] PG&E Smart Grid Deployment Plan, June 30 2011. Available online: http://www.pge.com/includes/docs/pdfs/shared/edusafety/electric/SmartGridDeploymentPlan2011_06-30-11.pdf

- Expectations of an acceptable restoration time (system and specific local area) are not detailed or specified. As a starting point, work will focus on determining the restoration time a representative case study using actual data from one or more representative segments of grid operations among the California IOUs.

h) Unique Capabilities Offered by LLNL:

This project will leverage LLNL's findings on previous related research work, apply lessons learned and build on validated models. Furthermore, the unique capability at LLNL's High Performance Computing will be utilized to accomplish these goals.

Alternatives	Assessment
Transmission Level Simulator Proprietary software tools: • GE's PSLF • Siemens's PSS/E • Powerworld Open-source software tools: • SWITCH • Matpower • Interpss	Simulation software for transmission system. SWITCH is a software package used to examine cost and carbon impact of capacity expansion planning across WECC.
Distribution Level Simulator Proprietary software tools: • ETAP • EDSA • SKN Open-source software tools: • Gridlab-D • OpenDSS	Simulation software for distribution system. Load flow analysis of these tools is generally for three-phase systems.
Grid Energy Research Organization • Power System Engineering Research Center (PSERC) • SWITCH	As a National Science Foundation Industry-University Cooperative Research Center, the Power Systems Engineering Research Center (PSERC) draws on university capabilities to creatively address the challenges facing the electric power industry. Its core purpose is to empower minds to engineer the future electric energy system. SWITCH is a software package used to examine cost and carbon impact of capacity expansion planning across WECC.

i) 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.

j) Duplication and synergies:

All project scope has been coordinated with other CES-21 projects, EPIC projects and other research efforts underway at the utilities and other research entities to ensure no duplication of effort. In addition, the CES-21 team will continue to monitor external RD&D projects to take advantage of synergies with external research and reduce the risk of future duplication.

2. Proposal Description

a) Background

Simulation technology for electric grid operations has developed over the last 3-4 decades following a piecemeal approach, within narrow functional silos, and well before the development of modern computational capabilities. Analytics are still built upon core technology from decades ago. The future electric grid will increasingly include renewable resources and electric energy storage in both the transmission and the distribution systems. This electric grid will require a simulation system which can ensure reliable long-term operation of an extremely complex system comprised of an array of millions of distributed units. For example, a coupled model of the California power grid network would include approximately 6,000 substations in a transmission network, 10,000 distribution circuits, and 10 million houses.

Because full systems of interest require simulations of millions of units, current grid operating platforms have relied on decoupled approaches to transmission and distribution. This approach is insufficient to address pending complex smart grid systems where modeling effects of renewables and electric energy storage in the distribution network will have significant impacts throughout the entire network. In the last few years, parallel computing techniques, new mathematical algorithms and other related technologies have become readily available. These hold the promise for faster simulation methods and scalability necessary for next generation electric grid operating and simulation systems.

This project will expand on the idea of recognizing the real-time state of the distribution system when modeling transmission reliability and contingency studies. By knowing the real time state/topology of the distribution network during a loss of one or more critical transmission resources, the analysis may be able to recognize the impacts of the distribution topology in order to get a better understanding of the effects on the transmission system reliability . Since the topology on the distribution side changes more frequently than on the transmission system, the model will be constantly updated to the model as the system configuration changes. Distribution operators observe significant MWs of load shifts around distribution networks and between transmission sources with little involvement or analysis from transmission operation. This suggests a disconnected paradigm in need of a better computational model for these proposed "integrated grid modeling" platforms.

As a benefit from the project and by using more data coming from the distribution side, it could justify smarter and smaller transmission mitigation schemes. These schemes would account for the distribution topology and DG loading on a real-time or short window forecast. In this manner, the transmission studies would not have to predict and cope with such a “worst-case” loading contingency. An important task of this project will be to determine the percentage of DG resources that operators can statistically rely on for load support day-to-day and emergency operations given various independent variables. This topic may also need to consider what percentage of DG vs. conventional generation requires increased investigation for both stability and transient fault analysis.

Furthermore, in the event of a cyber-attack or a major cascading outage, utilities could face significant challenges to restore power to the backbone of the system. There is a need to understand the real capabilities to restore the system with current black-start resources. As more renewable generation comes online, utilities need to understand the increased challenges posed by having resources without dynamic reactive power, which is essential to control voltage and frequency during restoration. Simulation of these extreme scenarios is essential for both planning and operations.

b) Objective

The objectives of this project are to:

- Expand the transmission network model to include distribution network and model distributed generation as a generator.
- Use results to analyze reliability impacts of increased renewable penetration in the distribution network.
- Identify the restoration impacts due to the increased penetration of renewable energy.
- Identify the impacts on restoration time of critical load in the first stage of restoration and customer load in the second stage.
- Identify the value of distributed resources and energy storage on transmission reliability

c) Expected results

This project proposes to develop the integrated transmission and distribution model in the power industry within 54 months.

3. Market Research

The alternative described in section 1.h is a complement, not a substitute to this project proposal.

4. Research Approach Assessment

Challenge	Assessment	Reason
The suitability of the HPC architecture for solving this hybrid digital simulation problem	Medium level risk	This project will leverage LLNL's findings on previous research projects, apply lessons learned and build on validated models. Specially, the team will conduct detailed performance studies to identify computational bottlenecks. Based on that, the team will utilize state-of-art parallel algorithms as needed to minimize bottlenecks and exploit parallel computer architectures.
The strength of coupling transmission and distribution models	Medium level risk	Once an initial coupled system is in place, we will ascertain how strongly we will need to couple the computations in order to balance between efficient parallel computation and numerical accuracy. We will conduct a suite of numerical studies employing the prototype model on problems which exhibit strong coupling between transmission and distribution systems such as high solar energy scenarios with cloud rollover and extreme transmission level contingencies resulting in solar inverter cutoffs.
Restoration time determination	Medium level risk	Determination of restoration time includes other variables such as manpower, SCADA control, switching writing, 3-way communications, life of station batteries, etc. These variables, though, may have an exponential effect on restoration time. This project is focused on developing methods and tools to provide decision support for system engineers during system restoration.

5. Partnership Opportunities

Potential Partner	Reason for Partnering
GE	Developer of PSLF – transmission simulation software vendor
Powerworld	Powerworld - transmission simulation software vendor
ETAP	Distribution simulation software vendor
PNNL	Gridlab-D– open source distribution simulation software developer
EPRI	Developer of the Generic Restoration Milestone method and tool. OpenDSS – open source distribution simulation software developer. Collaborate with other utility members outside California who are EPRI members.

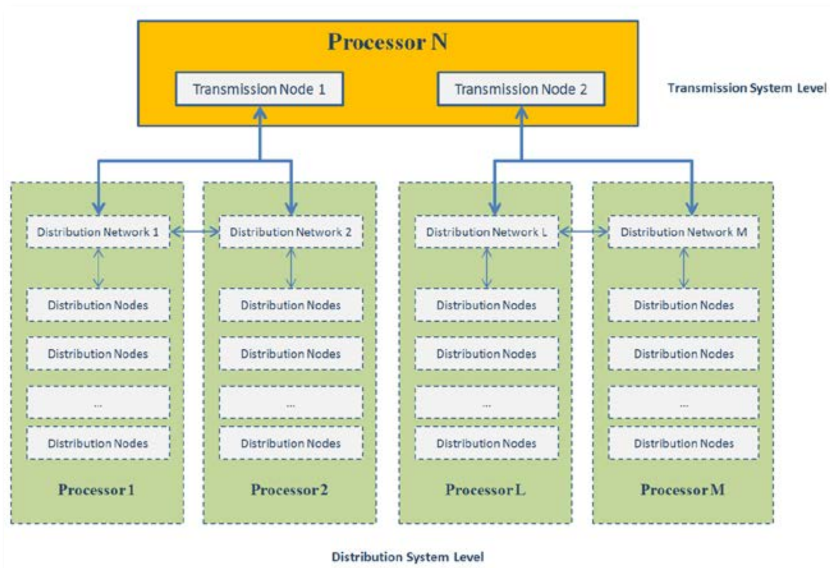
6. Implementation Plan and Schedule

a) Work plan

A Milestone Memo (along with any associated deliverables) will be sent to the IOUs upon completion of a Milestone. Furthermore, Quarterly Progress Memos and an accompanying web conference delivered from LLNL will provide a forum for reviewing Milestones, identifying other accomplishments, reviewing challenges, and describing next steps. Comments and feedback will be documented after each web conference. Any changes will be handled according to the established operating procedures for CES-21.

Phase 1: Integrated Transmission and Distribution Steady-state Model Development (PM1-24)

The first phase of the development will focus on achieving a coupling of steady-state between the existing transmission and distribution software. A single transmission model will be advanced then parallel instances of the distribution software for each substation on the transmission network will be advanced. This coupled model leads to a natural decomposition of the domain; the distribution models will be solved in parallel enabling the use of thousands of processors. The coupling should also be achievable with minimal impact on the existing code bases.



Major tasks:

1) (IOUs & LLNL) Gather and analyze the pertinent data. (PM1-2)
2) (IOUs & LLNL) Identify existing software packages that will be coupled. (PM1-3)
3) (LLNL) Complete parallel framework design and implementation for steady-state model. (PM4-9)
4) (IOUs) IOUs will provide both transmission and distribution data to LLNL for modeling and test runs. (PM10-12)

5) (LLNL) Verify the coupled simulations on a test case evaluating distributed generation's impact on transmission reliability. (PM12-24)

Phase 2: Integrated Transmission and Distribution Dynamic Model (PM24-48)

Once an initial coupled system is in place, LLNL will add the dynamic transmission model into the integrated platform and then ascertain how strongly it will need to couple the computations in order to balance between efficient parallel computation and numerical accuracy. LLNL will conduct a suite of numerical studies employing the prototype model on problems which exhibit strong coupling between transmission and distribution systems such as high solar energy scenarios with cloud rollover and extreme transmission level contingencies resulting in solar inverter cutoffs. Based on those findings, LLNL will refine the parallel approach and develop effective solution methods for the sub-problems.

Major tasks:

1) (LLNL) Assess strength of coupling between dynamic models. (PM24-30)
2) (LLNL) Refine the parallel framework and approach. (PM30-36)
3) (IOUs) IOUs will provide transmission dynamic model info to LLNL for modeling and test runs. (PM36-39)
4) (LLNL) Refine parallel solution strategies for each submodel. (PM39-45)
5) (LLNL) Complete performance tests. (PM46-48)

Phase 3: Restoration Capabilities in Extreme Scenarios Title (PM19-42)

LLNL will use the integrated T&D model developed under phase 1 and 2 to investigate black-start strategy options to establish backbone transmission paths in San Francisco area. LLNL will also interface the restoration tools to be developed with operator training simulator or dispatcher training simulator employing engineers with real-time experience.

Major tasks:

1) (IOUs & LLNL) Gather and analyze the pertinent data. (PM19)
2) (IOUs & LLNL) Identify a partner on power system restoration decision support tools. (PM20-24)
3) (LLNL) Couple the partner's restoration tool with the integrated T&D model developed under phase 1. LLNL will also enhance the optimization algorithms to assess black start capability requirements during system restoration. (PM20-24)
4) (IOUs) PG&E will provide system data to LLNL for this study including but not limited to base case (network topology), security constraints, black-start units, critical loads, generator start-up and ramping characteristics. (PM24)
5) (LLNL) Perform test on PG&E's system. (PM24-32)
6) (LLNL) Add the dynamic model developed under phase 2. With this enhancement, LLNL may be able to model the closure of breaker for energizing line, picking up load and other operations during restoration.

Frequency response and dynamic response of generator will be investigated too. (PM33-36)

7) (LLNL) Interface the enhanced restoration decision support tool with operator training simulator or dispatcher training simulator. (PM37-42)

Phase 4: Integrated Electric Grid and Information Network Simulation (PM 43 - 54)

The integrated T&D model developed through this project will be leveraged by the project "**Modeling and Simulation to Identify Cyber Security Vulnerabilities"** under the cyber research area. The project under electric operations research area will focus on the integrated electric transmission and distribution model development. Cyber research area will be responsible for coupling information network simulator and the integrated transmission and distribution model developed by this project. This project will provide support to Cyber research area's coupling work.

