Next Generation Renewables and, Separately, Energy System Transformation, and Related Topics

Cooperative Research and Development Final Report

CRADA Number: CRD-14-557

NREL Technical Contacts: Doug Arent and Jill Engel-Cox

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-6A50-76744
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Report Date: 4/15/2020

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the final CRADA report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: General Electric Company

CRADA Number: CRD-14-00557

CRADA Title:

Original: Conduct analytic research and publish short research reports on Next Generation Renewables and, separately, Energy System Transformation
Modification #1: Conduct analytic research and publish short research reports on Next Generation Renewables and support data collection and basic analysis on several identified challenges
Modification #2: No change; this modification was a no-cost time extension.
Modification #3: A white paper for internal GE use on "Energy Storage and Solar Energy"
Modification #4: A market analysis and white paper for internal GE use on Hybrid Solutions - Global Market Potential.
Modification #5: Research and Analysis on Topics Related to Power Reform
Modification #6: No change; this modification was a no-cost time extension.
Modification #7: Research and Analysis on Topics Related to Energy Systems Integration (ESI).

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1, Original Agreement	$.00
Year 2, Modification #1	$.00
Year 2, Modification #2	$.00
Year 3, Modification #3	$.00
Year 4, Modification #4	$.00
Year 4, Modification #5	$.00
Year 4, Modification #6/7	$.00
TOTALS	$.00

Abstract of CRADA Work:

Original Agreement: The Joint Institute for Strategic Energy Analysis (JISEA, an institute within NREL) will support the design, development, delivery and dissemination of two (2) informational whitepapers, identified as Task 1 and Task 2, respectively: *Next Generation Renewables* and *Energy Systems Integration*.

Modification #1: Replacement of Task 2 of the Original Agreement: JISEA will research and author one high level paper describing recent history and trends, and future prospects for renewable electricity technologies (the same as Task 1 of the Original Agreement); and support data collection and basic analysis for quantifying the potential environmental impact and commercial opportunity of solving several challenges (replacement for Task 2 of the Original Agreement).

Modification #2: This was a no-cost time extension with no other changes.

Modification #3: Additional Task: The Joint Institute for Strategic Energy Analysis (JISEA) will support the design, development, delivery and dissemination of one informational whitepaper for internal GE use on "Energy Storage and Solar Energy".

Modification #4: Additional Task: The Joint Institute for Strategic Energy Analysis (JISEA) will support the design, development, delivery and dissemination of one informational white paper for internal GE use on ""Hybrid Solutions - Global Market Potential."

Modification #5: Additional Task: The Joint Institute for Strategic Energy Analysis (JISEA) will support the design, development, delivery and dissemination of a paper on the topic of "Transformational Innovations for Power Reform." (Note: this was replaced by Modification #7).

Modification #6: This was a no-cost time extension with no other changes.

Modification #7: Replacement of the Additional Task of Modification #5: The Joint Institute for Strategic Energy Analysis (JISEA) and the Energy Systems Integration Group (ESIG) will support the design, development, delivery and dissemination of a paper on the topic of "Energy Systems Integration." (replacement of the paper that was to be delivered under Modification #5).

Summary of Research Results:

The purpose of this section is to capture the original or modified scope, completed work and outcomes of this project. DOE requires that this template address all the planned tasks in the Joint Work Statement.

Original Agreement: Task 1:
JISEA researched and provided analysis to evaluate wind, solar, and hybrid systems and related innovations to identify opportunities for new developments in next generation renewables. This resulted in delivery of a whitepaper to the client that was published as an NREL Technical Report NREL/TP-6A50-63604: Renewable Electricity: Insights for the Coming Decade.[1] No

[1] Camila Stark, Jacquelyn Pless, Jeffrey Logan, Ella Zhou, and Douglas J. Arent, "Renewable Electricity: Insights for the Coming Decade," Joint Institute for Strategic Energy Analysis, Technical Report 63604 (2015), NREL/TP-6A50-63604, https://www.nrel.gov/docs/fy15osti/63604.pdf.

new data were collected for this project. Research consisted of a review of publicly available literature, as noted in the reference section of the paper.

