Pacific Gas and Electric Company

EPIC Final Report

Program	***Electric Program Investment Charge (EPIC)***
Project	***EPIC 3.41 – Drone Enablement and Operational Use***
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Table of Acronyms

API	Application Programming Interface
AWS	Amazon Web Services
BVLOS	Beyond Visual Line of Sight
C2	Command and Control
CA	California
CEC	Cellular Carrier
ConOps	Concept of Operations
CPUC	California Public Utilities Commission
DAA	Detect and Avoid
DRO	Dock Remote Operations
EPIC	Electric Program Investment Charge
5G	5 Gigahertz
FAA	Federal Aviation Administration
GHG	Greenhouse Gases
GIS	Geographic Information System
IOU	Investor-Owned Utility
IQA	Information Quality Act or Internal Quality Assurance
IQA/DQA	Information Quality Act/Data Quality Act
IR	Infrared
KML	Keyhole Markup Language
LOS	Line of Sight
LiDAR	Light Detection and Ranging
LTE	Long-Term Evolution
MMTCO2e	Million Metric Tons of Carbon Dioxide Equivalent
MP	Megapixels
MW	Mega Watt
PG&E	Pacific Gas & Electric
PSPS	Public Safety Power Shutoff
RFP	Request for Proposal

RPIC	Remote Pilot in Command
RTH	Return to Home
SOW	Statement of Work
SCE	Southern California Edison
SD	Secure Digital
SDG&E	San Diego Gas & Electric
SME	Subject Matter Expert
sUAS	Small Unmanned Aircraft System
3D	Three Dimensional
TD&D	Technology Demonstration and Deployment
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
VLOS	Visual Line of Sight
VO	Visual Observer
VPS	Vision Positioning System

1 Executive Summary

This report summarizes the project objectives, technical results and lessons learned for EPIC Project EPIC 3.41 – Drone Enablement and Operational Use (Drone Enablement), as listed in the EPIC Annual Report. The project was authorized in April 2022 and concluded in May 2025.

The objective of this project was to demonstrate automated and Beyond Visual Line of Site (BVLOS) drone operations drone docks for select PG&E operational use cases. As part of the project, the docks and drones were deployed throughout Pacific Gas and Electric Company's (PG&E) service area. The docks served as housing units for the drones and provided charging and communications capabilities. The project was conducted with two drone system vendors and aimed to improve current processes of manual flight inspections of electric assets with the goal of improving safety and efficiency. The equipment and systems used to evaluate the automated and BVLOS capabilities showed that the concept is very promising but that some incremental improvements need to be made to the industry's current offerings to fully unlock the potential of advanced dock-based drone operations for utility use cases.

To evaluate the project's objectives of successfully conducting automated and BVLOS patrols and electrical asset inspections safely through a remote dock system, a few methods were deployed. The methods deployed involved manually flying the mission to perform the inspections, building automated missions and running them frequently to evaluate the repeatability and reliability of the automated missions. The data was handed to PG&E's internal team and quality was compared to current means of collections. This was measured through testing performance and mission types.

This project was motivated by the desire to find safe, cost effective, and reliable means of conducting both routine inspections of assets and ad hoc investigations while experiencing significantly reduced response times. This project evaluated the hypothesis that using small unmanned systems that are already on site and on standby to be flown remotely is more efficient conventional methods of either manual drone inspections, truck rolls or other conventional aviation operations.

Key Objectives

To help address these barriers, EPIC 3.41 established the following objectives:

- Assess multiple existing vendor systems
- Develop a Beyond Visual Line of Site (BVLOS) waiver for submission to the FAA for Approval
- Evaluate the UAS capabilities to fly BVLOS remotely from a control room to inspect PG&E Transmission lines and Substation assets
- Evaluate the UAS capabilities to fly BVLOS remotely from a control room to inspect PG&E Distribution assets
- Develop PG&E's internal functioning capabilities for managing drone operations as part of Aviation Services
- Continue to obtain more operational flexibility through FAA waivers

Key Accomplishments

The following summarizes some of the key accomplishments of the project over the project's duration:

- Conducted rigorous industry landscaping and benchmarking with other utilities which culminated in an RFP process and the selection of two drone vendor partners (referred to as Vendors A & B throughout) with distinctly different solution offerings
- Obtained a waiver award from the FAA to fly BVLOS using the dock systems as per the proposed Concept of Operations (ConOps). This represented the most advanced and flexible FAA waiver obtained by PG&E at the time of the project.
- Staffed the control room with full-time personnel to fly dock systems
- Explored and tested use cases across various functional areas
- Objectively evaluated both drone system vendors' system offerings
- Materially contributed to the maturation of one vendor's system offering to the benefit of both PG&E and the broader utility industry for a range of use cases
- Developed internal PG&E processes and procedures for remotely operated UAS

Key Takeaways

The following are the key challenges faced by demonstrating each of the vendor partners' solutions:

- Vendor A – Incumbent vendor with conventional approach to BVLOS operations, and well-established supplemental capabilities for a proven, comprehensive industrial solution offering.
- Challenges,
    - **Sensor Quality Issues:** The sensor's low megapixel count is insufficient for PG&E's current means of inspections. The video data detail and quality are not acceptable when taken at a distance from the inspected assets that PG&E deems safe.
    - **Cumbersome flight controls:** The UAS was not as responsive as current UAS models used by PG&E.
    - **Limited battery life:** The battery did not operate nor charge as the vendor's advertised specifications.
    - **No collision avoidance systems:** The lack of an onboard, automated collision avoidance system dictated an operational concept with inherent limitations and required maintaining a distance from assets that exacerbated sensor quality limitations.
    - **Extensive system installation process:** The size and power requirements of the system made installation highly cumbersome. Multiple groups had to work together to deliver, install, and run power to the system before operation.
- Vendor B – Newer vendor with promising but nascent core platform and approach to BVLOS operations, and initially limited supplemental capabilities for a comprehensive industrial solution offering.
- Challenges,
    - **Sensor Quality Issues:** The sensor's low megapixel count did not meet PG&E's current means of inspection.
    - **Limited C2 Connectivity:** The range from which the UAS could venture from the docking system was limited due to not having LTE integration at the time.
    - **Limited Battery Life:** The battery did not operate nor charge up to the vendor's advertised specifications.

- **Hardware Limitations:** The system had design flaws causing continuous damage to the UAS' propellors requiring repairs and created obstacles for the operations team.
- **Software Bugs**: Numerous software bugs initially plagued the UAS system, due to its infancy.