Major tasks:

1) (IOUs and LLNL) Support the development of integrated system models which use IEC 61970 CIM standard and Harmonized CIM model to provide both Electric Topology and its associated Communication Topology. (PM42-48)
2) (LLNL) Support the development of coupling information network simulator and the integrated T&D model developed by this project. (PM42-48)
3) (IOUs and LLNL) Work with IOUs to develop a project for evaluating and quantifying the impacts of communication latency on smart grid installation, in particular protection controls and coordination functions. This project will be used by the cyber area to perform the case study of latency issues on system grid controls. (PM48-54)

b) Interdependency with other Business Cases

Business Case with Dependency (Phase)	Type of Dependency (provider, consumer, informational)	Required or Beneficial	Explanation
Modeling and Simulation to Identify Cyber Security Vulnerabilities (Phase 2)	provider	required	The integrated T&D model developed will be leveraged by the project "**Modeling and Simulation to Identify Cyber Security Vulnerabilities"** under the cyber research area. The project under electric operations research area will focus on the integrated electric transmission and distribution model development. Cyber research area will be responsible for coupling information network simulator and the integrated transmission and distribution model developed by this project.

c) Milestones/Deliverables

Phase	Type	Description	Due Date	Responsible
1.3	Deliverable	Design document	PM9	LLNL
1.4	Deliverable	Data from IOUs	PM12	IOUs
1.5	Deliverable	Prototype the integrated transmission and distribution (T&D) model	PM18	LLNL
1.5	Deliverable	Release 1.0 of the integrated T&D model	PM21	LLNL
1.5	Deliverable	Technical report on verification results	PM24	IOUs & LLNL
2.1	Deliverable	Memo report on assessment results	PM30	LLNL
2.2	Milestone	Improved the performance of the T&D model	PM36	LLNL
2.3	Deliverable	Data from IOUs	PM39	IOUs
2.4	Deliverable	Release 2.0 of the integrated transmission and distribution model	PM45	LLNL
2.5	Deliverable	Memo report on performance test results	PM48	LLNL
3.3	Deliverable	Prototype the restoration assessment software	PM24	LLNL
3.4	Deliverable	Data from IOUs	PM24	IOUs
3.5	Deliverable	Memo report on study results	PM33	LLNL
3.6	Deliverable	Release 1.0 of the restoration assessment software	PM36	LLNL

Phase	Type	Description	Due Date	Responsible
3.7	Deliverable	Release 2.0 of the restoration assessment software with the interface with operator training simulator	PM42	LLNL
4.1	Milestone	Data format change to read CIM data	PM48	LLNL
4.2	Milestone	Refined software tool	PM48	LLNL
4.3	Milestone	Use case	PM54	LLNL & IOUs

d) Resource requirements

An average of 4 people will be required. This estimate includes LLNL, IOU, and potential partner resources in the following areas.

- Modeling
- Programming
- Engineering
- Transmission Planning
- Distribution Planning

7. Cost Estimate and Allocation

Expense	PM1-18 ($K)	PM19-30 ($K)	PM31-42 ($K)	PM43-54 ($K)	PM55-66 ($K)
LLNL & subcontract costs	1,071	1,230	1,285	1,230	
IOU costs	435	520	440	440	
TOTAL	**$1,506**	**$1,750**	**$1,725**	**$1,670**	

8. Benefits Estimate and Methodology

The potential benefits to California can be summarized into the following three broad categories:

- Reliability and Power Quality – reduction in interruptions and power quality events
- Economic – reduced costs, or increased production at the same cost, that results from optimized system operation and asset utilization
- Environmental – reduced impacts of climate change and effects on human health and ecosystems due to pollution
- Security - Reduced Wide-Area Blackouts

Benefit			Value ($ Million/Yr)	Value Basis
Economic	T&D Capital Savings	Deferred Transmission Capacity Investment (R)	Variable	
		Reduced Equipment Maintenance Cost (S/R)		
		Reduced Distribution Operations Cost (S/R)		
	Energy Efficiency	Reduced Electricity Lossess (S/R)	$200	In 2010, total $33.5 billion spent on electricity in California. The average transmission and distribution loss is around 6% in California, which is around $2 billion each year.
Reliability	Power Interruptions	Reduced Sustained Outage (R)	Quantifiable but non-monetizable Improve 5% in SAIDI, SAIFI, CAIDI	IOUs Annual Reliability Report
		Reduced Major Outage (R)		
		Reduced Resoration Cost (S/R)	non-Quantifiable	
Environmental	Air Emissions	Reduced Carbon Dioxide Emission (P)	non-Quantifiable	
Security	Energy Security	Reduced Wide-scale blackout (R/P/S)	$68-$144	California State Legislature and the Electricity Oversight Board estimated that California customer losses during an 8-hour workday outage ranged between $95 to $200 per kW of load

The quantification of benefits is challenging. It depends more upon how utilities utilize the developed algorithms and tools to inform operational and planning decisions to avoid major blackouts, reduce line losses, and defer transmission and distribution capital investment. We use the DOE/EPRI Smart Grid Cost and Benefit Analysis Framework[3] to quantify these benefits. The conceptual and provisional preliminary estimates of the quantifiable benefits from the proposed research area are as follows:

- Reduced Electricity Losses: This project may help manage peak feeder loads, locate electricity production closer to the load and ensure that customer voltages remain within service tolerances, while minimizing the amount of reactive power provided. These improve the power factor, and reduce line losses for a given load served. In 2010, total $33.5 billion spent on electricity in California. The average transmission and distribution loss is around 6% in California4, which results in equivalently approximate $2 billion each year. Assuming that this project has a 1% positive contribution to the transmission and distribution loss reduction, the benefits would amount to $200 million each year.

- Reduced wide-scale blackouts and avoid customer costs of outage – this project could help improve grid stability, and help grid operators avoid conditions that could lead to generator tripping or other results that could cause outages.

3"Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects", EPRI TR-1020342, January 2010.
4 "A Review of Transmission Loss in Planning Studies", California Energy Commision Report # CEC-200-2011-009, August 2011. [Online]. Available: http://www.energy.ca.gov/2011publications/CEC-200-2011-009/CEC-200-2011-009.pdf

Benefits to California	Dollars / Year	Basis for Estimation of Benefits
Avoiding Customer Costs of Major Outage	**$68-144 million**	A report[5] prepared for the California State Legislature and the Electricity Oversight Board estimated that California customer losses during an 8-hour workday outage ranged between $95 to $200 per kW of load[6]. The study projected that 3600 MW of load in WSCC could be shed following the loss of the California-Oregon Interties. Of that amount, half would be in California, giving a cost to California of $170 to $360 million. With the frequency of these cascading outages occurring about once every two years in the last ten years, the average cost per year to California is about $85-180 million. Assuming that this project could reduce the blackout frequency to about once in 10 years, the average outage cost would be reduced to $17-36 million, resulting in a savings of $68 - 144 million per year.

The benefits from the sub-category of T&D Capital Savings depends more upon how IOUs utilize the developed algorithms and tools. For example, in PG&E's Smart Grid Deployment Plan, it is estimated that avoided or deferred future capital costs are between $240 million and $360 million. This project may help avoid unnecessary capacity buildup through more representative modeling and simulation and through better understanding of technology adoption scenarios across the state. If we that these electric system operations research projects have a 1% positive contribution to the deferred future capital cost, the benefits from this sub-category would amount to $2.4-$3.6 million each year to PG&E.

In addition to the primary reliability and economic quantifiable benefits, the Integrated Transmission & Distribution Model will support broad state environmental goals and policies, and it will also generate the main inputs for a cyber-security model, essential to the security of the California grid.

[5] "A Survey of the Implications to California of the August 10, 1996 Western States Power Outage," California Energy Commission, Report P700-97-003, June 1997.
[6] "1998 Transmission Reliability Report," prepared by the California Independent System Operator in consultation with The AB 1890 Report Steering Committee

California Energy Systems for the 21st Century

Electric System Monitoring and Control

Proposed Research Project: Business Case

1. Executive Summary

a) Research Project Opportunity Statement:

One of the key operational issues faced by California utilities is the ability to manage intermittent resources effectively while utilizing grid assets efficiently. With the increasing amount of intermittent resources, stability analysis becomes more critical than ever to understand associated potential issues and to develop an appropriate portfolio mitigation plans for the relevant use cases. The reliability of the grid system is studied and monitored for 1) future events such as line and generator outages; 2) real-time monitoring and control; and 3) post-mortem analysis to discover root causes of significant system events and deliver results of this analysis with effective implementation measures. This process leads to a tremendous amount of system data that is created, reduced, and analyzed. While there are few tools and computing analysis software capable of accommodating voluminous data sets, much of the recorded data is not used in any system that enables analysis of the data, holistically, for trends or indicators of system stress. Furthermore, none of present simulation tools consider the intermittency of renewable resources. This proposal is to establish a relationship between the three California Investor Owned Utilities (IOU) and Lawrence Livermore National Laboratory (LLNL)[1] to develop methods to monitor and control the bulk power system in the presence of these renewable resources and methods to increase the analytical capabilities of tools which will be of meaningful value to planners and operators of the participating California utilities, as well as sector-wide stakeholders.

b) Utility Sponsors:

☒ PG&E ☒ SCE ☒ SDG&E

c) This research focuses on the following area:

☐ Cyber Security ☐ Electric Resource Planning
☒ Electric System Operations ☐ Gas System Operations

d) This research maps to the following value chain categories:

☒ Grid operations/market design

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- ☐ Generation
- ☒ Transmission
- ☐ Distribution
- ☐ Demand side management
- ☐ Cyber Security

e) This research supports one or more of the following objectives identified in Public Utilities Code §740.1:

- ☐ Environmental improvement
- ☐ Public and employee safety
- ☒ Conservation by efficient resource use or by reducing or shifting system load
- ☒ Development of new resources and processes, particularly renewable resources and processes which further supply technologies
- ☒ Improve operating efficiency and reliability or otherwise reduce operating costs

f) Potential Customer Benefits:

The potential benefits from this use case include:

- Improved monitoring capability and system dynamics understanding to advance efforts to reduce overall system outages through early warning and mitigation plans
- Reduced generation and load spillage through implantation of specific application-focused protection schemes
- Increased wide-area system awareness to improve capabilities in enabling increased transmission capacity

g) Research Challenges and Hurdles to Overcome:

The research challenges as derived from the defined scope of the project:

- Inclusion of variable generators and their associated intermittency as a complementary module to integrate with and advance capabilities of existing simulation packages.
- Handle large volumes of data, both in real time and post-processed, and interpret these data to provide valuable information for real time system operator benefit.
- Use the interpreted data as an input to the design of specific protection schemes.
- Design and develop optimized algorithms and implementation schemes that would minimize generation spillage and load shedding.
- Exploit transmission path capabilities based on actual system conditions and Dynamic Line Ratings to improve upon historic static ratings and traditionally conservative operations.

h) Unique Capabilities Offered by LLNL:

Because of significant investments as part of the American Recovery and Reinvestment Act (ARRA) in synchrophasor technology, there are many organizations interested in leveraging synchrophasor data to provide meaningful improvements in grid operations, reliability, integration of renewable generation as well as compensatory technologies such as reactive power injection and energy storage. Much of this work is coordinated among California utilities and CAISO that have significant involvement and collaboration in system operation and data sharing. This proposed initiative intends to exploit existing and forthcoming data streams from the major utilities in the State and create useful correlation algorithms and mitigation strategies. By using these data and enhanced computational tools (long term dynamics and intermittency) the project seeks to deliver meaningful control algorithms which have broad applicability to the participating California utilities. The growing synchrophasor data pool is already large and the complexities of the correlation and mitigation strategies are significant across the asset base owned by the IOUs. The project seeks to deliver solutions which build on existing assets, as well as identify methods for effectively integrating promising new technologies.

Lawrence Livermore National Laboratory is one of a handful of organizations with the capabilities needed in handling this category of data analytics and implantation of control methods needed for real time electric utility operations. For example, the National Atmospheric Release Advisory Center (NARAC) computer systems collect and store global meteorological data and weather-forecast model results, as well as terrain, geographic and population data, and maps (~5GB/day for weather observation, ~120GB/day for gridded weather forecasting data, and ~1TB/day static data.)

Alternatives	Assessment
EPG RTDMS	Provide visualization platform expertise in data mining
GPA	Provide phasor gateway development service.
EPRI	Multi-utility and industry wide RD&D programs.

i) 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 to the standard operating procedures, including sole source and competitive solicitation, according to the specific needs and market analysis.

j) Duplication and synergies:

All project scope has been coordinated with other CES-21 projects, EPIC projects and other research efforts underway at the utilities and other research entities to ensure no duplication of effort. In addition, the CES-21 team will continue to monitor external RD&D projects to take advantage of synergies with external research and reduce the risk of future duplication.