Summary of Findings: Task 1:
With the reductions in costs and RE innovations that have occurred over the past decade, RE is better positioned than at any time in history to provide increased value to customers, utilities and system operators, and contribute to the new wave of electricity systems solutions. From the paper, figure ES-1 shows the unsubsidized LCOEs for wind, centralized utility-scale solar PV, natural gas combined-cycle, and coal in the United States, Germany, and China for the year 2014, and projections for 2025 based on 2014 estimates of changing costs.

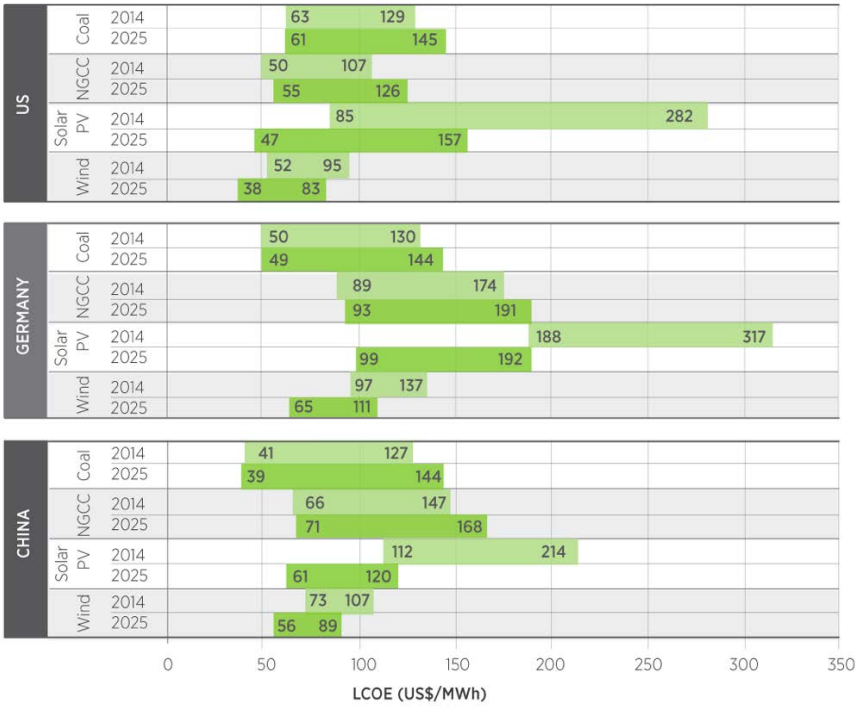


Figure ES-1: Unsubsidized LCOE ranges (2014$) calculated for the United States, Germany, and China in 2014 and 2025

Over the next few decades, RE options are anticipated to continue expanding owing to the many benefits they provide, including: low water intensity, use of valuable and abundant domestic resources, and contribution to local, regional, and national policy goals.