Although faced with these myriads of challenges, the project team was able to improvise, adapt, and overcome the challenges while providing feedback to the vendors on their solutions for future product improvements. Midway through the project, it became clear that Vendor B's offering held more long-term potential to provide value across PG&E's use cases, and the demonstration with Vendor A was concluded early. The project team fulfilled its goals of demonstrating the ability to fly BVLOS safely using automated missions while collecting actionable data. More specifically, the project validated the viability of an "infrastructure masking" approach in which drones with advanced control systems fly close to PG&E assets to ensure separation from other aerial systems within the same airspace. Camera quality issues with Vendor B were managed by flying closer to the assets, and range issues were overcome where possible by creating mission paths that maintained better line of sight with the dock. In the case of Vendor B in particular, collaboration resulted in material iterative improvements to their solution offering within the course of this project itself and informed their longer-term capability roadmap.

Recommendations

The demonstration highlighted the following capability improvements which would be beneficial to unlocking even greater value for PG&E operations across a range of use cases:

- **Range Extenders** to enable communications over a greater distance between the UAS and the Docking System.
- **Ability for a drone to "hop docks"** by taking off from one dock and landing at a different dock, from one substation to another
- **Improved Reliability** of the overall system software and hardware to enable less downtime and a more seamless operating experience
- **Improved UAS Batteries** to enable longer flight times, faster charging time, and improved environmental resiliency.
- **Improved Payload/Sensor (Camera)** with higher resolution, better focus capabilities, swappable payloads, and radiometric IR.
- **Interfaces** to seamlessly feed the coordinates from alerts generated by various PG&E grid monitoring sensors into the drone system as the basis for seamless mission planning and execution

Conclusion

Through the EPIC 3.41 – Drone Enablement project, PG&E conducted a rigorous demonstration of two vendors' drone systems to assess the readiness and value of automated and BVLOS flight operations for multiple PG&E use cases. One of the vendor partners' solutions demonstrated significant promise, and PG&E collaborated closely with them to iteratively iron out numerous issues with their system over the course of the demonstration, and provided valuable feedback for their product roadmap, to the direct benefit of PG&E as well as the broader utility industry. During the project, PG&E's Aviation

Services organization significantly increased its maturity around managing the company's drone operations. PG&E also successfully obtained a FAA BVLOS waiver to conduct operations leveraging the capabilities demonstrated in this project, and this marked the most advanced waiver PG&E had been granted to date at the time of the project. PG&E aims to continue more advanced demonstrations through its EPIC 4 program based on the learnings and recommended future improvements from this project, to position PG&E to unlock significant operational value by utilizing drones across a wide range of use cases.

2 Introduction

This report documents the EPIC 3.41 project achievements, highlights key learnings from the project that have industry-wide value, and identifies future opportunities for PG&E to leverage this project.

The California Public Utilities Commission (CPUC) passed two decisions that established the basis for this demonstration program. The CPUC initially issued D. 11-12-035, *Decision Establishing Interim Research, Development and Demonstrations and Renewables Program Funding Level*[1], which established the Electric Program Investment Charge (EPIC) on December 15, 2011. Subsequently, on May 24, 2012, the CPUC issued D. 12-05-037, *Phase 2 Decision Establishing Purposes and Governance for Electric Program Investment Charge and Establishing Funding Collections for 2013-2020*[2], which authorized funding in the areas of applied research and development, technology demonstration and deployment (TD&D), and market facilitation. In this later decision, CPUC defined TD&D as "the installation and operation of pre-commercial technologies or strategies at a scale sufficiently large and in conditions sufficiently reflective of anticipated actual operating environments to enable appraisal of the operational and performance characteristics and the financial risks associated with a given technology."[3]

The decision also required the EPIC Program Administrators12 to submit Triennial Investment Plans to cover three-year funding cycles for 2012-2014, 2015-2017, and 2018-2020. On November 1, 2012, on A.12-11-003, PG&E filed its first triennial Electric Program Investment Charge (EPIC) Application with the CPUC, requesting $49,328,000 including funding for 26 Technology Demonstration and Deployment Projects. On November 14, 2013, on D.13-11-025, the CPUC approved PG&E's EPIC plan, including $49,328,000 for this program category. On May 1, 2014, PG&E filed its second triennial investment plan for the period of 2015-2017 in the EPIC 2 Application (A.14-05-003). CPUC approved this plan on D.15-04-020 on April 15, 2015, including $51,080,200 for 31 TD&D projects.13 On April 28, 2017, in A.17-04-028, PG&E filed its third triennial EPIC Application at the CPUC, requesting authorization for its for 43 Technology Demonstration and Deployment Projects. CPUC approved this plan through D.18-10-052 on October 25, 2018, and D.20-02-003 on February 10, 2020, and authorized $49,771,845 for the 43 TD&D projects.

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[1] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/156050.PDF
[2] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/167664.PDF
[3] Decision 12-05-037 pg. 37

Pursuant to PG&Es approved 2018-2020 EPIC triennial plan, PG&E initiated, planned and implemented EPIC 3.41 – Drone Enablement. Through the annual reporting process, PG&E kept CPUC staff and stakeholders informed on the progress of the project. The following is PG&E's final report on this project.

3 Project Summary

This project intended to apply the concept of remotely and autonomously operating UAS beyond visual line of sight (BVLOS) for detailed asset health inspections and ad hoc investigation of issues. The project team performed market research and selected two vendors that manufactured Remote UAS systems as partners for the project's demonstrations. The project intended to validate a pathway for integration of automated and BVLOS drone operations with PG&E's rapidly expanding networks of predictive grid sensors, to inspect and validate the alerts generated through those sensor networks as a more efficient and effective alternative to conventional methods of investigation. The selection of two UAS system vendor partners was informed by extensive market research and a rigorous Request for Proposals (RFP) process.

In recent years, PG&E has been exploring and progressively deploying sensor and system solutions that would make distribution and transmission monitoring and inspections safer, cheaper, and more reliable. Current methods of conducting these inspections include truck rolls, manual drone operations within Line of Sight (LOS) and helicopter operations. Though effective, these methods have shortcomings that can be addressed by rapidly maturing drone solution offerings. Shortcomings include comparatively slower response times, data quality issues related to manual flights which are dependent on pilot experience, long commutes to conduct flights and higher operational costs. This project was designed to explore options that address these shortcomings to improve current inspection and ad hoc investigation methods.

Although PG&E has utilized UAS for the purposes of conducting comprehensive visual inspections, these inspections are flown manually within visual line of sight by a pilot who may or may not have advanced flying and sensor control skills. Manual drone flights carry inherent risks such as pilot error, potential safety impacts, and poor data quality. Manual drone flight operations for conducting these visual inspections are also typically limited to one lattice tower per flight due to reaction time limitations that are unavoidable in manual flight.

The technological advancements of drone technology over the years have tremendously improved the safety and reliability of these aircraft such that the FAA has begun issuing more waivers to companies and operators approving the implementation of advanced drone use for commercial operations. In turn, vendors have begun developing more integrated and robust solutions that meet their clients' needs for new use cases that have been unlocked through the waivers.

The key deliverables for the project were the creation of the Concept of Operations (ConOps) for the project and Federal Aviation Administration (FAA) waiver acquisition, delivery of the UAS systems, development of the processes and procedures for the daily operations, and the testing of use cases across multiple PG&E functional areas.