2. Proposal Description

a) Background

One of key operational issues faced by California utilities is the ability to manage intermittent resources effectively while utilizing grid assets efficiently. Historically, the resource management has been done through centralized collection of field data monitored by various operational entities (e.g., regional coordinators, balancing authorities, and transmission providers) with support from operational engineering personnel. It has also been accomplished using generation resources with fairly predictable and controllable output. Even in this very mature generation mix, instability and system wide outages occur on a periodic basis. With the increasing amounts of intermittent resources, stability analysis becomes more critical than ever to understand the possible issues and to develop mitigation plans.

The health of the system is studied and monitored for 1) future events like line and generator outages; 2) real-time monitoring and control; and 3) post-mortem analysis to discover root causes of significant system events. This leads to a tremendous amount of system data that is created, processed, and analyzed. While there are useful tools and computing analysis software, much of the recorded data is not used in any single system that could analyze the data holistically for trends or indicators of system stress. The goal of this project is to develop methods to monitor and control the bulk power system and methods to increase the analytical capabilities of the utilities.

b) Objective

The goal of this project is to develop methods to monitor and control the bulk power system and methods to increase the analytical capabilities of the utilities. The objectives of this project are to:

- Enhance existing simulation packages for long term dynamics and resource intermittency
- Develop predictive engine based on data mining and pattern recognition algorithms
- Develop adaptive protection and control schemes
- Enhance Transmission path capability calculation based on actual system conditions

c) Expected results

The potential benefits from this use case include:

- Improved monitoring and control capability and system dynamics understanding to reduce overall system outages through early warning and mitigation plans
- Reduced generation and load dropping on special protection schemes
- Increased wide area system awareness and understanding to increase transmission capacity

3. Market Research

There are many research organizations that are leveraging synchrophasor data as there was a significant investment as part of the American Recovery and Reinvestment Act (ARRA) in synchrophasor technology. Much of this work is coordinated among California utilities and CAISO that have significant involvement and collaboration in system operation and data sharing in State of California. The proposed in this initiative is taking existing data for the major utilities in the State and creating correlation algorithms and mitigation strategies using the data and enhanced computational tools (long term dynamics and intermittency). The data set is very large and the complexity of the correlation and mitigation strategies would be significant across the asset based owned by the IOUs.

The initiative is unique in accumulating and processing data across three large utilities. The team would leverage existing work that has been done on a smaller scale and the emerging work in this area.

4. Research Approach Assessment

Challenge	Assessment	Reason
Enhancement of present computational software packages for long term dynamics and resource intermittency	Medium level risk	Present software packages may be used via a master program to make them capable of handling long term dynamics and the intermittency of variable generators. This computational tool will be used for off-line simulations of system dynamics.
Accuracy of the data mining tool for stability analysis and system response prediction	Medium level risk	The tool will be developed based on existing techniques developed by LLNL through previous research on scientific data mining (Sapphire and SciDAC program). These techniques have been validated. To ensure the performances of the proposed data mining tools, detailed studies would be conducted on tuning up their parameters. Also, off-line simulation will generate different insecure and secure scenarios to train the data mining tool and verify the results.
Data sets to support model development and analysis	Low Level risk	The proposed in this project will take existing data for the major utilities in the State and create correlation algorithms and mitigation strategies using the data. Non-disclosure agreements will be executed for the Critical Energy Infrastructure Information (CEII).

5. Partnership Opportunities

Potential Partner	Reason for Partnering
Grid Protection Alliance (GPA)	Developer of the openPDC (Phasor Data Concentrator). A phasor data concentrator collects phasor data from hundreds of measurement units installed on power transmission lines, aligns the data by GPS time-tag, and creates a single time-synchronized dataset that is forwarded on to other software applications.
Electric Power Group (EPG)	Developer of the RTDMS. Phasor-RTDMS® (Real Time Dynamics Monitoring System) is a synchrophasor software application for providing real time, wide area situational awareness to Operators, Reliability Coordinators, Planners and Operating Engineers, as well as the capability to monitor and analyze the dynamics of the power system.
GE Energy	The EMS vendor of SCE and SDG&E
Alstom	Provide Integrated synchrophasor solution to PSS/E
OSISoft	OSIsoft delivers the PI System, the world's leading highly-scalable and secure infrastructure for the management of real-time data and events.
Power System Engineering Research Center	Power Systems Engineering Research Center (PSERC) draws on university capabilities to creatively address the challenges facing the electric power industry.
University of Tennessee's CURENT center	CURENT is a National Science Foundation Engineering Research Center. Jointly supported by NSF and the Department of Energy, the Center is led by the University of Tennessee, Knoxville.

6. Implementation Plan and Schedule

a) Work plan

A Milestone Memo (along with any associated deliverables) will be sent to the IOUs upon completion of a Milestone. Furthermore, Quarterly Progress Memos and an accompanying web conference delivered from LLNL, will provide a forum for reviewing Milestones, identifying other accomplishments, reviewing challenges, and describing next steps. Comments and feedback will be documented after each web conference. Any changes will be handled according to the established operating procedures for CES-21.

This project is categorized as 1 year project, where we assume no budget $ allocation in years 2-5. Phases 2 -4 listed below are the suggested tasks for future consideration. The intent is to evaluate the project and its deliverables by the end of year one and evaluate to extend years two and three.

Phase 1: Situational Awareness (PM1-PM21)

The situational awareness work development phase involves data mining to create predictive algorithms to identify system stress and determine notifications/alarms to transmission and system operators. This phase will utilize the considerable computational resource at LLNL to correlate the sub-second data (such as PMU and DFR data) with the second by second data (such as SCADA data), along with historical events on the system. Correlations of these data can provide predictive indicators for system operators, enabling a real-time awareness. Pattern recognition algorithms and multivariate time series models will be investigated to provide predictive capability. These predictive indicators will also be used for the Western Interconnection Synchrophasor Program (WISP) currently being developed with the WECC and many of the western states IOUs as well as Federal Power Marketers.

The correlation between the synchrophasor data and system events will also be used to compare results derived from load flow, stability, and electromagnetic transient software systems to validate model accuracy across major software tools.

Major tasks:

1) (IOUs) Data Collection and Requirements (PM1-PM4):
   A large sampling of historical data and simulated data will be collected and produced as a baseline to calibrate the data mining algorithms. The first step of the project will be to identify a set of events of interest to the partner IOU's and obtain the appropriate historical synchrophasor data surrounding those events. In addition to the PMU data around the events of interest the IOU's will provide appropriate electric grid system data to model and simulate the event.
2) (LLNL) Prepare offline simulations (PM2-PM11)
   We will work with the dynamic simulation software and the system and modeling data provided by the utilities to develop event simulations to assist in algorithm development and testing. Simulations might include load flow, transient stability, and electromagnetic transient simulation.
3) (LLNL) Algorithms development (PM2-PM12)
   We will apply recently developed data mining and analytical methods to phasor measurement data to create metrics and signals about system state. Robust motif detection techniques will then be developed for the metric time series data to understand, identify, and predict precursor signals for instability.
4) (LLNL) Offline training and method validation (PM13-PM21)
   The algorithms resulting from Task 3 will be tested against the simulations from task 2 and data from Task 1 to further refine the training and efficacy of the algorithms and test their effectiveness at identifying instability precursors.

b) Interdependency with other Business Cases

Business Case with Dependency (Phase)	Type of Dependency (provider, consumer, informational)	Required or Beneficial	Explanation
Advanced Threat Analysis Capability: Phase 1 – Threat Modeling and Data Mining	Provider	Beneficial	This project will collect event data and electric grid system information. The data and information collected through this project might be useful for the Advanced Threat Analysis Capability project.

c) Milestones/Deliverables

Phase	Type	Deliverable	Due Date	Responsible
1.1	Deliverable	Collected historical event data and historical database of non-event PMU data	PM4	IOUs
1.2	Milestone	Off-line simulation results	PM11	LLNL & IOUs
1.3	Milestone	Prototype Algorithm and data mining	PM12	LLNL
1.4	Deliverable	Draft technical report and presentation on algorithms, offline training results and initial verification results	PM18	LLNL & IOUs
1.4	Deliverable	Final technical report	PM21	LLNL & IOUs

d) Resource requirements

An average of 3 people/year will be required. This estimate includes LLNL, IOU, and potential partner resources in the following areas.

- Modeling
- Programming
- Engineering
- Data Science
- Protection and Controls

7. Cost Estimate and Allocation

Expense	PM1-18 (K$)	PM19-30 (K$)	PM31-42 (K$)	PM43-54 (K$)	PM55-66 (K$)
LLNL & Subcontract costs	900	200			
IOU costs	300	100			
TOTAL	**$1,200**	**300**			

8. Benefits Estimate and Methodology

With the changing load characteristics and emergence of renewable generation (variable energy resources), difficulties in transmission system expansion, and market structure of electric system operation, system operators encountering serious challenges to operate efficiently and maintain system security. With the proposed research for Electric System Monitoring and Control, we intend to develop advanced technologies for electric system operators that enable them to operate securely while making optimal use of the available facilities (assets).

The potential benefits to California can be summarized into the following three broad categories:

- Economic – reduced costs, or increased production at the same cost, that results from optimized system operation and asset utilization
- Reliability and Power Quality – reduction in interruptions and power quality events
- Security - Reduced Wide-Area Blackouts

Below, we summarize the conceptual and provisional preliminary estimates of the quantifiable benefits from the proposed research area. The quantifiable benefits are as follows:

1. Optimized System Operation – Due to difficulties in transmission system expansion, Special Protection Systems (SPS) are widely utilized in transmission planning. SPS are designed based on off-line studies for certain credible contingencies and assumptions. SPS operation leads to exceptional generation dispatches and move the system away from optimized operation. With advanced Electric System Monitoring and Control, grid operators may have new capabilities to reduce generation tripping on SPS and to optimally schedule generation to meet demand. Total energy from all exceptional dispatches in 2010 reported to be 0.3 percent[2] . Total estimated wholesale costs of serving load in 2010 were $8.6 billion. So, the estimated total exceptional dispatches were around $ 25.8 million. With implementation of products from this project, we expect to achieve a sizable reduction in the cost of exceptional dispatches.

2. Reduced Congestion Cost – With California's goal of 33% Renewal Portfolio by 2020, the volatility of congestion due to wind generation will be magnified. The total import congestion charge in 2010 was around $73 million[3] ; and will likely increase even more with the higher penetration of wind power, so improvements

2 2010 Market Issues & Performance Annual Report, CAISO, available online: http://www.caiso.com/2b66/2b66baa562860.pdf

3 The data is from CAISO's "Annual Report Market Issues and Performance", April, 2007. [Online]. Available: http://www.caiso.com/1bb7/1bb776216f9b0.pdf.

in congestion management could yield significant cost savings and help achieve the State's public goals. The advanced Electric System Monitoring and Control research may enable grid operators in raising stability limit of a transmission line or system interface, so that congestion cost could be reduced without reducing grid reliability.

3. Reduced Electricity Losses: With advanced monitoring and control system technology, operators may optimally manage VAR flows in transmission system, locate electricity production closer to the load and ensure that customer voltages remain within service tolerances, while minimizing the amount of reactive power provided. These actions will improve the power factor, and reduce line losses for a given load served. In 2010, total of $33.5 billion spent on electricity in California. The average transmission and distribution loss is around 6% in California[4] , which is around $2 billion each year. With implementation of results from this project, transmission losses will be minimized.

4. Reduced wide-Area blackouts and avoid customer costs of outage – this project could help improve grid stability, and help grid operators avoid conditions that could lead to generator tripping or other events that could cause outages.

   A report[5] prepared for the California State Legislature and the Electricity Oversight Board estimated that California customer losses during an 8-hour workday outage ranged between $95 and $200 per kW of load[6]. The study projected that 3600 MW of load in WSCC could be shed following the loss of the California-Oregon Interties. Of that amount, half would be in California, giving a cost to California of $170 to $360 million. With the frequency of these cascading outages occurring about once every two years in the last ten years, the average cost per year to California is about $85-180 million.

   In terms of $/kWh of energy not supplied, industry surveys had typically come up with the societal cost of outage to be about 100 times that of the average retail electricity rates. For example, in 2003, the average $/MWh electricity cost in the northeastern region of the US is about $90/MWh, so the cost of outage would be about $9/kWh or $9000/MWh. With this assumption, a blackout lasting 1 hour and

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4 "A Review of Transmission Loss in Planning Studies", California Energy Commision Report # CEC-200-2011-009, August 2011. [Online]. Available: http://www.energy.ca.gov/2011publications/CEC-200-2011-009/CEC-200-2011-009.pdf

5 "A Survey of the Implications to California of the August 10, 1996 Western States Power Outage," California Energy Commission, Report P700-97-003, June 1997.