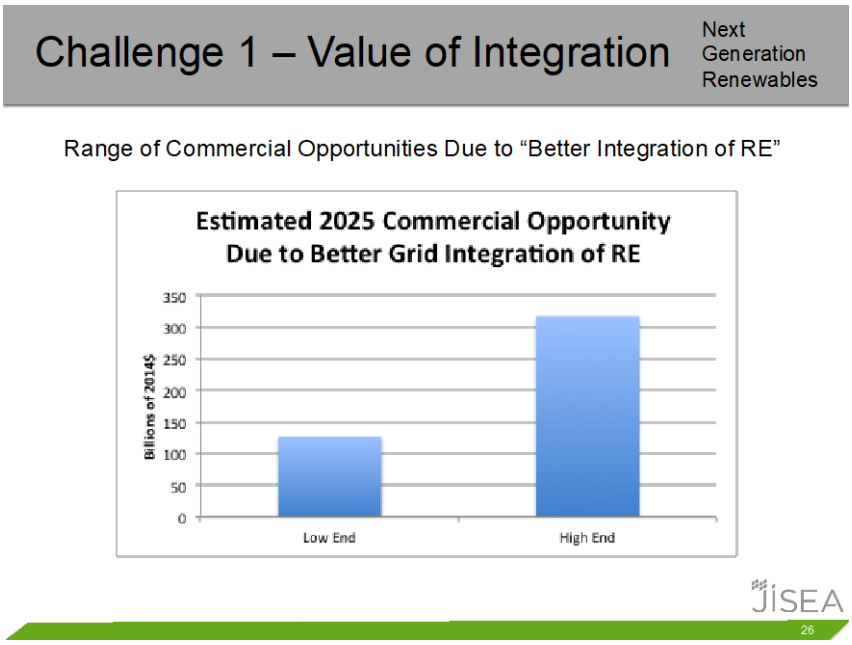
Task 2:
After delivery of Task 1, the client requested we eliminate this task and instead focus on deeper analysis of some of the challenges identified in Task 1. See Modification #1, Task 2.

Modification #1:
Task 1: Same as Original Agreement

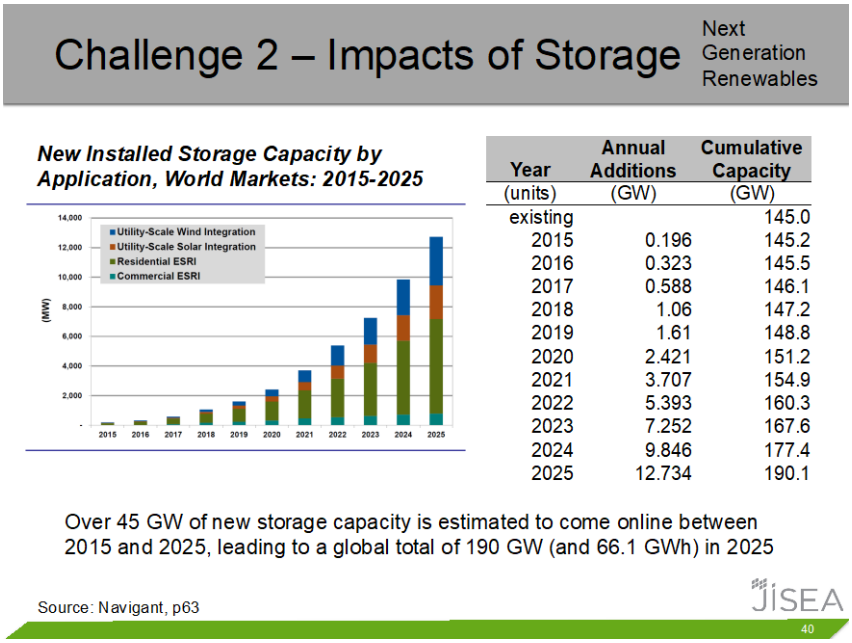
Task 2: Replaced Task 2 of the Original Agreement. JISEA supported data collection and basic analysis for quantifying the potential environmental impact and commercial opportunity of solving several challenges with respect to new developments in renewable energy technologies.

No new data were collected for this project. Work consisted of review of literature and publicly available databases, to include basic analysis and no complex modeling. This task was delivered as a PowerPoint presentation (Please refer to "Next Generation Renewables/Ecoimagination" as an external supplemental document A) to the client.

Summary of Findings:
The analysis identified two challenges where the client's core business capabilities might have positive impact on advancing renewable energy deployment: Grid Integration and Energy Storage.



Slide 26 from the presentation.



Slide 40 from the presentation

Modification #2:
Not applicable; this modification was a no-cost time extension.