3.1 Issue Addressed

To have a more reliable grid and to help maintain the electric infrastructure and prevent catastrophic wildfires for our customers and hometowns, PG&E has begun using more advanced Unmanned Aerial System (UAS) operations to assist with inspections. With the UAS industry moving towards Remote Autonomous UAS and the FAA allowing for Beyond Visual Line of Site operations, PG&E chose to explore the possibilities enabled by these trends through the demonstrations conducted in this project. Automated and BVLOS drone operations have the potential to unlock extensive safety and efficiency value across a range of use cases, as compared to conventional methods of employing truck rolls, helicopter operations or manual drone operations.

3.2 Project Objectives

The following were the key objectives of the EPIC 3.41 project:

- Assess multiple existing vendor systems.
    - Measure Unmanned Ariel System (UAS)'s
        - Range
        - Endurance
        - Battery charging times
    - Evaluate flight planning, modes, and commands
    - Demonstrate
        - Fail safe behaviors
        - Any special capabilities
    - Docking System
        - Evaluate the ability to extend communications range between drone and docking station.
        - Acquisition and comparison of these systems from separate vendors to decide which vendor would provide a system that meet PG&E's needs through a series of tests and evaluations to determine capabilities.

- Develop a Beyond Visual Line of Site (BVLOS) waiver for submission to the FAA for approval.
    - Development of the Concept of Operations and submission to the FAA is integral to acquiring the BVLOS waiver to fly drones remotely from a control room to perform UAS inspections on PG&E Transmission and Distribution line, plus Substation assets.

- Evaluate the UAS capabilities to fly BVLOS remotely from a control room to inspect PG&E Transmission line and Substation assets.
    - Manual drone flight operations inherently carry a risk of pilot error creating potential safety risks as well as poor data quality of the visuals of potential hazards taken by the drone cameras. Flight operations for asset inspections are typically limited to a few spans at a time due to the VLOS restrictions and pilot proficiency, which impacts the speed of the inspections performed. This makes for a less productive and efficient inspection process compared to an automated BVLOS drone flight operation.

- Evaluate the UAS capabilities to fly BVLOS remotely from a control room to inspect PG&E Distribution line assets.

- PG&E needs a safe, fast, and effective solution for alert validation. The manual mode of operations for responding to hazards detected by sensors deployed in the distribution network require a deployment of a truck, helicopter, or a UAV along with the required personnel. Replacing this mode of operations with an automated BVLOS drone flight operations is more cost effective and improves safety for our workforce because their required presence in the field will be reduced. In addition, response times for PSPS will be faster because there will be no VLOS restrictions to contend with.

- Develop PG&E's internal functioning capabilities for managing drone operations as part of Aviation Services.
    - Ongoing training and development of process and procedures to develop BVLOS drone flight operations will ensure that drone flight operations remain healthy, effective, and proactive in identifying issues on PG&E's Transmission, Distribution, and Substation assets and initiating corrective action to eliminate or mitigate the issues.
- Continue to obtain more operational flexibility through FAA waivers.

3.3 Scope of Work and Project Tasks

The project's scope of work was focused on addressing two primary opportunities and associated hypotheses:

- Transmission Line & Substation Inspections:
    - **Opportunity**: Although PG&E has integrated and deployed drone operations into its inspection processes, drone flights are still manually conducted by pilots and performed within Visual Line of Sight (VLOS). Manual drone flight operations have inherent risks of pilot error and potential safety hazards. Additionally, there is a risk of poor data quality and data capture impacts the overall effectiveness of the Aerial Inspections Program. Manual drone flight operations for conducting inspections are also limited to one tower per flight, making this method of inspecting time and resource intensive.
    - **Hypothesis**: Automated flights using Beyond Visual Line of Sight (BVLOS) drone flight rules can offer a more accurate, safer, and more efficient alternative to transmission line & substation asset inspections compared to today's manual flight drone operations.

- Distribution Alert Verification:
    - **Opportunity**: PG&E has been in the process of demonstrating and evaluating several different sensors on the distribution system for monitoring asset health and risk. The company will roll out a subset of these solutions broadly across the system over the next 3-5 years. PG&E needs a safe, fast, and effective solution for field-validating a range of alerts and warnings that will be produced through these various solutions. Current processes of field patrolling hazards detected by sensors require mobilization of a truck or helicopter and associated personnel making it inefficient and costly.
    - **Hypothesis**: Automated BVLOS drone operations can provide a fast, safe and effective alternative for field-validating alerts and warnings that will be produced through predictive sensors that are planned to be installed across the distribution system.

The **project's scope of work** is detailed below:

1. Create and develop RFP package for drone solution provider vendor contracts: Involves developing the Statement of Work (SOW), questionnaires, scorecard rubrics and compiling a list of invitees.
2. Execute contract with drone technology vendors & Federal Aviation Administration (FAA) regulatory consultant for compliance.
3. Conduct RFP, score and select drone vendors moving forward, and execute contracts per the terms outlined.
4. Demonstrate automated drone flight plan generation capabilities leveraging existing remote sensing payloads and data (LiDAR, imagery, etc.) as well as GIS data
5. Select sites for each use case.
    - Transmission Line Inspection Use Case: Inspect via video/photo 3-5 towers on one segment of transmission line
    - Substation Inspection Use Case: one substation inspection run
    - Distribution Alert Verification Use Case: Patrol 1-2 feeders with existing deployment of various field sensor solutions
6. Conduct evaluation of vendor capabilities which include remote drone dock housing/charging and drone sense & avoid capabilities.
7. Develop a sound concept of operations (ConOps) by defining detailed technology setups and operational procedures for all sites and use cases and develop/submit associated FAA Part 107 application for a waiver for BVLOS operations approval.
8. Demonstrate execution of automated flight plan using VLOS operations (not contingent on FAA BVLOS waiver approval). In this phase, for each use case listed below, a series of compared and contrasted test cases ran in parallel, will be conducted in which the operation is manually flown by the drone pilot, and then flown by the drone system autonomously with pilot supervision. Pilot training will be conducted before this phase begins. This phase pertains to all use cases as follows:
    - Transmission Inspection
    - Substation Inspection
    - Distribution Alert Verification
9. Demonstrate autonomous flight plan executions using BVLOS operations (contingent on FAA BVLOS waiver approval). This phase pertains only to the Transmission Inspection and Distribution Alert Verification use cases.
    - Transmission Inspection
        - Leverage autonomous flight technology developed and vetted within VLOS operations from step 4 above to expand operation to BVLOS utilizing a Visual Observer (VO) onsite. Where the previous phase inspected one tower at a time per operation, which assesses how many towers can be comprehensively inspected sequentially before drone battery exhaustion.
        - Once operations with a VO is successfully tested, we can expand our testing to flights that utilize radar technology to reduce ground and air risks.
    - Distribution Alert Verification
        - Develop an interface to allow for alerts and corresponding issue locations generated from the field sensor networks to be ingested by the drone system's flight plan generation capability
        - Demonstrate an end-to-end process for generating alerts through field sensor networks, having PG&E analysts review and decide which alerts are a go for drone

investigation, passing the alert to the drone flight plan generator, and execution of a fully autonomous drone flight to inspect and validate the alert.