6 "1998 Transmission Reliability Report," prepared by the California Independent System Operator in consultation with The AB 1890 Report Steering Committee.

affecting an average city with an electric demand of 5000 MW, the cost of that outage would be about $45 million.

Presently WECC is upgrading and deploying new network infrastructure at the transmission level to connect an estimated 250 – 300 PMUs throughout the U.S. portion of the Western Interconnection. The Electric System Monitoring and Control will give grid operators in each control area a wide area view of the bulk power system and allow them to better coordinate resources and operations between regions. This enhanced coordination will reduce the probability of wide-scale blackouts. Since future wide-spread blackouts are not predictable, the cost savings from reduction of future blackouts are not quantifiable.

California Energy Systems for the 21st Century

Geographic Data Integration for Enhanced Gas System Risk Management

Proposed Research Project: Business Case

1. Executive Summary

a) Research Project Opportunity Statement:

Natural gas utilities are faced with the dual challenge of managing aging infrastructure while adapting that infrastructure to current and future customer needs and safety requirements. New and emerging approaches to data fusion, information visualization and risk characterization are needed to adjust current risk assessment tools and methods to new requirements. Historical operations and maintenance must be fused with current conditions to provide a comprehensive understanding of the system's integrity.

This proposal is to establish a relationship between the three California Investor Owned Utilities (IOU) and Lawrence Livermore National Laboratory (LLNL)[1] to improve the understanding and quantification of risk from and to natural gas infrastructure. This will be done by working with the utilities to better understand their multifaceted approach to risk assessment and in improving those data risk assessments are based upon. This project will do so, in part, by creating tools that enable the integration of large amounts of both traditional (paper records) and non-traditional (electronic data and models) forms of gas infrastructure and environmental information to support comprehensive integrity assessment studies as well as asset operation integrity, and maintenance planning.

To the best of our knowledge natural gas utilities have not implemented data integration projects of this scope. Therefore, we expect to evolve requirements through a pilot study. The pilot will investigate extracting geographic and other contextual information from historical operation and maintenance records. This pilot will lead to a follow-on effort in future years that develops visualization products to optimally use data to make risk models meaningful for decision makers.

The success of the pilot will provide the foundation for an automated, comprehensive and dynamic management of all assets of the utility in interaction with its environment. This effort will advance the approaches used in the industry to understand risk to and from natural gas infrastructure. In addition, the efforts presented here will explore new

[1] Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344.

and developing concepts of “Big Data”: integration of disparate and vast data forms to generate actionable information, and visualization of multifaceted and complex data-intensive concepts, like understanding risk.

b) Utility Sponsors:

☒ PG&E ☐ SCE ☐ SDG&E

c) This research focuses on the following area:

☐ Cyber Security
☐ Electric Resource Planning
☐ Electric System Operations
☒ Gas System Operations

d) This research maps to the following value chain categories:

☐ Grid operations/market design
☐ Generation
☒ Transmission
☒ Distribution
☐ Demand side management
☐ Cyber security

e) This research supports one or more of the following objectives identified in Public Utilities Code §740.1:

☒ Environmental improvement
☒ Public and employee safety
☐ Conservation by efficient resource use or by reducing or shifting system load
☐ Development of new resources and processes, particularly renewable resources and processes which further supply technologies
☒ Improve operating efficiency and reliability or otherwise reduce operating costs

f) Potential Customer Benefits:

This research is foundational for bringing the use of high-resolution data in the business practices of gas utilities. The expected benefits combine improved safety and reliability as well as cost reduction by effective data-driven decisions and priorities. It will address two major challenges of this radical business transformation: the acquisition of reliable data, and the integration of a huge amount of multi-format data into the decision process.

The plan outlined below will lead to a variety of direct customer benefits, including:

- Leveraging databases and models developed for a broad range of security and business applications by the National Laboratories provides a reliable solution at a minimal cost.
- Enabling new possibilities in operation and resource management to minimize response time, reduce costs, and improve safety.
- Providing a reliable, fast and cost-effective method to process very large numbers of historical records of assets for pipeline maintenance and risk assessment.

- Accelerating the development of understanding quantitative comprehensive risk-based integrity management plans that are currently limited by the lack of accurate and reliable data.

g) Research Challenges and Hurdles to Overcome:

Integrating multiple disparate sources of data in electronic and paper forms, which range in quality, currency, and domain into a single system, is a known challenge in Data Science. In the case of natural gas systems, current infrastructure existed before the computer age, and much of the information regarding the systems was not created with an understanding of how it might merge with other data sources. Natural gas management systems are evolving to take advantage of complex computer simulations and models for whole system management. Integrating simulations and historical information into scenarios that are relevant to decision-makers is the subject of current research in emergency response and transportation studies. This project will leverage current advanced computing techniques in data fusion, information extraction, and knowledge visualization.

h) Unique Capabilities Offered by LLNL:

This project will initially rely on Lawrence Livermore National Laboratory's (LLNL) expertise in Data Science, including capabilities of data fusion, information extraction, data visualization and multivariate risk analysis. In the future, this project will utilize large-scale computational resources to model future system operations in the context of massive quantities of information. LLNL has a unique role in Data Science due to its breadth in multiple informatics domains, including data mining, demonstrated integration of simulation and forecasting with operational management, and historical record management and information extraction. LLNL has developed many different ways of assessing and presenting risk in domains from stockpile stewardship to infrastructure security. All of these capabilities are needed for advancing gas system analysis and management into a mode of real-time risk mitigation, cloud-based maintenance operations, and emergency management.

Alternatives	Assessment
Individual pipeline section-based risk assessment	Both section and system-wide risk of gas infrastructure are needed.
Commercial document management system enterprise software	Alternatives cannot appropriately assign quality assessments to information retrieval quality
Commercial optical character recognition (OCR) software and services	Low performance with non-standard documents of varying quality
Geographic information extraction embedded in GIS software	Alternative methods cannot geocode from text strings of "real language"

i) 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.

j) Duplication and synergies:

All project scope has been coordinated with other CES-21 projects, EPIC projects and other research efforts underway at the utilities and other research entities to ensure no duplication of effort. In addition, the CES-21 team will continue to monitor external RD&D projects to take advantage of synergies with external research and reduce the risk of future duplication.

2. Proposal Description

a) Background

Natural gas utilities are faced with the dual challenge of managing aging infrastructure while adapting that infrastructure to current and future customer needs and safety requirements. In order to update and adjust models of risk, operations, and maintenance, data from the past has to be fused with information on current conditions to provide a comprehensive view of the system's status. This project aims to create an integrative framework to address the fusing of data from multiple sources in order to improve the understanding of the historical, current, and future state of the natural gas system.

The California utilities have started the process of gathering and integrating data to evaluate the risk posed by transmission and distribution pipelines[2]. PG&E considers the availability and accessibility of accurate information about gas networks to be critical for improving safety[3] in line with recent PHMSA requirements[4].

PG&E has been developing new information management systems to centralize in a standard format all data about the characteristics and history of its Natural Gas Transmission and Distribution systems[5]. Their general architecture is based on three major software products: a Geographic Information System (GIS), document management software, and database. There is therefore an opportunity to extend the framework of PG&E's information systems to incorporate data such as historical records to advance risk assessment. This research will develop a new framework for the incorporation of detailed geospatial information to the existing and developing GIS

[2] CPUC "Risk Assessment Unit Hazard Database Project Report on Status and Initial Recommendations" March 2012 Threat#4: Operators unaware of the location and specification of the pipe in the ground.
[3] PG&E "Gas Transmission Operations Pipeline Safety Continuous Improvement Plan" October 2012
[4] PHMSA Bulletin "Pipeline Safety: Establishing Maximum Allowable Operating Pressure or Maximum Operating Pressure Using Record Evidence, and Integrity Management Risk Identification, Assessment, Prevention, and Mitigation", January 2011
[5] S. Singh "Gas Safety Margin Informed by Records Verification and Maximum Allowable Operating Pressure Validation" AGA May 2012

systems, to enable advanced analysis of risk, integrity management, maintenance, operations, and planning.

b) Objective

The goal of this project is to create tools that enable the integration of large amounts of both traditional (paper records) and non-traditional (e.g., electronic data and models) forms of gas infrastructure and environmental information to support comprehensive integrity assessment studies as well as asset operation and maintenance planning.

Since, to the best of our knowledge, projects of this scope have not been executed in any natural gas utilities, we expect to evolve requirements through a pilot study. The pilot will investigate extracting geographic and other contextual information from historical operation and maintenance records. This will lead to the development of a second phase of the project focused on developing visualization products which fuse models and data sources into meaningful information for decision-makers.

What follows is a description of both of these phases.

Phase 1: Extraction of geographical information from historical maintenance records

PG&E is developing new information management systems to centralize in a standard format all data about the characteristics and history of its Natural Gas Transmission and Distribution systems. To build these information management systems, millions of paper based records must be transformed in digital data sets. They are mainly GSR (Gas Service Record) forms completed at the time maintenance work is done on the gas systems[6]. There are about 50 different templates of forms employed over the past 70-80 years.

PG&E is looking to use the results of this research to reduce the time and cost required for extraction of data from the historical records. The expedited information extraction will ensure the newly developed information management system is complete, thereby contributing to efficient and safe gas distribution and transmission monitoring and management.

The goal of this project is to improve the process of paper-based information transfer into the electronic environment by automating it as much as possible and providing guidance to operators through a user-friendly interface. This will be done by:

- Developing triage techniques for identifying the quality of each record and the effort needed to extract relevant data from the records
- Developing and demonstrating a semi-automatic tool that will capture

[6] Sumeet Singh, Robert Brooke "Enhancing Gas Pipeline Safety using PODS to Improve the Accessibility and Reliability of Gas Transmission Pipeline Information" PODS users conference August 2012

geographical information from records
- Propose possible geographic location of the asset from the record to the user for validation.

Phase 2: A framework for assessing system-wide risk from natural gas infrastructure.
The benefits of risk assessments are manifold. For natural gas infrastructure, they can include tools that inform current maintenance schedules, determine future planning factors, and assist in communicating with the public. Performing a system-wide risk assessment of the entire natural gas system would entail the integration of multiple data sources and analyses, including those discussed for Phase 1, material from other CES-21 projects, and considerable input from PG&E and national gas experts.

A formal system-wide risk assessment is a continuous improvement process that is regularly revised based on many factors, including fluctuating demand, population migration, evolution of pipeline properties, etc... This phase would entail identifying the parameters of a system-wide risk assessment tool for PG&E.

c) Expected results

This project will have multiple benefits to customers through reduced costs and improved system-wide safety. For each of the phases of this project, these may include:

Phase 1) Extraction of geographical information from historical maintenance records
At the end of stage one of this phase, PG&E will assess the proposed method as a viable approach to augment the current information extraction methodology from historical records. The key deliverable will be a report detailing the pilot study results, which may include:

- The approximate locations of the work recorded in each document
- The characterization of the templates examined
- A review of OCR techniques used to develop the scanned text
- Suggestions of how to improve the computer-assisted extraction workflow.

At the end of second stage, the tools will be developed and demonstrated on a sample of documents following the defined forms. Deliverables may include:

- Software environment allowing:
  - Up-loading a PDF document for analysis
  - Running the OCR and interpretation tool on the geographical fields
  - Flagging documents that cannot be analyzed effectively
  - Indicating possible locations with measurement of confidence
- Documentation of the software, to include:
  - User guide
  - Specification document

- o Validation document

At the end of the third stage of this phase, the tools will be deployed within PG&E information management environment and will be ready to be used by the operators in charge of the transfer of handwritten documents.

Phase 2) A framework for assessing system-wide risk from natural gas infrastructure.
The results of this phase will be the definition of a data-centric dynamic risk-assessment tool, applied to PG&E's natural gas infrastructure.
The deliverables for this phase may include:

- A review of current approaches to pipeline risk assessments as the result of the findings of Phase 1
- A report containing the functional and operational needs of a system-wide risk assessment tool
- An integrated quantitative risk assessment framework containing a compilation of models and data

3. Market Research

Improved location of historical work orders
What follows is a review of each of the stages of translating historical scanned documents to useful geographic GSRs, and how this proposal addresses new approaches for each stage.