Modification #3:
JISEA supported the design, development, delivery and dissemination of one informational whitepaper for internal GE use on energy storage and solar energy. This resulted in the publication of a paper in The Electricity Journal: Power couples: The synergy value of battery-generator hybrids.[2] No new data were collected for this project. Research consisted of a review of publicly available literature, as noted in the reference section of the paper.

Summary of Findings:
The market for battery storage is still small and the market for battery hybrids is even more nascent. However, falling battery and balance-of-system costs are making the economics of battery storage increasingly compelling. Battery-generator hybrids can complement each other to provide services more efficiently than a battery or generator alone could. The benefits of hybridization may speed the growth of battery installations, with battery hybrids becoming increasingly larger proportion of total battery projects.

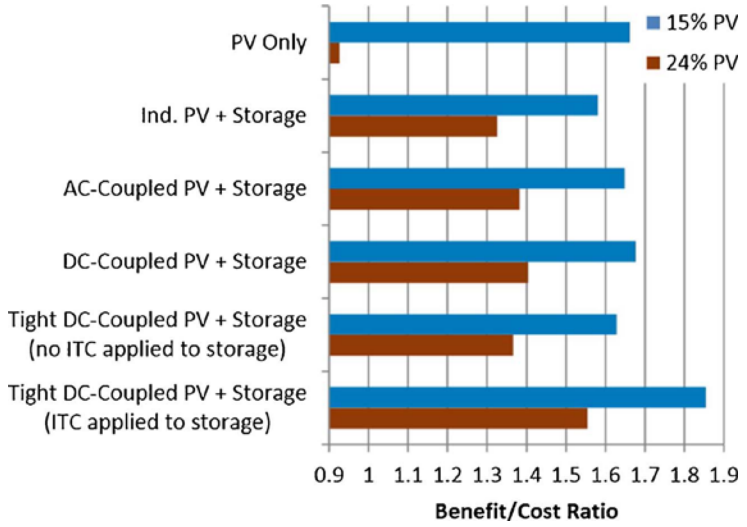


Fig. 1. Benefits to cost ratio of solar and solar-storage hybrids at varying levels of solar penetration.

Modification #4:
JISEA supported the design, development, delivery and dissemination of an informational white paper for internal GE use on the global market potential of hybrid storage solutions. This resulted in the publication of an NREL Technical Report NREL/MP-6A50-70237: Hybrid Storage Market Assessment[3]. No new data were collected for this project. Research consisted of a review of publicly available literature, as noted in the reference section of the paper.

[2] Sean Ericson, Kate Anderson, Jill Engel-Cox,Harshit Jayaswal, Doug Arent, "Power couples: The Synergy value of battery-generator hybrids," *The Electricity Journal* 31, no. 1, (January–February 2018): 51-56, https://doi.org/10.1016/j.tej.2017.12.003.
[3] Sean Ericson, Eric Rose, Harshit Jayaswal, Wesley Cole, Jill Engel-Cox, Jeffery Logan, Joyce McLaren, Kate Anderson, and Doug Arent, "Hybrid Storage Market Assessment," Joint Institute for Strategic Energy Analysis, Technical Report 70237 (2017), NREL/MP-6A50-70237, https://www.nrel.gov/docs/fy18osti/70237.pdf.

Summary of Findings:
The market potential for battery storage and battery hybrid storage varies by application and geographic location. Capacity markets provide the largest potential market application for utility-scale battery storage, while the primary applications for distributed storage are to reduce consumer demand charges and enable greater resiliency and emergency power. California is the most attractive geographic market for U.S. battery storage because of its storage mandates, high renewable penetration, and regulatory framework conducive to battery storage projects. Isolated grids and remote locations such as island locations offer significant opportunities for battery hybrids due to increasing penetration of renewable generators that reduce high fuel costs for thermal generating plants.