- Demonstrate compliance to requirements and define risk mitigations associated with operating over densely populated areas.
- Demonstrate integration of remote drone housing via docks and charging capabilities

10. Develop a final report of use cases, system setup along with its relevant procedures, and associated test case results.
11. Develop a detailed path to production as the project scales for broader post-EPIC project deployment.

3.3.1 Tasks and Milestones

Task #1: Demonstration #1 - Evaluate vendors' basic UAS and docking capabilities.

Evaluate the remote drone housing/charging and drone detect and avoid capabilities.

Task #2: Develop an Advanced UAS Testing Plan.

Define the technology setup and operational procedures for all test sites and use cases for the FAA Part 107 BVLOS waiver application tender.

Task #3: Demonstration #2 - Automated flight plan execution within VLOS not requiring an approved FAA BVLOS waiver.

Task #4: Demonstration #3 - BVLOS automated flight plan to inspect PG&E Transmission and Substation assets, plus verification of Distribution Alert use cases.

PG&E will leverage automated drone flight plan technology developed and vetted within demonstration #2 using VLOS rules for demonstrating the transmission inspections. Where the previous phase will inspect one tower at a time per operation, this phase will assess how many towers can be inspected sequentially before drone battery life becomes a limiting factor.

Once operations with VOs is successfully tested, PG&E will expand its testing to flights utilizing detect and avoid (DAA) technology to mitigate ground and air risks.

Task #5: Develop a Distribution Alert Verification interface between the UAS and the field sensors.

Demonstrate end-to-end process for generating alert through field sensor network, having AH&PC analyst review and decide which to approve for drone investigation, passing to the drone flight plan generation capability, and executing automated drone operation to inspect and validate the alert.

Demonstrate adherence to requirements and defined risk mitigations associated with operating over more densely populated areas.

Demonstrate integration of remote drone housing/charging capability.

The **goal of the program** was to address gaps associated with current inspection methods used in drone technology particularly with Transmission, Substation, Distribution, and PSPS/Emergency response. Milestones were set with each vendor to execute the project as follows:

Vendor A: Incumbent vendor with conventional approach to BVLOS operations, and well-established supplemental capabilities for a proven, comprehensive industrial solution offering.

Milestone #1: Delivery of the docks
Milestone #2: System Evaluation
Milestone #3: Part 107 Waiver Application
Milestone #4: Report & Proposal

Vendor B: Newer vendor with nascent core platform and approach to BVLOS operations, and initially limited supplemental capabilities for a comprehensive industrial solution offering.

Milestone 1: Delivery of the docks
Milestone 2A: Evaluate the basic performance and capabilities of the Dock and Remote Operations (DRO) system
Milestone 2B: Evaluate the system's ability to execute the use cases that PG&E outlined in the SOW
Milestone 2C: Evaluate the system's ability to conduct automated t-line structure inspections and distribution and alert verification flights
Milestone 3: Creation of the final report.

4 Project Activities, Results, and Findings

PG&E developed a scope of work to determine if BVLOS remote autonomous drone flights were operationally and regulatorily viable with the appropriate governing bodies. After performing market research, PG&E selected two vendors, Vendor A and Vendor B, who were developing solutions for remote autonomous drone flights to evaluate their-based dock systems for viability.

The testing and evaluation were set up into multiple demonstrations broken into sections, and a scorecard was created to objectively assess the operational functionality of each vendor's system.

The following showcases the activities, results, and findings of the project.

4.1 Task #1: Demonstration #1, Evaluate the vendors' basic UAS and docking capabilities.

4.1.1 Technical Developments and Methods

Each of the vendors were expected to conduct a demonstration on different dates of the basic performance and capabilities of their UAS. The Silverado Substation in St. Helena, California, was the site for the basic evaluation of the UAS and Docking System capabilities. Due to regulatory restrictions, the RPICs had to be onsite while operating because there was no BVLOS waiver in place yet.

<u>The **Tactical Plan** for evaluating Vendor A's UAS and Docking system was the following,</u>

- Measure UAS Range:
    - This was done by flying the UAS in a linear path as far away from the dock until it lost connection and executed an automated return to home maneuver. The distance was measured by noting the distance written on the telemetry box of the controller when the UAS lost link and executed its return to home maneuver.

- Measure UAS Endurance:
    - RPIC flew the aircraft under normal circumstances until the UAS recommended a return for landing due to low battery. A timer was used to record how long the flight time was.
- Measure UAS Charging Time:
    - RPIC used a timer to measure how long it takes for the battery to fully charge after touching down with the lowest battery possible for flight.
- Evaluation of flight planning, flight modes, and flight commands:
    - RPIC executed the following:
        - Built and launched missions
        - Manually controlled UAS flights
- Demonstration of safety failsafe automated flight behaviors including Lost link low battery, and critical battery.
- Evaluation of the ability to extend range.
- Demonstration of additional special capabilities.

The **Tactical Plan** for evaluating Vendor B's UAS and Docking System was the following,

- Measure UAS Range:
    - The UAS flew linearly away from the RPIC until Command and Control (C2) and telemetry were no longer available, and the aircraft executed its return-to-home maneuver.
- Measure UAS Endurance:
    - The RPIC flew the aircraft normally until the controller interface recommends returning home due to low battery. The time will be recorded using a recording device from launch to landing.
- Measure UAS Charging Time:
    - The RPIC charged a battery depleted from a normal flight. The time was recorded using a recording device from the moment the battery starts charging to the moment the battery completes charging.
- Evaluation of flight planning, flight modes, and flight commands:
    - RPIC executed a manual flight, and demonstrated all autonomous features, such as, proximity obstacle avoidance, 360° superzoom, point of interest orbit, track in place, offline maps, and reduced obstacle avoidance, and 3D scan feature.
- Demonstration of safety failsafe automated flight behaviors including lost link, low battery, critical battery, loss of GPS, and return to home. The RPIC initiated the lost link scenario by powering down the controller.
- Evaluation of the ability to extend range.
- Demonstration of additional special capabilities:
    - The RPIC demonstrated obstacle avoidance by flying the aircraft at common obstacles not to be smaller than ½ inch in diameter. Aircraft must avoid obstacles in all directions. Success will be measured by the ability of the aircraft to avoid obstacles successfully.

4.1.2 Challenges

The initial challenge was to determine a suitable PG&E location that could host demonstration #1. The docking systems had to be installed where our operations under normal Part 107 operations would be allowed inside of the national airspace system. The facilities at the location had to have the proper infrastructure for our setup and had to meet the testing parameters for demonstration #1. The Silverado Substation in St. Helena, CA, met our criteria and was selected as the site for the demonstration.