- Computer-assisted historical form triage: Many document management services offer form document sorting, based on OCR results. This project will explore additional non-OCR techniques for segmenting scanned images of forms into regions, converting each segmented image into a compact graph representation (whose vertices represent regions and whose edges represent adjacency or containment relations), and comparing the graph representation to graph representations for various form templates until a match is found. This work will leverage LLNL's Image Content Engine (ICE), a toolbox designed to extract regions and objects from images. LLNL has applied the Image Content Engine to various national security problems involving remote sensing images[7] [8] [9].
- Block Extraction and OCR: Optical character recognition (OCR) is a well-established technology for converting scanned text documents to character strings. OCR systems are challenged by low quality documents (old, poorly scanned, etc.) and multi-media documents with complex layouts (such as documents with comingled pictures,

[7] J. M. Brase, D. W. Paglieroni, D. N. Poland, G. F. Weinert, C. W. Grant, A. S. Lopez and S. Nikolaev, "Image Content Engine (ICE): A System for Fast Image Database Searches", Proceedings SPIE, vol.5781, Defense and Security Symposium, Orlando, FL, 28-30 March 2005.

[8] D. W. Paglieroni and S. Manay, "Signal-to-Noise Behavior for Matches to Gradient Direction Models of Corners in Images", Proceedings SPIE Defense & Security Symposium, Orlando, FL, 9-13 April 2007.

[9] S. W. Paglieroni and S. Manay, "Using Particle Filters to Detect Polygon Structures of Fixed Shape in Still Images", Proceedings 10th IASTED International Conference on Signal and Image Processing (SIP), Kona, HI, 18-20 Aug. 2008.

figures, graphics, equations, and handwriting).[10] This project will address these challenges by identifying the individual regions extracted from scanned forms by type (e.g., text-filled, photo, figure, etc.) so that appropriate regions can be submitted to the OCR for further analysis.

- Geographic location estimation: LLNL has extensive experience in assigning geographic locations to various entities through text evaluation. Geolocation is the process of assigning geographic coordinates to an entity based on its characteristics; Geocoding assigns geographic coordinates based on a street address or place name[11]. Geocoding services are now built into popular GIS packages, like ESRI's ArcGIS, and are also available online as APIs from Google, Yahoo, MapQuest, etc…
- However, this project will entail researching assignment of coordinates based on probabilistic location. For example, a recorded location such as "200 feet South on Main Street the intersection of Elm Street in Alto, CA" from an eighty-year-old document may not yield a precise set of coordinates, as streets move, street names change, and place names change as well (Alto, CA is in Marin County, it is now a part of Mill Valley). These challenges will result in a process that probabilistically assigns a location to a document, and can be represented in graphical form to the user for further refinement. The earlier example could be represented as a circle or oval on a map, not an explicit "X" with exact coordinates.
- Computer-assisted validation and document management: There are a large number of private companies that offer services in automated document management. These systems enable the extraction of structured text from standardized forms, and link the scanned image to the data record. These service providers include:
    - Adobe (Adobe.com)
    - EMC Documentum (www.emc.com/domains/documentum/
    - OmniPage Professional (www.nuance.com)
    - Xerox Docushare (docushare.xerox.com/products/ds_products_ocr.html)
- In addition, some of these services include the tagging of documents for human assessment and data validation. LLNL has been performing these activities for the Federal Government for nuclear weapons documentation. Called the "Nuclear Weapons Information Project"[12] , LLNL is tasked with the full workflow system of managing historical nuclear weapons data, from scanning, to data extraction, to digital organization. The documents in this project vary in quality, and create challenges when the documents include handwritten notes, images and notes, and missing contextual information. At times, documents are flagged for human interpretation and text refinement.

[10] Kluzner, V., A. Tzadok, D. Chevion and E. Walach." Hybrid Approach to Adaptive OCR for Historical Books.". ICDAR2011, 18-21 September, Beijing, China.

[11] Ratcliffe, Jerry H. (2001). "On the accuracy of TIGER-type geocoded address data in relation to cadastral and census areal units". *International Journal of Geographic Information Sciences* **15** (5).

[12] https://www.llnl.gov/str/Lowns.html

A framework for assessing system-wide risk from natural gas infrastructure. Assessing multivariate risk to and from gas pipeline infrastructure is a perennial focus of both academic research[13,14,15,16] and regulatory activities. While most efforts have focused on accidents and accident rates[17], few have emphasized the dynamic and probabilistic nature of future risk for the purposes of improved management and safety. The National Pipeline Mapping System (NPMS)[18] is a federally funded activity and repository that captures pipeline data with some attributes of risk. However robust the NPMS, it is too coarse for utility-scale risk assessment. In addition, most commercial services that provide gas utilities with metrics of risk do so at the "section" scale, not the system-wide scale. This is partially due to the cost of a system-scale model, the perennial changing nature of the natural gas system, and the vast volumes and types of data in need of integration for such a tool.

4. Research Approach Assessment

Challenge	Assessment	Reason
Segmentation of scanned document image into regions by type.	Likely to succeed	Techniques for image segmentation (by texture or gray value), line-corner-rectangle extraction have been developed and demonstrated, but performance degrades on low quality documents.[19,20,21,22,23]
Conversion of scanned documents to compact graph representations.	Likely to succeed	Spatial relations between image regions can be readily determined once the scanned document is segmented.

[13] Jo YD, Ahn BJ. A method of quantitative risk assessment for transmission pipeline carrying natural gas. J Hazard Mater 2005; A123:1–12.
[14] Henselwood F, Phillips G. A matrix-based risk assessment approach for addressing linear hazards such as pipelines. J Loss Prevent Process Ind 2006;19:433–41.[15] Dziubnski M, Fratczak M, Markowski AS. Aspects of risk analysis associated with major failures of fuel pipelines. J Loss Prevent Process Ind 2006;19:399–408.
[15] Dziubnski M, Fratczak M, Markowski AS. Aspects of risk analysis associated with major failures of fuel pipelines. J Loss Prevent Process Ind 2006;19:399–408.
[16] Yuhua D, Datao Y. Estimation of failure probability of oil and gas transmission pipelines by fuzzy fault tree analysis. J Loss Prevent Process Ind 2005;18:83–8.
[17] Restrepo, Carlos E.; Simonoff, Jeffrey S.; and Zimmerman, Rae, "Causes, Cost Consequences, and Risk Implications of Accidents in US Hazardous Liquid Pipeline Infrastructure" (2008). *Published Articles & Papers.* Paper 18. http://research.create.usc.edu/published_papers/18
[18] https://www.npms.phmsa.dot.gov/[19] Hasan, Y.M.Y.; Karam, L.J. 2000 , "Morphological text extraction from images," *Image Processing, IEEE Transactions on* , vol.9, no.11, pp.1978-1983, Nov 2000
[19] Hasan, Y.M.Y.; Karam, L.J. 2000 , "Morphological text extraction from images," *Image Processing, IEEE Transactions on* , vol.9, no.11, pp.1978-1983, Nov 2000
[20] Z. Lu, 1998."Detection of text region from digital engineering drawings", *IEEE Trans. Pattern Anal. Machine Intell.*, vol. 20, pp.431-439
[21] F. M. Wahl, K. Y. Wong, R. G. Casey, 2000. *Block segmentation and text extraction in mixed text/image documents* Computer Graphics and Image Processing, Volume 20, Issue 4, December 1982, Pages 375-390
[22] D. W. Paglieroni and S. Manay, "Signal-to-Noise Behavior for Matches to Gradient Direction Models of Corners in Images", Proceedings SPIE Defense & Security Symposium, Orlando, FL, 9-13 April 2007.
[23] D. W. Paglieroni and S. Manay, "Using Particle Filters to Detect Polygon Structures of Fixed Shape in Still Images", Proceedings 10th IASTED International Conference on Signal and Image Processing (SIP), Kona, HI, 18-20 Aug. 2008.

Challenge	Assessment	Reason
Identifying the type of form by matching graph representations of various templates to the scanned document.	Likely to succeed with some challenges	The graph matching techniques must be customized to the form template identification problem. The matcher must be robust enough to gracefully handle inexact matches. Performance will degrade on low quality documents.
Text extraction and geographic string creation	Likely to succeed	Techniques have been developed and demonstrated.[24,25,26]
Performing OCR on documents, comparison of strings to gazetteers and creation of geographic strings.	Likely to succeed	OCR is a technique that has been demonstrated for over thirty years. New techniques have perennially been incorporated using new algorithms.
Geocoding of documents– identifying geographic coordinates of each scanned record	Challenging to succeed	The challenge will be ensuring the historical gazetteers are sufficient for the complexities of the historical documents. Geolocation services are included in the standard GIS software package, ArcGIS. In addition if the geographic text is not consistent nor incomprehensible (messy handwriting), the Geolocation of the documents may be challenging. However, if geographic locations cannot be determined, the documents will be flagged for human interpretation.
Integration with the tools currently used by PG&E teams to enter information into the GIS system	Likely to succeed	This will require cooperation with PG&E's IT team. New workflows that incorporate computer-assisted OCR have been demonstrated[27]. The challenge will be in ensuring the linkages between the new tools and the extant workflows and databases.

[24] F. M. Wahl, K. Y. Wong, R. G. Casey, 2000. *Block segmentation and text extraction in mixed text/image documents* Computer Graphics and Image Processing, Volume 20, Issue 4, December 1982, Pages 375-390

[25] Hasan, Y.M.Y.; Karam, L.J. 2000 , "Morphological text extraction from images," *Image Processing, IEEE Transactions on* , vol.9, no.11, pp.1978-1983, Nov 2000

[26] Z. Lu, 1998."Detection of text region from digital engineering drawings", *IEEE Trans. Pattern Anal. Machine Intell.*, vol. 20, pp.431-439

[27] Neudecker, C., S. Schlarb, M. Dogan, P. Missier, S. Sufi, A. Williams and K. Wolstencroft. *An experimental workflow development platform for historical document digitisation and analysis.* Workshop on Historical Document Imaging and Processing (HIP '11), 16-17 September, Beijing, China.

Challenge	Assessment	Reason
System-wide risk assessment model	Medium risk of success	A comprehensive system-wide risk model will entail the merging of the new data-centric risk tools and the existing PG&E gas information system. The risk lies in adapting a vast, in-use enterprise system to account for new data, visualizations, and models. In addition, workforce will have to develop skills to use the advanced system.

The challenges stated above all leverage advanced computing capabilities, focused on data-centric analysis, modeling, and visualization. LLNL has a dedicated effort to leveraging existing and developing new Data Science innovations and applying them to their mission areas. This means that other ongoing Data Science projects will all contribute to this project through their own tools and techniques that have been or have to be developed. With extensive experience in data fusion from multiple sources, LLNL has people and software capabilities that can easily be adapted to this research project.

LLNL has long been scanning, extracting, and managing historical records for its many programs for the US Federal Government, focusing on national security applications. For these projects, LLNL is tasked with the full workflow of managing historical documents and drawings, from scanning to data extraction, to digital organization. In addition, LLNL has developed approaches to use computers to interpret text and images utilizing open-source tools and in-house computing expertise for numerous government sponsors. In CES-21, LLNL brings its expertise in secure document management and in developing innovative document analysis to the tasks presented here.

5. Partnership Opportunities

Potential Partner	Reason for Partnering
University of California, Berkeley	Geospatial Risk Assessment
University of Southern California	Energy Informatics resource
UCLA	Risk Assessment and the Public
EPRI	Natural Gas Risk Assessment
New York University	Pipeline Hazards
Stanford University	Risk Assessment
Pipeline Research Council International (PRCI)	Integrity Management, Risk Assessment
Gas Technical Institute (GTI)	Safety, Risk Assessment

6. Implementation Plan and Schedule

a) Work plan

A Milestone Memo (along with any associated deliverables) will be sent to the IOUs upon completion of a Milestone. Furthermore, Quarterly Progress Memos and an accompanying web conference delivered from LLNL will provide a forum for reviewing Milestones, identifying other accomplishments, reviewing challenges, and describing next steps. Comments and feedback will be documented after each web conference. Any changes will be handled according to the established operating procedures for CES-21.

Phase 1: Extraction of Geographical Information from Historical Maintenance Records (PM1-24)

This phase will work with the current PG&E historical document management system to enable a computer-assisted information extraction system for expedited and automated improvement of the gas records system. This Phase will be carried out using a limited set of PG&E Gas Service Record (GSR) templates (on the order of 200 for the pilot stage and the order of 10,000 for the demonstration of the integrated tool). Early tasks will focus on recent GSRs and standard text extraction, for a geographically constrained region (e.g. "SF Peninsula"). Later tasks will focus on all GSRs and hand-written entries for the entire network.