Table 4. Estimated Market Size

	U.S. Market Potential (MW of capacity)[a]			World Market Potential (MW of capacity)		
Primary Application	Market Upper Bound[b]	Market Estimate[c]	Hybrid Estimate[d]	Market Upper Bound	Market Estimate	Hybrid Estimate
Capacity	18,000	9,000	4,500	112,000	40,000	20,000
Frequency Regulation	2,000	600	0	12,000	3,000	0
Spinning Reserves	6,000	400	400	37,000	2,500	2,500
Transmission Deferral	10,000	2,000	1,000	62,000	12,000	6,000
Demand Charge Reductions	32,000	8,000	5,000	200,000	30,000	20,000
Resilience and Reliability	9,200	1,300	1,000	57,000	8,000	6,000
Decreased Diesel Generation[e]	-	-	-	50,000	15,000	15,000
Total	77,200	21,300	11,900	530,000	110,500	69,500

[a] Measured in cumulative capacity additions.
[b] U.S. Market Upper Bound Estimates from Sandia National Laboratory (44).
[c] Market Estimates from (3), (46), (47), (48), (49) and communication with industry experts.
[d] Hybrid numbers for battery capacity in hybrid.
[e] Estimates from (46).

Modification #5:
In consultation with the client, this deliverable was replaced with a different paper. See Modification #7.

Modification #6:
Not applicable; this modification was a no-cost time extension.

Modification #7:
JISEA researched and provided analysis on the integration of renewable energy into the existing power grid, with a focus on the ability of industry to absorb low-cost, dispatch-constrained electricity to avoid electricity curtailment. Research focused on four industrial processes: chlor-alkali, electric arc furnaces, methane pyrolysis, and atmospheric CO2 capture. No new data were

collected for this project. Research consisted of a review of publicly available literature, as well as analysis to analyze the willingness of the above mentioned industrial facilities to participate in a negative control energy environment.

Summary of Findings:
The ability for industry to flexibly consume electricity poses an enticing opportunity to provide grid flexibility. Findings showed that, particularly for those industries already well-established (chlor-alkali and electric arc furnaces), industry's ability to absorb excess electricity generation is limited. In order to do so, industrial facilities would need to withhold operating assets until such time as their demand was needed to increase. This of course is highly costly. Our analysis showed that for chlor-alkali and electric arc, the electricity price at which these industries would choose not to run (from a purely profit-driven analysis, is $216.59 and $186.18/MWh, respectively. In other words, unless electricity prices are above said values, these industries could run their facilities profitably. These values are based on averages of historical market prices for the respective products. In our analysis, electricity prices are not projected to hover these values for many hours of the year, into the year 2050.

We then analyze two nascent industries with significant potential for future growth, and therefore energy demand: methane pyrolysis and atmospheric CO_2 capture. Again, under published capital expenditure for these industries, they would attempt to operate at most hours of the modeled future year. However, particular innovations, both market and technological, could alter this paradigm. For methane pyrolysis, R&D efforts are underway to directly convert methane to carbon fiber plus hydrogen gas. Should these efforts bear fruit, we find that methane pyrolysis facilities could be so profitable that they choose to only produce during those hours of the year for which electricity reach a price floor. This would allow these facilities to become price setters in both the hydrogen and carbon fiber markets, undercutting and driving competition out of business. Similarly in CO_2 capture, the largest energy-consuming step involves the heating of the material that absorbs the CO2 from the atmosphere, in order to release the CO2 stream and regenerate the absorber. Technological innovations are being explored, for instance using metal organic frameworks, to greatly reduce the energy of this step. Should this research be productive, CO2 capture facilities could take a similar tack to that described above to methane pyrolysis, and profitably produce CO2 at price levels below the projected market rate of many carbon markets.

The researchers intend to publish more detail on the process and analysis as an article titled *Industrial Use of Curtailed Electricity: Current Paradigm and Future Needs* in an academic or industry journal. At the time this CRADA report was released, the researchers have submitted the proposed article to a couple of journals. In the event a journal does not accept the article, the researchers may publish the article as a NREL publication.

Subject Inventions Listing:

None

ROI #:

None

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Office of Energy Efficiency and Renewable Energy (EERE)