The process of executing the tactical plans for Vendor A and Vendor B also experienced the following challenges,

- Command and control connectivity issues due to the systems hardware limitations.
- Poor data quality due to limited sensor capabilities and the data not meeting PG&E's Image Quality and Control Standards (IQA).
- Software bugs and user experience issues due to the infancy of the systems and technology.

4.1.3 Results and Observations

The scorecard of results and observations for **Vendor A's** demonstration of the capabilities of its' UAS are shown below.

Table 1: Vendor A – Scorecard Demonstration #1

Test Location Silverado	Expected Behavior	Observed Behavior	Criteria Met/Not Met
Measure UAS C2 Range	Maintain connectivity during all phases of VLOS flight	Telemetry was maintained during all phases of flight	Met
Measure UAS Endurance	40 Minutes of continuous flight	27 minutes, 20 seconds	Not Met
Measure Battery Charging Time	40 Minutes	41 minutes and 20 seconds to charge from 9% to 100%	Not Met
Evaluation of flight planning modes	Safe execution of mission planning	Waypoint and manual flight executed safely	Met
Evaluation of Imagery	Imagery to be reviewed by IQA/DQA	Image quality was insufficient compared to current methods of collection	Not met
Lost Link	RTH unless C2 is reestablished	2ndary communications disconnect, UAS RTH Primary communications disconnect, UAS RTH	Met
Low Battery	RTH	UAS returned to home	Met
Loss of GPS	Maintain altitude and RTH	Unable to simulate	N/A
RTH Behavior	Safe flight profile to landing	UAS RH safely	Met
Special Capabilities	Demonstration of stated capabilities	None Stated or observed	N/A

The data shows that criteria for endurance and battery charging time were not met and the Loss of GPS criteria was unable to be simulated. Also, the UAS exhibited no special capabilities. The criteria for range, flight planning modes, lost link, low battery, and RTH behavior were met.
In general, where the criteria were met was related to safe and stable execution of the flight mission while maintaining connectivity throughout all phases of flight. Thus, it can be concluded that for this task Vendor A had a moderate success rate in aligning with the expected outcomes based off the intended goal when the systems were created and marketed by the vendor.

The scorecard of results and observations for **Vendor B's** demonstration of the capabilities of its' UAS are shown below.

Table 2: Vendor B – Scorecard Demonstration #1

Test Location Silverado	Expected Behavior	Observed Behavior	Criteria Met/Not Met
Measure UAS C2 Range	Maintain connectivity during all phases of VLOS flight	Did not maintain connectivity during flight. UAS initiated RTH successfully	Not Met
Measure UAS Endurance	35 minutes of flight time	29.08 minutes	Not Met
Measure Charging time	60 minutes	Hot Battery – battery was unable to charge after flight due to heat within box.	Not Met
Evaluation of flight planning modes	Safe execution of missions	Manual Waypoint mission planner	Met Met
Evaluation of Imagery	Imagery suitable for inspection	Manual Poor livestream, unable to see conductors	Not Met
Lost Link	RTH unless C2 is reestablished	RTH safely executed	Met
Low Battery	RTH	RTH but landed on ground near box due to insufficient battery reserve	Not Met
RTH Behavior	Safe flight profile to landing	RTH safely executed, did not land in dock	Not Met
Special Capabilities	Demonstration of stated capabilities	Collision avoidance worked in all phases of flight	Met

The data shows that Vendor B did not meet any of the Success Criteria for UAS Range, Endurance, Battery Charging Time, nor the RTH Behavior. It did meet the Success Criteria for the Flight Planning Modes and the Special Capabilities. The Evaluation of the Imagery was not conclusive.

The docking station used for this test was an indoor dock because the vendor had not yet fully developed its outdoor dock at the time of this evaluation. The indoor dock depends on its operating environment to be climate controlled whereas the outdoor dock (delivered to PG&E later in the year) comes with a thermoelectric heater and cooler to help get the battery to an optimal temperature which should facilitate quick charging. Improvements to the communications between the docking station and the UAS as well as the UAS endurance were identified as being needed to be successful in the subsequent demonstrations.

Vendor B was a new entrant and though its demonstration of the capabilities of its UAS did not meet most of the criteria set forth in the scorecard, we did provide them feedback to help them improve and develop their product to make it more successful in the next set of demonstrations.

4.2 Task #2: Performed advanced planning to define the technology setup and operational procedures for all sites and use cases as part of the FAA Part 107 BVLOS waiver application.

4.2.1 Technical Development and Methods

Created the Concept of Operations (ConOps) for the project and the Federal Aviation Administration (FAA) waiver acquisition using a template developed by Vendor A. The ConOps detailed the technology setup and operational procedures for all sites and use cases and collaborated with Vendor A to develop associated FAA Part 107 BVLOS waiver application. Technology setup for each use case included establishment of a process to download imagery from the UAS' SD cards, and upload to AWS, and analyze in PG&E's internal data viewing software.

4.2.2 Challenges

Identifying potential candidates who could develop a Remote BVLOS Waiver on behalf of PG&E was a challenge. Also, at the start of this project there were no Remote BVLOS waivers granted from the FAA for the type of operations we were proposing.

4.2.3 Results and Observations

A Certificate of Waiver effective from October 3, 2023, to July 31, 2027, was granted by the FAA to PG&E for authorized operations of small unmanned aircraft system (sUAS) operations beyond the visual line of sight of the remote pilot in command. At the time of the project, this was the most advanced and flexible FAA waiver obtained by PG&E to date.

4.3 Task #3: Demonstration #2 of an automated flight plan within VLOS which did not require an approved FAA BVLOS waiver.

4.3.1 Technical Development and Methods

Each of the vendors were expected to conduct a demonstration on different dates of their UAS' capabilities to execute an automated flight plan within the visual line of site of a controlling drone pilot and not requiring an approved FAA BVLOS waiver. The Silverado Substation in St. Helena, California, was the site chosen for both Vendor A's and Vendor B's demonstration.

In this task, for each use case listed below, a series of side-by-side test cases were conducted in which the operation was manually flown by the drone pilot and then flown automatically by the drone system with pilot supervision. Pilot training was conducted at the onset of this task. This task pertained to the transmission and substation inspections and distribution alert verification use cases**.**

The **Tactical Plans** for each vendor were as follows,

Vendor A

- Transmission Inspection – Execute a flight to achieve the transmission structure shot list, a collection of precisely positioned images around the transmission asset for a single structure.
- Distribution Alert Verification – Execute a flight to respond to an alert and respond in real-time to follow-on mission updates/re-tasking.
- Substation Inspection – Execute a flight to achieve one substation asset inspection shot list, a collection of precisely positioned images around the substation asset.