Major tasks in PM1-24:

1) (LLNL and PG&E) Clarification of goals, data and metrics of success. (PM1)
2) (PG&E) Delivery of subset of documents to be assessed, including existing scanned documents already entered into system, with digital information (for validation and training purposes), Gas Service Record (GSR) templates and relevant fields lookup table. (PM1)
3) (LLNL) Template determination formulation: For a subset of the GSR templates, an evaluation of commercial and LLNL-created image processing tools to identify optimal approaches to be used for automated template identification and block extraction. (PM1-2)
4) (LLNL) Trial template characterization identification and block extraction workflow. (PM3-7)
5) (LLNL) Text extraction tool: exploring both commercial and open-source approaches to Optical Character Recognition (OCR), a workflow will be created that uses template field constraints, a geographic gazetteer, resulting in a data record of relevant data and a geographic string of possible GSR location. Initial fields of focus may include GSR, data, and location fields. (PM3-7)
6) (LLNL) Geographic Approximation: For each geographic string, identify a possible location on a map for further investigation by PG&E analyst. (PM3-9)

7) (LLNL) Integrate the stages of the extraction into a pilot workflow for interpretation of a set of recent, geographically constrained set of GSRs. (PM9-14)

   Upon review of results of the pilot (on the order of 200 documents), additional tasks will follow a decision point with IOUs to assess results.

8) (LLNL) Integrated Computer-assisted Geographic information extraction tool: integrate the stages of the extraction into a production-scale workflow for interpretation of additional documents. (PM14-24)

Phase 2: System-Wide Risk Assessment of PG&E's Natural Gas System (PM 19-42)

This phase will entail a comprehensive safety and economic risk assessment of PG&E's entire natural gas system.

Major tasks:

1) (IOUs & LLNL) A review of current approaches to multivariate pipeline risk assessments. (PM19-21)
2) (LLNL) An assessment of other results of risks to gas infrastructure from natural disasters, including sea-level rise[28]. (PM21-29)
3) (LLNL) An integrated quantitative risk assessment framework containing a compilation of available models and data, including from other CES-21 projects investigating the Gas sector. (PM26-42)

b) Interdependency with other Business Cases

Business Case with Dependency (WBS)	Type of Dependency (provider, consumer, informational)	Required or Beneficial	Explanation
Phase 1 (PY1)	informational	beneficial	This project could integrate the results of the other CES-21 Gas Project Areas; without those results, the integrative risk visualization will proceed.

[28] This subject will be treated in collaboration with UC Berkeley in connection with the project funded mid 2012 by the California Energy Commission. Contract# 500-11-016 started on May 28th, 2012.

c) Milestones/Deliverables

Phase	Type	Description	Due Date	Responsible
1	Milestone (M1)	Preliminary scoping meeting with partners	PM01	PG&E
1	Milestone (M2)	Delivery of documents, scanned and unscanned, and templates	PM01	PG&E
1	Milestone (M3)	Template methodology determination	PM02	LLNL
1	Milestone (M4)	Document Template determination and block extraction update	PM07	LLNL
1	Milestone (M5)	Text extraction tool pilot (addressing O(200) documents)	PM07	LLNL
1	Milestone (M6)	Geographic approximation of document set pilot complete	PM09	LLNL
1	Deliverable (D1)	Pilot workflow of document extraction complete	PM11	LLNL
1	Deliverable (D2)	Report on integrated computer assisted geographic information extraction tool to support project next step decision	PM13	LLNL
1	Milestone (M7)	Integrated computer assisted geographic information extraction tool; integrate the stages of the extraction into a production scale workflow for interpretation of ~10,000 documents	PM16	LLNL
1	Milestone (M8)	Integration of the tool in the information management environment of IOUs; integrate the production scale tool with IOU gas information system for the extraction of IOU's historical gas documents	PM22	PG&E and LLNL
1	Deliverable (D3)	Report on methodology of integration of tool with IOU systems	PM24	PG&E and LLNL

Phase	Type	Description	Due Date	Responsible
2	Milestone (M9)	Review of current approaches to pipeline risk assessments as the result of the findings of Phase 1	PM20	PG&E and LLNL
2	Milestone (M10)	Assessment report of other risks to natural gas infrastructure	PM24	LLNL
2	Milestone (M11)	Determination of functional and operational needs of a system-wide risk assessment tool	PM30	LLNL

d) Resource requirements

We estimate an average of 4 people per year will be required. This estimate includes LLNL, IOU, and potential partner resources in the following areas.

- Gas System Engineering
- Statistics
- Geospatial analysis
- Machine Learning
- Image Processing
- Computer Programming
- Multivariate Risk assessment
- Advanced Visualization techniques

7. Cost Estimate and Allocation

Expense	PM1-18 ($K)	PM19-30 ($K)	PM31-42 ($K)	PM43-54 ($K)	PM55-66 ($K)
LLNL & Subcontract costs	1,131	666			
IOU costs	86	72			
TOTAL	**$1,217**	**$738**			

8. Benefits Estimate and Methodology

The customer benefits brought by this research combine improved safety, reliability and cost optimization. The expected value is to develop tools to do much more while maintaining the affordability of gas delivery.

In this context, an estimate of quantitative benefits is provided by comparing the costs of tool development with the cost of using current methods to perform the same task. Often, the envisioned level of performance simply cannot be reached without the tools developed through this research.

From a recent study processing A-form to collect information about leak repair, the cost per manually processed document (including information extraction, location identification and data recording in a flat file) is estimated to $50.

Assuming that the residual manual work will represent 5% of the time required in the current process when the automated process is successful, that the success rate of the automated process is 50%, and that the scaling-up discount is of 80%, the value created by the Phase 2 of the projects is estimated to $90M for PG&E (20 million documents to be processed).

California Energy Systems for the 21st Century

Advanced Modeling and Simulation Environment for Gas System Planning and Operation

Proposed Research Project: Business Case

1. Executive Summary

a) Research Project Opportunity Statement:

PG&E currently makes extensive use of pipeline modeling software for system planning purposes. Planning needs are evolving due to the integration of renewable energy sources, the availability of substantially more monitoring data on the transmission and distribution networks, and new opportunities to improve system operations by using simulations as a tool to guide operators for complex real time decisions. High-fidelity modeling will be needed to support pipeline network management, including the use of systems modeling to provide insight into complex "what if" scenarios for planning and operation purposes, as well as potentially to detect leaks or other equipment failures.

This proposal is to establish a relationship between the three California Investor Owned Utilities (IOUs) and Lawrence Livermore National Laboratory (LLNL)[1] to advance the state of the art in pipeline modeling by implementing a quantified uncertainty framework, which will enhance modeling accuracy as well as the level of understanding and confidence in modeling results. We plan to implement new forms of uncertainty quantification and stochastic inversion to be applied to pipeline models. These general techniques have been applied by the laboratory to a wide variety of nonlinear modeling applications, including seismic modeling[2], climate research[3], and stockpile stewardship. The high computational demands of these types of analysis allow the laboratory to make a unique contribution to enhancing gas systems modeling. Unique challenges and opportunities for applying such strategies to pipeline system models include determining the best methods to leverage the graph structure of pipeline analysis to better capture uncertainty and reduce computational demands, as well as the eventual integration of massive amounts of sensor data in the form of Smart Meter readings. This will require the laboratory to leverage expertise in applied mathematics, statistics, high-performance computing, and big data management and integration.

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[1] Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344.

[2] Myers, S.C., Johannesson, G., and Hanley, W. A Bayesian hierarchical method for multiple-event seismic location. Geophysical Journal International. 171:1049-1063. 2007.

[3] Johannesson, G. Accounting for global climate model projection uncertainty in modern statistical downscaling LLNL-TR-426343, Lawrence Livermore National Laboratory. 2010.

From the perspective of the utility, this enhanced modeling approach can help to prioritize physical testing and upgrades, enable more informed sensor placement, enhance contingency planning exercises, and evaluate a broad range of renewable deployment scenarios. For example, risk reduction through prioritized upgrades (e.g., smart sensor placement or pipe replacement) and maintenance (e.g., hydraulic testing) can be based on modeled predictions when the accuracy of the model is high and sources of uncertainty are well understood. Other possible uses include capturing emerging information about underground gas transmission and distribution systems to streamline operations and identify potential problems, such as leaks or failing equipment. The proposed model enhancements are likely to provide an improved overall understanding of system characteristics and performance, thereby enabling more efficient management of the natural gas pipeline network. This will reduce risk and cost by allowing the utility to prioritize maintenance and possibly modify operational decisions (e.g. lower operating pressures) based on model predictions.

b) Utility Sponsors:

☒ PG&E ☐ SCE ☐ SDG&E

c) This research focuses on the following area:

☐ Cyber Security
☐ Electric Resource Planning
☐ Electric System Operations
☒ Gas System Operations

d) This research maps to the following value chain categories:

☐ Grid operations/market design
☐ Generation
☒ Transmission
☒ Distribution
☐ Demand side management
☐ Cyber Security

e) This research supports one or more of the following objectives identified in Public Utilities Code §740.1:

☐ Environmental improvement
☒ Public and employee safety
☒ Conservation by efficient resource use or by reducing or shifting system load
☐ Development of new resources and processes, particularly renewable resources and processes which further supply technologies
☒ Improve operating efficiency and reliability or otherwise reduce operating costs

f) Potential Customer Benefits:

The benefit to PG&E will be an improved understanding of the operational state of their pipeline system. Advanced modeling techniques have the potential to save the utility money by automating resource intensive model calibration, rapidly identifying potential problem areas where unexpected changes are occurring in the system, and increasing the value of pipeline network models by providing quantified accuracy assessments that can justify basing high-consequence decisions on modeling results. Our proposed work has the potential to reduce risk posed by the consequences associated with possible pipeline failure both by identifying potential problems early and by allowing the utility to explore the effects of various proposals to increase safety in their operations (e.g. lowering operating pressures) based on modeling results. Benefits to customers include an anticipated increase in reliability and reduction in cost for gas services, as well as more flexibility in planning that will allow the existing system to adapt to the increased deployment of renewable energy sources.

g) Research Challenges and Hurdles to Overcome:

The proposed research plan is graded in such a manner as to ensure flexibility to accommodate the needs of the utility as well as to respond to unforeseen events. Year one goals and deliverables are clearly stated, and represent an identified opportunity to upgrade the state-of-practice for the utility. As the relationship between the laboratory and PG&E's gas operations and modeling groups develops, we anticipate that additional high-priority goals will be identified that will build upon the initial modeling framework. Some ideas for these potential future projects are described herein. When measured in terms of general operational enhancement and overall system risk reduction, the likelihood of success is high, given that we anticipate a close relationship with both gas utilities and software vendors to ensure that our work is of direct benefit to gas operations.

h) Unique Capabilities Offered by LLNL:

Pipeline modeling software is used extensively in the natural gas industry, and improvements to this software are an active area of research. However, the existing industry focus is on improving system performance on commodity (desktop) hardware and improving model fidelity through modifications of mathematical representations of model elements (e.g. compressors). While model calibration and validation are recognized as being critically important to model quality, they are not typically focuses of research in themselves. The lab's access to and experience with HPC (High Performance Computing) capabilities and corresponding computationally intensive calibration, validation, and sensitivity analysis methods represents an opportunity for a unique contribution to state-of-the-art pipeline modeling. Similarly, our experience with computationally demanding codes with complex output puts us in a unique position to integrate simulation and planning capabilities by identifying and implementing data summaries and visualization methods such that they are accessible and interpretable to decision makers. Our plan is to develop such methods in a way that leverages off of commercially available software wherever possible, thereby providing valuable enhancements to planning operations without duplicating modeling effort.

LLNL has previously employed the general techniques proposed here (stochastic modeling and inversion, sophisticated visualization tools) in other areas that have provided considerable benefits to customers.

Stochastic inversion was employed by LLNL to assess the viability of a CO2 sequestration project in In Salah, Algeria (funded jointly by Fossil Energy DOE and a consortium of BP/Statoil/Sonatrach). The goal was to establish whether the fractures created by the injection of CO2 into the reservoir had impinged through the caprock, thus compromising the integrity of the reservoir. A loss of reservoir integrity would lead to leakage of the injected CO2 into the upper "water potable" aquifers, and eventually releases of the CO2 to the atmosphere. Releases to the upper aquifer would also alter the geochemical composition of the water (changes in pH, alkalinity and releases of metal contaminants such as lead etc.), and thus cause serious environmental damage. If the caprock were found to be broken, this would cause a total halt of CO2 injection. LLNL employed stochastic inversion (in the form of the "stochastic engine" model) to generate probabilistic estimates of the height, width, and depth of the resulting fracture and showed that there is less than a 10% chance that the fracture went through the caprock. Results were confirmed by independent studies by LBNL and by additional analytical hydro-mechanical analysis of the data from LLNL.