Vendor B

- Transmission Inspection - Execute a flight to achieve manual and automated data capture of a Mono Pole and Lattice Tower.
- Distribution Inspection - Execute a flight to achieve a manual and automated patrols of a distribution circuit followed by an automated data capture.

4.3.2 Challenges

The initial challenge was to determine a suitable PG&E location that could host demonstration #2. The docking systems had to be installed where our operations under our VLO waivers would be allowed inside of the national airspace system. The facilities at the location had to have the proper infrastructure for our setup and had to meet the testing parameters for demonstration #2. The Silverado Substation in St. Helena, CA, met our criteria and was selected as the site for the demonstration.

The process of executing the tactical plans for Vendor A and Vendor B also experienced the following challenges,

- Connectivity issues due to system technology limitations
- Poor data quality due to limited mega pixels on the sensors and connection issues due to system communications limitations
- Software bugs and interface issues due to the infancy of Vendor B's technology

4.3.3 Results and Observations

Table 3: Vendor A – Scorecard Demonstration #2

Test Location Silverado	Expected Behavior	Observed Behavior	Criteria Met/Not Met
Manual Transmission Inspection	Safe and stable execution while maintaining connectivity during all phases of flight	Stable, safe flight, and remained connected throughout flight.	Met
Manual Transmission Image Capture	Imagery to be reviewed by PG&E IQA/DQA for inspect ability and to provide feedback	Image quality not up to par with current IQA standards. Level of detail does not meet current solutions.	Not Met
Automated Transmission Inspection	Safe and stable execution while maintaining connectivity during all phases of flight	Image quality not up to par with current IQA standards	Met
Automated Transmission Image Capture	Imagery to be reviewed by PG&E IQA/DQA for inspect ability and to provide feedback	Image quality not up to par with current IQA standards.	Not Met
Manual Distribution Alert Verification	Safe and stable execution while maintaining connectivity during all phases of flight	Stable, safe flight.	Met
Manual Distribution Alert Image Capture	Imagery to be reviewed by PG&E IQA/DQA for inspect ability and to provide feedback	Image quality not up to par with current IQA standards.	Not Met
Automated Distribution Alert Verification	Safe and stable execution while maintaining connectivity during all phases of flight	Safe, stable, was able to maintain connectivity during flight.	Met
Automated Distribution Alert Image Capture	Imagery to be reviewed by PG&E IQA/DQA for inspect ability and to provide feedback	Image quality not up to par with current IQA standards. Unable to see conductor for the flight	Not Met
Manual Substation Inspection	Safe and stable execution while maintaining connectivity during all phases of flight	Safe, stable, was able to maintain connectivity during flight.	Met
Manual Substation Image Capture	Imagery to be reviewed by PG&E IQA/DQA for inspect ability and to provide feedback	Image quality not up to par with current IQA standards. Not comparable to 100mp imagery.	Not Met
Automated Substation Inspection	Safe and stable execution while maintaining connectivity during all phases of flight	Flight was stable and safe. Aircraft stayed on course	Met
Automated Substation Image Capture	Imagery to be reviewed by PG&E IQA/DQA for inspect ability and to provide feedback	Image quality not up to par with current IQA standards. Not comparable to 100mp current imagery	Not Met

Demonstration of "box hopping" capabilities	Safe execution of take-off and landing at different boxes	Flight was complete with no issue	Met

The data for **Vendor A** shows that the criteria for all Manual and Automated Transmission, Distribution Alert Verification, and Substation Inspection flights were all met. But the image capture for all the flights did not have the image quality required by the current IQA standards, thus the image criteria for all of the flights was not met.

Overall, all the inspection flights were safely flown, stable, and were able to maintain connectivity during flights. The image quality of the camera was an issue. To improve this, the UAS would have to fly closer to the inspected asset, but that would increase the risk of the UAS coming into contact with the surrounding equipment leading to an incident.

Table 4: Vendor B – Scorecard Demonstration #2

Test Location Silverado	Success Criteria	Observed Behavior	Criteria Met/Not Met
Manual Transmission Inspection	Safe and stable execution while maintaining connectivity during all phases of flight	Safe Stable Operations. Unable to complete full shot sheet due to signal loss from building obstructions.	Not Met
Manual Transmission Image Capture	Imagery to be reviewed by PG&E IQA/DQA for inspect ability and to provide feedback	Unable to complete shot sheet. Camera resolution too low.	Not Met
Automated Transmission Inspection	Safe and stable execution while maintaining connectivity during all phases of flight	Unable to complete mission due to "visual waypoint drift". UAS successfully used collision avoidance to avoid contact with asset. Missed landing possibly due to length of flight and VPS (vision positioning system). Need to reposition dock/access point to avoid signal obstructions.	Not Met
Automated Transmission Image Capture	Imagery to be reviewed by PG&E IQA/DQA for inspect ability and to provide feedback	Unable to complete shot sheet.	Not Met
Manual Distribution Alert Verification	Safe and stable execution while maintaining connectivity during all phases of flight	Safe stable operations. Lost connectivity at 2800 feet. Loss of connection due to flying at a lower altitude.	Not Met
Manual Distribution Alert Image Capture	Imagery to be reviewed by PG&E IQA/DQA for inspect ability and to provide feedback	Able to identify markers along flight path but unable to properly identify the conductor throughout the flight.	Not Met
Automated Distribution Alert Verification	Safe and stable execution while maintaining connectivity during all phases of flight	System flew automated path out to 3000 feet after adjusting altitude. Discussed improvement to add functionality to adjust camera pitch and aircraft yaw while following flight path.	Met
Automated Distribution Alert Image Capture	Imagery to be reviewed by PG&E IQA/DQA for inspect ability and to provide feedback	Unable to locate conductors during entirety of flight.	Not Met
Manual Substation Inspection	Safe and stable execution while maintaining connectivity during all phases of flight	Safe Reliable Flight. All landings successful	Met
Manual Substation Image Capture	Imagery to be reviewed by PG&E IQA/DQA for inspect ability and to provide feedback	Unable to inspect vs current method collection process. Higher MP is needed to match current collection process.	Not Met
Automated Substation Inspection	Safe and stable execution while maintaining connectivity during all phases of flight	Safe Reliable Flight.	Met

Automated Substation Image Capture	Imagery to be reviewed by PG&E IQA/DQA for inspect ability and to provide feedback	Unable to inspect to vs current method. Higher MP is needed to match current collection process.	Not Met

The data for **Vendor B** shows that the Transmission inspections, both manual and automated, did not meet their success criteria, primarily due to signal loss because of building obstructions and "visual waypoint drift". The only inspection flights that met their success criteria were the Manual Distribution Alert Verification plus both the Manual and Automated Substation Inspections. The images captured in all of the inspection flights, both manual and automated, did not meet their success criteria due to the camera resolution being too low, unable to fully complete the shot sheet, and the MP being too low to match our current collection process. A demonstration of "box hopping" capabilities was not performed because Vendor B's product did not have this capability at the time Demonstration #2 was performed.