If not for the probabilistic inversion analysis, there would be serious doubt as to the extent of the created fracture, and thus the integrity of the reservoir. The inversion process therefore gave confidence that CO2 injection could continue in the reservoir.

In the visualization area, LLNL developed the fast running tunnel modeling assessment tool (STUNTool, funded by DHS) to predict the impact of explosive damage to tunnels. Part of this software package was a "breach prediction tool" that leverages hundreds of sophisticated hydrocode runs that were performed using LLNL's HPC infrastructure, and, using machine learning techniques, allows users to enter in the relevant construction parameters for their tunnel system to assess what types of threats (explosive charge size, standoff distance) could cause a tunnel breach. Although the initial structural analysis required high performance computing, the resulting prediction and visualization tools can be run on a laptop computer, and have been distributed to infrastructure owners for threat assessment purposes.

Alternative	Assessment
3rd party pipeline modeling software	Does not offer full calibration or validation capability, limited HPC capabilities

i) 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.

j) Duplication and synergies:

All project scope has been coordinated with other CES-21 projects, EPIC projects and other research efforts underway at the utilities and other research entities to ensure no duplication of effort. In addition, the CES-21 team will continue to monitor external RD&D projects to take advantage of synergies with external research and reduce the risk of future duplication.

2. Proposal Description

a) Background

High-fidelity system analysis and modeling with the explicit goal of understanding uncertainty can provide a cost effective methodology for better predicting system performance and reducing risk. In the gas operations context, such an approach can assist with system planning by providing high-fidelity predictions of system performance under a wide range of scenarios, ranging from short-term effects due to maintenance to the long-range consequences of adding more renewable energy sources to the grid. Combining such modeling efforts with real-time data also has the potential to identify potential problems in the physical system (e.g. leaks or failing equipment). Under these scenarios, modeling can help pipeline owners with activities such as planning maintenance, determining optimal sensor placement, and implementing operational changes that will reduce risk or cost without reducing service reliability.

b) Objective

We will implement an advanced calibration methodology, known as stochastic inversion, for PG&E pipeline models. In addition to automating what is currently a costly and time-consuming calibration process, stochastic inversion often increases the accuracy of the calibrated model and also provides an accuracy assessment for model predictions. Access to predictions with quantified accuracy, in turn, increases confidence in model-based assessments and enables models to be used in new contexts. Such models, when combined with data reduction and visualization strategies, constitute a valuable tool to guide risk assessment and inform decisions by energy stakeholders. This effort will be accomplished by the application of expertise in computation, optimization, network modeling, and uncertainty quantification.

c) Expected results

We propose to contribute the following solutions to assist gas operations at PG&E:

- Enhance the current state of industry for pipeline systems modeling through the development of automated calibration and validation tools, which will include the implementation of an accuracy quantification approach for pipeline modeling. (First Year, Out Years)
- Implement data visualization tools to effectively summarize multivariate responses, potentially from multiple simulation runs (representing, for example, the pipeline system response to a large array of possible combinations of relevant variables such as changes in ambient temperature

and loads, or changes in compressor efficiency), in the data-rich environment of gas operations modeling. (First Year, Out Years)

- Enhance state of the industry pipeline modeling software by increasing software robustness and usability. (Out Years)
- Develop and deliver contingency planning tools that leverage multiple simulated scenarios with quantified uncertainty and advanced visualization to aid decision makers in responding to sudden system changes. (Out Years)

3. Market Research

Gas pipeline operations has been the focus of modeling groups in industry such as the Pipeline Simulation Interest Group (PSIG), which includes a number of software vendors, academia, and different professional associations coordinated through both the Pipeline Research Council International (PRCI) and the Gas Technology Institute (GTI). In regard to modeling, research efforts can largely be divided into the broad categories of system model improvement[4,5], model optimization and preconditioning [6,7], and gas-electricity integration[8]. The current research plan focuses initially on improving methods for applying existing pipeline models, such as improved calibration, sensitivity analysis, and interpretation. The emphasis shifts in later years to improving simulation speed, robustness, and fidelity.

Some commercial pipeline modeling software (e.g. SIMONE, SynerGEE) include API (Application Programming Interface) specifications that allow modeling capabilities to be embedded in other software applications, such as MS Excel. This capability can be used to generate multiple model runs for optimization or planning purposes[9,10]. LLNL anticipates leveraging an API if it is determined that the use of commercial software is appropriate. However, while various uses of APIs have been noted both in the literature and in discussions with PG&E, the proposed applications in calibration and validation have not been observed in industry practice. While the necessity of effective model calibration is a recognized issue[11,12,13,14], it does not appear that industry is employing automated

[4] Zhu, G., Henson, M.A. and Megan, L. Dynamic modeling and linear model predictive control of gas pipeline networks. Journal of Process Control, 11(2):129-148. 2001.

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[6] Rios-Mercado, R.Z., Wu, S., Scott, L. R., and Boyd, E.A. A reduction technique for natural gas transmission network optimization problems. Annals of Operations Research, 117:217-234. 2002.

[7] Rios-Mercado, R.Z. and Borraz-Sanchez, C. Optimization problems in natural gas transmission systems: A state-of-the-art survey, Northwestern University. January 2012.

[8] Carter, R.G. and Rachford, H.H. Optimizing line-pack management to hedge against future load uncertainty. Annual PSIG Meeting. 2003.

[9] Network Modeling Software Review: A Report to National Grid. Poyry Energy Consulting. 2009.

[10] PG&E currently uses an Excel interface for SynerGEE Solver for backbone modeling applications.

[11] Lagoni, P. and Barley, J. On simulation accuracy. Annual PSIG Meeting. 2007.

probabilistic calibration. This is likely due to both the computationally intensive nature of such calibration and a lack of high performance computational resources. Therefore, this represents a unique potential contribution by LLNL. The planned effort will draw upon existing expertise developed in a wide variety of application areas[15,16]. In addition, the existing software interfaces may not be providing information in the most useful manner for system planning. Model output relevant for planning purposes may be complex, particularly when drawing upon models from multiple scenarios, and therefore not easily interpretable from a spreadsheet. This requires the development of custom interfaces that provide visual tools for summarizing information. Again, LLNL has existing unique expertise in summarizing and presenting information from computationally intensive simulations in a usable, readily interpretable manner[17,18].

In later stages of the project, there is an interest in pursuing performance enhancements such as increased speed and robustness for pipeline modeling. An obvious method for increasing speed is the implementation of parallelization in pipeline models. Parallelization has been implemented in commercial software in some limited contexts, but the need for more extensive use of parallel algorithms is recognized within the pipeline modeling community[19]. LLNL has extensive experience in implementing parallelized algorithms and improving optimization for both in-house and commercial applications[20], and this expertise could be applied to industry software development if this is of interest to the sponsor and an agreement can be made with a suitable software vendor. Even without access to software source code, opportunities exist to leverage parallelization through the running of many discrete models to explore uncertainty in operating conditions. This represents an advance over methods for exploring uncertainty that are based on a limited number of model runs or that do not leverage sophisticated graphical summarization techniques[21]. Even extensive contingency planning exercises leveraging thousands of simulations[22] can

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[12] Dickerson, P. Pipeline modeling: Getting the right data and getting the data right. Annual PSIG Meeting. 2009.

[13] Schroeder, D.W. Pipeline efficiency considerations in natural gas networks. Annual PSIG Meeting. 2010.

[14] Schroeder, D.W. A tutorial on pipe flow equations. Annual PSIG Meeting. 2010.

[15] Ramirez, A.L., Nitao, J.J., Hanley, W.G., Aines, R., Glaser, R.E., Sengupta, S.K., Dyer, K.M., Hickling, T.L. and Daily, W.D. Stochastic inversion of electrical resistivity changes using a Markov Chain Monte Carlo approach. Journal of Geophysical Research, 110(B2):B02101. 2005.

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[21] Vostrý, Z and Stýblo, M. Gas network simulation and uncertainty of pipe leg surroundings parameters. PSIG Annual Meeting. 2009.

[22] Truong, N. The challenges of modeling a probabilistic pipeline. PSIG Annual Meeting. 2009.

benefit from more comprehensive coverage of low-probability/high-consequence events through the application of high performance computing.

As discussed, LLNL has extensive experience with and expertise in optimization, data synthesis and integration, uncertainty quantification, stochastic inversion, and machine learning, and in applying such techniques to large-scale high-consequence infrastructure problems.

4. Research Approach Assessment

Challenge	Assessment	Reason
The IOU's existing modeling tools may not be amenable to stochastic inversion or HPC implementations	Low risk	The team is qualified based on their previous experience in this area to develop an alternative pipeline flow model if necessary

One challenge in Phase 1 will be that LLNL is still developing an understanding of how commercial modeling is used by the utility and how best to apply resources to the benefit of PG&E. We need to assess the commercial code's usability in batch mode, parallelization capability and functionality on operating systems other than Windows. Also, increasing the efficiency and robustness of optimization may require access to the underlying code of the modeling software. If source code is not immediately available or if batch or parallel versions of necessary features are still in development, a fallback position, especially in Phase 1 of the project, is to develop an alternative pipeline flow model. The team is qualified to do so based on previous experience in this area. The final decision as to how to proceed will depend upon both the receptivity of commercial vendors to collaboration and the value to PG&E of using existing software versus independently developed code.

5. Partnership Opportunities

Potential Partner	Reason for Partnering
GL Noble Denton	Makers of SynerGEE software
Gregg Engineering	Makers of NextGen software
Energy Solutions International	Makers of Pipeline Studio software
ATMOS International	Makers of ATMOS Sim software
Simulation Software Limited	Makers of Varisim software
Eucalypt	Makers of GNSA software
Liwacom	Makers of SIMONE software
Sandia National Laboratory	Experience working with commercial pipeline model developers
Lawrence Berkeley National Laboratory	Experience in simulation and complex systems modeling

Potential Partner	Reason for Partnering
Pipeline Research Council International	Industry research organization
Pipeline Simulation Interest Group	Industry research organization
University of California at Santa Barbara	Expertise in system modeling and research

6. Implementation Plan and Schedule

a) Work plan

A Milestone Memo (along with any associated deliverables) will be sent to the IOUs upon completion of a Milestone. Furthermore, Quarterly Progress Memos and an accompanying web conference delivered from LLNL will provide a forum for reviewing Milestones, identifying other accomplishments, reviewing challenges, and describing next steps. Comments and feedback will be documented after each web conference. Any changes will be handled according to the established operating procedures for CES-21.

We envision a set of phases to solve the problems discussed previously. The phases will be executed over a period of three to five years depending on the level of technological development desired by stakeholders in the out years. Greater detail is given for the first year which focuses on improving modeling and modeling applications to gas operations.

Phase 1: Model Calibration and Accuracy Quantification (PM1-30)

The backbone, transmission and distribution teams at PG&E use industry standard software to help assess the state of pipeline operations for supply, demand and storage estimates. This includes a package that leverages an API to provide a more automated capability for a reduced set of operations relative to the standard graphical interface. When a network model needs to be updated due to changes in the physical system (for example, every 3 to 5 years for backbone), model parameters are calibrated “by hand” (a labor-intensive process that can take months). For some transmission and distribution systems, so many parameters are in play that high-fidelity calibration is not currently possible. We propose in the first year to demonstrate an automated process for calibration of a real-world backbone model using the utility’s preferred pipeline simulation software, and to simultaneously implement an accuracy assessment system for all model predictions. This automated capability can be extended in later project phases to other modeling problems (e.g. fast transient) and more complex pipeline systems (e.g. distribution) as desired by the utility. This proposal provides immediate benefits in the form of a newly automated process for backbone model calibration, which will allow more frequent calibration and which will include quantified model accuracy that can be used for a variety of planning purposes. This project also lays the foundation for future calibration efforts in transmission and distribution systems, which could provide unprecedented levels of accuracy for those models.

The primary goal of Phase 1 is to automate the calibration process for models in a way that is compatible with the IOU's existing modeling tools. In addition to reducing the resource requirements for model calibration and increasing accuracy, this process will provide accuracy assessments for model predictions. Such "uncertainty boundaries" can be used to identify system changes and potential problems; for example, degraded compressor performance could cause observed flow rates and pressures to disagree with model predictions, and uncertainty bounds would allow this to be definitively attributed to a change in the physical system rather than random variability.

Initially we will only need to interact directly with the PG&E gas operations team in working with an existing commercial tool, as there is no immediate need to access software source code. However, as an eventual goal is to improve the efficiency and robustness of the pipeline models, we may eventually need to modify the modeling software itself. We propose to approach industry partners regarding possible agreements to collaborate on source code development, but are prepared to develop another pipeline system model if necessary. Uncertainty analysis and calibration require numerous model runs, so securing such an agreement would also be useful since it could enable the use of large numbers of software licenses. LLNL plans to accomplish the calibration and accuracy assessment task through the use of a stochastic inversion process[23] on pipeline network models and corresponding sensor data, to generate a high-accuracy model that provides predicted pressures and error bounds at locations throughout the system.

Major tasks:

1) (IOU & LLNL) Engage gas operations to learn how pipeline models are used for backbone, transmission and distribution lines, and to assess and acquire historical pressure and flow data for these systems. (PM1-4)
2) (LLNL) Demonstrate an automated calibration process for backbone models using industry software, which would include the implementation of uncertainty bounds for model predictions. We also plan to quantify model

[23] Glaser, R.E., Hanley, W.G., Lee, C.L., and Nitao, J.J. A Markov chain Monte Carlo based method for system identification, UCRL-JC-150494, Lawrence Livermore National Laboratory. 2003.

accuracy and performance in terms of computational speed for different sized problems. (PM3-18)

3) (IOU & LLNL) Assess the state of the industry software and engage industry partners. (PM6-18)
4) (LLNL) Implement automated calibration and uncertainty quantification process for additional models and model types (e.g. transient models) by working with either PG&E's current modeling software or another gas pipeline network model. Based on sensitivity of the model to parameter changes and changes in demand, the enhanced model could be used, for example, to optimize new sensor placement or develop more efficient control algorithms. This will be integrated with the visualization development task from Phase 2. (PM 12-30)
5) (LLNL) Once validated, pipeline models that include accuracy assessments can identify changes or problems in the system by highlighting regions where observed sensor readings are outside of the known bounds based on the model prediction and uncertainty analysis. The final uncertainty assessment can also highlight regions where pressure and flow predictions may not be sufficiently reliable for this kind of change detection, which could indicate the need to confirm pipeline location and dimensions, improve the underlying model, or suggest the placement of additional sensors. These benefits are in addition to the fact that this process would allow models to be calibrated more frequently and at lower cost. The predicted pressures at multiple locations and the uncertainty of those predictions will be determined for pipeline systems selected by the utility based on planning or research goals. (PM4-30)

Phase 2: Operational Enhancement through Contingency Planning Tools, Visualization Capabilities and Other Software Enhancements (PM9-42)

After initial work with the gas operations models, successive phases of the project would address more complex networks and the integration of increasing amounts of available data, possibly including Smart Meter data for distribution networks. Sophisticated tools are necessary to help understand relevant parameters and multivariate response in a data-rich environment. The effort could include, for example, the integration of multiple model runs to assess transient effects across the system to develop contingency plans for sudden outages. Presenting the outcome of multiple model runs in an intuitive manner useful to decision makers is a challenge that depends heavily on the intended use of the simulations. The LLNL team will work with gas operations and planning personnel throughout the first phase of the project to identify high-value applications for visualization tools. Once top priority problems are identified, the LLNL team will proceed with implementing software that combines the output from many model runs in a form that is of maximal value to decision makers. The research team has previously performed similar work for homeland security applications[24].

Other possible future enhancements would include the integration of additional data sources to improve model performance. For example, detailed pipeline and materials assessments can be used to better quantify overall system uncertainty and detect anomalies, or the inclusion of supply and demand forecasting will help longer term planning including maintenance scheduling and integration with renewables.

Major tasks:

1) (LLNL) Data integration for larger pipeline networks. (PM12-42)
2) (LLNL) The current modeling tool employed by the utility lacks some visualization tools that can be used to better understand the simulation output. As we propose to increase the amount of information from such simulations by including both accuracy information and change detection, it becomes increasingly important that simulation output be presented in a user-friendly way. We propose the development of visualization tools that can present simulation output and summarize the results of multiple simulations used for planning or uncertainty quantification purposes. If the software vendor is receptive, this portion of the project may be undertaken in conjunction with them, and ultimately be included in their software packages. Otherwise, we would anticipate the visualization module operating as a standalone application including a graphical user interface. (PM9-42)
3) (LLNL) In the course of developing calibration and validation tools, we anticipate that shortcomings of the existing modeling software may become apparent. As such situations arise, assuming the commercial vendor is receptive, it may be possible to implement further enhancements to the underlying simulation program, such as enhanced parallelization capabilities, improved model conditioning, or more robust optimization routines. (PM13-42)
4) (LLNL and IOU) To demonstrate the power of advanced visualization, PG&E and LLNL will partner to develop a planning tool to address at least one specific planning problem through the use of multiple simulation runs and visualization tools. Possible scenarios include addressing uncertainty in pipeline network performance due to uncertain weather or fluctuations in demand. (PM15-42)

[24] Glascoe, L., Neuscamman, S., Lennox, K., Elmer, W., Glenn, L., and McMichael, L. A fast-running tool to characterize shock damage on structures. Proceedings for ASCE Structures Congress. 2012.

b) Interdependency with other Business Cases

Business Case with Dependency (Phase)	Type of Dependency (provider, consumer, informational)	Required or Beneficial	Explanation
Phase 2 (PY2)	informational	beneficial	The enhanced modeling capabilities developed in PYs 1 and 2 could be integrated with aspects of the Geographic Data Fusion Project for Gas Operations.

c) Milestones/Deliverables

Phase	Type	Description	Due Date	Responsible
1	Deliverable (D1)	Delivery of backbone model and appropriate calibration/validation data to LLNL	PM2	PG&E
1	Milestone (M1)	Complete assessment of selected commercial software as applies to anticipated automation and visualization efforts	PM4	LLNL
1	Deliverable (D2)	Preliminary presentation of automated calibration capability using commercial software for backbone model	PM12	LLNL
1	Milestone (M2)	Complete vendor selection for post-Phase 1 modeling completed, or decision to move forward with an in-house model	PM12	LLNL & PG&E
1	Milestone (M3)	Selection of additional model for automated calibration (e.g. transmission, distribution, or high-pressure distribution system models)	PM16	LLNL & PG&E
2	Milestone (M4)	Selection of demonstration planning need to be addressed by advanced visualization tools	PM14	LLNL & PG&E
1	Deliverable (D3)	Delivery of pipeline model and appropriate calibration/validation data to LLNL for second calibration task	PM17	PG&E
2	Deliverable (D4)	Presentation of automated calibration using commercial software for backbone model	PM18	LLNL

Phase	Type	Description	Due Date	Responsible
1, 2	Milestone (M5)	Complete assessment of optimization capabilities of selected software and options for increasing robustness	PM18	LLNL
1, 2	Deliverable (D5)	Presentation of automated calibration capability for additional model (e.g. transmission, distribution, or high-pressure distribution system models)	PM23	LLNL
1, 2	Milestone (M6)	Complete conceptual framework for integration of Smart Meter data into model calibration framework, as well as integration of backbone, transmission, and distribution models.	PM26	LLNL
1, 2	Deliverable (D6)	Delivery of uncertainty quantification and accuracy assessment software as well as strategies for increasing numerical robustness of modeling for pipeline operations. This will include complete documentation, allowing the utility to perform model calibration using these methodologies independent of LLNL.	PM30	LLNL
2	Milestone (M7)	Demonstration of advanced visualization capability for selected planning exercise	PM42	LLNL
2	Deliverable (D7)	Presentation on advanced visualization capability for selected planning exercise	PM42	LLNL

d) Resource requirements

An average of 5 people per year will be required. This estimate includes LLNL, IOU, and potential partner resources in the following areas.

- Pipeline modeling
- Statistics
- Applied mathematics
- Programming and software development
- Project management

7. Cost Estimate and Allocation

Expense	PM1-18 ($K)	PM19-30 ($K)	PM31-42 ($K)	PM43-54 ($K)	PM55-66 ($K)
LLNL & Subcontract cost	1,502	1,501	1,505		
IOU costs	113	154	285		
TOTAL	**$1,615**	**$1,655**	**$1,790**		

8. Benefits Estimate and Methodology

PG&E anticipates that this project will provide benefits in the following areas:

- Modeling Accuracy: Current modeling techniques do not utilize the latest technology (such as Smart Meter Data) to model accurate system demand and usage. New modeling and analyses techniques and tools are required to better understand gas system response during critical design conditions.
- Safety: Improved accuracy of flow calculations allows planning to ensure there is sufficient capacity on the system to meet customer demand. During a Cold Weather Day event or an Abnormal Peak Day event, PG&E is better able to assess system constraints and avoid unplanned disruption (curtailments) of gas service.
- Emergency Response: Planners will be able to diagnose system response to a gas leak with confidence and offer repair solutions that reduce system disruption.
- Cost Saving: Accurate modeling allows PG&E to determine critical flow constraints on the system, and undertake only the required improvements. Inaccurate modeling, would lead to overly conservative planning, resulting in extra cost for system improvements to ensure demand can be met. Currently, in order to meet capacity of the gas system and to ensure safety to customers, upgrades and replacements are needed to address over-pressure conditions on transmission and distribution pipelines. The annual costs associated with such infrastructure improvements are estimated to be $40M. An accurate modeling tool will allow more effective planning and consequently reduce the cost for upgrades to the gas infrastructure. A conservative assumptive reduction of 5% of the cost means that $2M can be saved per year.
- Environmental: Accurate knowledge of system capacity and customer usage allows crew members to reduce the response time during emergency (such as a gas leak), thereby reducing natural gas emissions.
- Efficiency: Planning will be able to run multiple system design scenarios without cumbersome model building data entry requirements. This will save significant hours of laborious system modeling without sacrificing the quality of results. The opportunity to increase efficiency by 5% for model building is a realistic and probable goal. With the current team of roughly 50 analysts dedicated to system modeling in the Gas System Planning organization, this translates to a savings of 2.5 FTEs worth of effort per year, or about $0.43M per year.
- Visualization: Planners will be able to visually see impact on the Gas Distribution, Transmission & Backbone system as parameters are changed. This results in

quicker and faster response time for requests. The benefits are multiplied during emergency scenarios to respond to a gas leak and implement repair alternatives.

Attachment 3:

CES-21 CRADA

DRAFT – FOR CES-21 Board of Directors Meeting 4/11/13
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 4, 2013

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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. <u>Term, Funding & Costs</u>

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 One Hundred Fifty Million Dollars ($150,000,000). PG&E's estimated cost is Eighty-two Million, Five Hundred Thousand Dollars ($82,500,000), of which PG&E's estimated in-kind contribution is [to be inserted] and PG&E's estimated funds-in contribution is [to be inserted].SCE's estimated cost is Fifty-two Million, Five Hundred Thousand Dollars ($52,500,000), of which SCE's estimated in-kind contribution is [to be inserted] and SCE's estimated funds-in contribution is [to be inserted]. SDG&E's estimated cost is Fifteen Million Dollars ($15,000,000), of which SDG&E's estimated in-kind contribution is [to be inserted] and SDG&E's estimated funds-in contribution is [to be inserted].

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. <u>Pre-Publication and Pre-Release Review</u>

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. <u>Reporting Subject Inventions</u>

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. <u>Title to Subject Inventions</u>

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. <u>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.</u>

F. <u>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</u> for research and development purposes<u>. The Parties agree to execute a Confirmatory License to affirm the Government's retained license.</u>

Article XVI. <u>Filing Patent Applications</u>

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. <u>Trademarks</u>

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. 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 XXIV. 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 XXV. 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 XXVI. 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 XXVII. 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 XXVIII. 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 XXIX. 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 XXX. 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 XXXI. 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: ____

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

The 21st Century Energy Systems Project

[To be inserted – pending approval of projects]

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.

<u>LLNS</u>:

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

[To be inserted– pending approval of projects]

<u>PG&E</u>:

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

[To be inserted– pending approval of projects]

<u>SCE</u>:

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

[To be inserted– pending approval of projects]

<u>SDG&E</u>:

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
Bear Valley Electric Service
Braun Blaising McLaughlin, P.C.
California Cotton Ginners & Growers Assn
California Energy Commission
California Public Utilities Commission
Calpine
Casner, Steve
Cenergy Power
Center for Biological Diversity
City of Palo Alto
City of San Jose
Clean Power
Coast Economic Consulting
Commercial Energy
Consumer Federation of California
Crossborder Energy
Davis Wright Tremaine LLP
Day Carter Murphy
Defense Energy Support Center
Dept of General Services
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.
Kelly Group
Lawrence Berkeley National Lab
Linde
Los Angeles Dept of Water & Power
MAC Lighting Consulting
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
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)