4.4 Task #4: Demonstration #3 of a BVLOS automated flight plan to inspect PG&E Transmission and Substation assets, plus, verification of Distribution Alert use cases.

4.4.1 Technical Developments and Methods

Each vendor was expected to conduct a demonstration on different dates of their UAS' capabilities to execute an automated flight plan requiring an approved FAA BVLOS waiver. Vendor A was disqualified during the period leading up to Demonstration #3 and therefore did not participate in the demonstration. Their disqualification was due to shortcomings of their system and concerns, among other issues, which would compromise the successful completion of the project goals.

Vendor B's demonstration had two major parts: (1) A retest of some of the elements of Demonstrations #1 and #2 to gauge the progress of improvements of the UAS's capabilities and, (2) Demonstration #3, an automated flight plan to inspect Transmission assets and verification of a Distribution Alert. All of the Demonstration #1, #2, and #3 flights were executed from the DRO by a Remote Pilot located in Concord, CA.

The Automated Transmission Inspection leveraged the automated flight plan developed and vetted in demonstrations 1 and 2. Where in Demonstration #2, one tower at a time per operation was inspected, this demonstration assessed how many towers could be inspected sequentially before drone battery life became a limiting factor.

Automated Flight Transmission Structure

Prior to the demonstration day, PG&E set up multiple structure inspection missions on lattice transmission towers using the standard shot sheet as a guide. These missions were set up using Vendor B's live mission planner and precise visual positioning for consistent navigation precision. While the requirement to fly these towers in an automated fashion was accomplished, demonstration 3 required 3-5 towers to be flown over the course of a single flight. Because of the large mission profile, mission planning time would have been an issue, and only one tower could be flown at a time.

Distribution and Alert Verification

Vendor B was given a KML to set up this demonstration, which showed the distribution infrastructure around Silverado Substation in St. Helena, CA. From that, the vendor planned the mission on one distribution circuit originating from the substation and terminating approximately 4,100.81 ft (1.25 km) away from the dock location. Each waypoint represented a distribution pole location

Figure 1 below depicts the flight path taken by Vendor B from the Silverado Substation, which covers 2 miles roundtrip, few physical obstructions, and a straight path. The white circles shown represent waypoints along the flight route with specific commands for the drone at those waypoints.

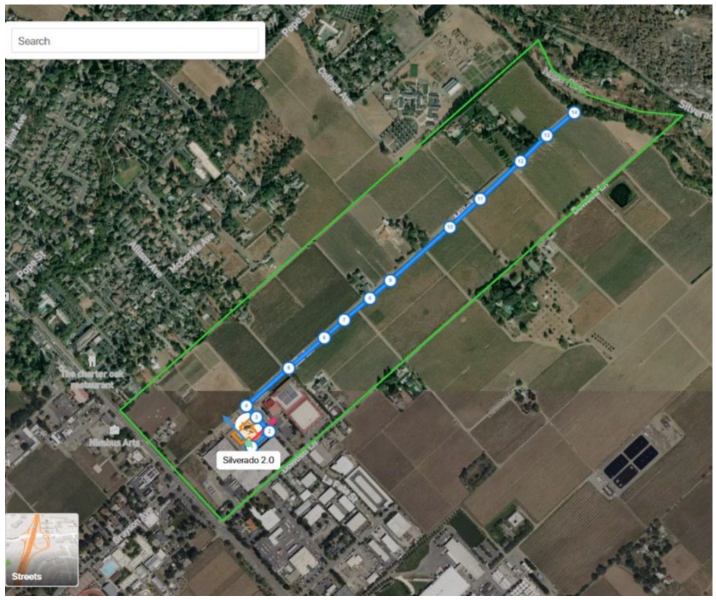

Figure 1: Demonstration #3, Vendor B Flight Path

The goal of this flight was to demonstrate the ability to dispatch the drone from outside the vendor's cloud using API endpoints to control when and how the drone is dispatched. This was accomplished using a web link and a custom API token generated on the PG&E organization.

Once the flight plan was generated via KML, an API call was made to fly the mission. From there, the user could go to the vendor's cloud and view the flight as it progressed. This mission showed that future iterations of this technology could be used in conjunction with PG&E's sensor network and Cloud-to-Cloud integration, which would allow for fully automated dispatch to alert locations.

4.4.2 Challenges

Overall, the infancy of Vendor B's Remote Operations was challenging. Prior to Epic 3.41, Remote Operations were nonexistent in the utility industry and all the processes and procedures had to be built from scratch. In addition, although the pilots had gone through training, they did not have depth of experience flying UAS remotely from a control room.

In addition, the following also posed major challenges to Vendor B's demonstration:

- Communications to the UAS was limited due to the antenna being low to the ground, which caused for less-than-ideal range in locations where there were obstructions.
- We were unable to integrate the distribution sensor-based alerting systems to Vendor B's system so the Distribution Alert Verification test could not be fully demonstrated.

4.4.3 Results and Observations

The results and observations for **Vendor B's** retest of Demonstrations #1 and #2, and Demonstration #3 of an automated flight plan to inspect PG&E Transmission assets, and Verification of Distribution Alert use cases are shown on Tables 5 and 6.

Table 5: Vendor B – Scorecard Demonstration #1 & #2 Retest

DEMONSTRATION #1 - RETEST			
Test Location Silverado	**Success Criteria**	**Observed Behavior**	**Criteria Met/Not Met**
Measure UAS C2 Range	4km (2.49 miles)	Silverado: 3570 feet	Not Met
Measure UAS Endurance	35 Minutes	26 min, 56 sec. Hovered and let drone return automatically	Not Met
Measure Battery Charging Time	45 minutes from landing	1 hour 30 minutes for a 96% charge, timer stopped.	Not Met
Ability To Extend Range	Vendor B to provide hardware to extend range	Not provided by Vendor B	Not Met
DEMONSTRATION #2 - RETEST			
Test Location Templeton	**Success Criteria**	**Observed Behavior**	**Criteria Met/Not Met**
Manual Transmission Inspection	Safe and stable execution while maintaining connectivity during all phases of flight.	Transmission structure flown successfully	Met
Manual Distribution Alert Verification	Safe and stable execution while maintaining connectivity during all phases of flight	Distribution patrol flown successfully	Met
Test Location Silverado	**Success Criteria**	**Observed Behavior**	**Criteria Met/Not Met**
Manual Transmission Inspection	Perform flight operations to capture 3 structures.	Tiger Creek: 3rd structure down 2 quadrants captured loss of connection at 42% battery charge	Not Met
Manual Distribution Alert Verification	Perform flight operation to perform patrol of 1 distribution feeder.	Distribution Patrol 1650'. Loss of connection safe RTH.	Not Met

The data shows that a re-test of Demonstration #1 did not strictly meet the criteria for range, endurance, nor battery charging time. Also, Vendor B still did not yet have the hardware to extend the communications range between the UAS and the docking station at the time of these demonstrations.

The retest of Demonstration # 2 of Manual Transmission Inspections and Distribution Alert Verifications was remotely executed from the Concord Control Center with one drone being remotely piloted in the Templeton Substation and another drone remotely piloted in the Silverado Substation. The data shows that the Templeton tests all met the success criteria but the Silverado tests did not. The Silverado tests were plagued with lost connections and low battery issues.

Table 6 Vendor B – Scorecard Demonstration #3

DEMONSTRATION #3			
Test Location Templeton	**Success Criteria**	**Observed Behavior**	**Criteria Met/Not Met**

Automated Transmission Inspection	Safe and stable execution while maintaining connectivity during all phases of flight	Transmission structure flown successfully	Met
Automated Distribution Alert Verification	Safe and stable execution while maintaining connectivity during all phases of flight	Distribution patrol flown successfully	Met
Test Location Silverado	**Success Criteria**	**Observed Behavior**	**Criteria Met/Not Met**
Automated Transmission Inspection	Perform flight operations to capture 3 structures.	2 structures in one mission. Battery life too short for 3rd structures. 70-way points per tower.	Not Met
Automated Distribution Alert Verification	Perform flight operations to measure maximum conductor distance of manual patrol	Lost connection but we believe it continued mission after loss of connection.	Not Met

The data for the demonstrations of Automated BVLOS Flight from the control room shows the flights conducted from the Tempelton Substation met all success criteria for Transmission Inspection and Distribution Alert Verification. However, the demonstration from the Silverado Substation did not meet any of the criteria for these same flights. Lost connections and low battery issues plagued the demonstration at Silverado.

In addition, image capture capabilities could not be evaluated because of Vendor B's known sensor hardware limitations not meeting PG&E standards.

4.5 Task #5: Develop a Distribution Alert Verification interface between the UAS and the field sensors.

This task was not completed because Vendor B's technology required to integrate Distribution Alert Verification between the UAS, and the field sensors was not mature enough at the time. The demonstration of this capability has been deferred into potential future EPIC 4 work.

5 Value Proposition

The purpose of EPIC funding is to support investments in technology demonstration and deployment projects that benefit the electricity customers of PG&E, San Diego Gas and Electric (SDG&E), and Southern California Edison (SCE). Epic 3.41 has demonstrated that

Operating UAS and monitoring automated missions remotely from a centralized location beyond visual line of site is possible and can be done so safely. It reduces the need for truck rolls to conduct aerial inspection type work and is particularly useful for missions that need to be conducted on a repetitive cycle. The project met the EPIC primary and secondary principles by proving out the following through our test flights and daily operations using the dock systems:

5.1 Primary Principles

The primary principles of EPIC are to invest in technologies and approaches that provide benefits to electric ratepayers by promoting greater reliability, lower costs, and increased safety. This EPIC project contributes to these primary principles in the following ways:

- Greater reliability: The reduction of time by reducing truck rolls will increase reliability by reducing the length of time for SMEs to commute to the site of a potential issue. With the ability to put eyes on real time the SME will also know exactly what they need to remediate the problem increasing.
- Improved Safety: Automating existing drone operations has the potential to reduce drone collisions with PG&E assets and other objects. Using UAS and conducting BVLOS operations for inspections and asset alert verification will reduce or eliminate the need to send contractors or employees to each location by helicopter, truck, off-road vehicle or by foot, thus improving personnel safety. During this project, there was no incident in which the drone collided with energized infrastructure during flight.
- Lower O&M costs: The reduction of truck rolls reduces the costs associated with travel such as fuel, lodging and per diem as well as adding efficiency.

Using zero emission-type UAS leads to reduced carbon emissions while still conducting aerial inspections effectively. This leads to an environmentally sustainable inspection program by not emitting greenhouse gases to conduct needed inspection work. Also, the reduced need for travel to conduct the aerial work further reduces the carbon emissions produced commuting to the areas for work. This also increases safety by reducing time spent driving on the roads. The automated nature of most of the flights reduces pilot error related incidents.

5.2 Secondary Principles

EPIC also has a set of complementary secondary principles. This EPIC project contributes to the following three secondary principles: <societal benefits, greenhouse gas (GHG) emissions reduction, the loading order, low-emission vehicles/transmission, economic development; and efficient use of ratepayer funds.

- Societal benefits: The improvements in the inspection process by reducing response times for inspection needs whether routine or emergency improves the reliability of the electric grid by proactively identifying potential problem areas. This leads to the prevention or reduced occurrences of power outages over large service areas and keeps the lights on for PG&E's customers. The quick inspection ability also reduces the occurrence of wildfires caused by degraded or damaged electrical equipment thereby keeping customers and natural ecosystems safe from destructive wildfires.
- Greenhouse gas (GHG) emissions reduction: The reduction of truck rolls to get on site to fly reduces the carbon footprint by not burning fossil fuels to get on site to fly. In addition to the reduced truck rolls, electrically powered UAVs which reduce greenhouse gases were in use.
- Economic development: The creation of jobs to staff the remote operations project, the reduction of wildfire incidents from our inspections and the reductions of electrical power outages to businesses and homes from proactive asset inspections all lead to economic development in the following ways:
    a. Remote operations staffing: Pilots needed to staff the control room and fly the UAS remotely and so job creation plays a positive role in economic development.

b. Reduction of wildfires: Quicker turnaround times and data delivery to the appropriate engineers from asset patrols and inspections proactively prevent or lessen the impact of wildfires thereby preventing the economic fallout associated with loss of life, infrastructure, and businesses from wildfire events.

c. Reduction of power outages or quicker restoration times: Reductions in power outages lead to businesses, particularly those that rely heavily on consistent electric supply for their operations, to stay operational more consistently with minimized down time. This improves businesses productivity, which in turn affects profits and employee compensation, thus improving economic development.

- Efficient use of ratepayer funds: Inspections are mandatory especially on aging infrastructure to improve reliability of the grid and electric assets to keep the public safe while producing and delivering electricity to businesses. Because of this, money must be allocated to inspection programs and if money must be allocated, it is best that it be allocated in a manner that uses the money efficiently. This program accomplished this by reducing the costs associated with inefficiencies related to current inspection methods such as travel costs to get on site. In addition, the improved security capabilities from daily security patrols at historically compromised locations, reduce break-ins, vandalism, and theft which saves the company money from replacement costs which allows the company to better use funds on other projects.

5.3 Key Accomplishments

The following summarize the key accomplishments of the project over its duration:

- Conducted rigorous industry landscaping and benchmarking with other utilities which culminated in an RFP process and the selection of two drone vendor partners (referred to as Vendors A & B throughout) with distinctly different solution offerings
- Obtained a waiver award from the FAA to fly BVLOS using the dock systems as per the proposed Concept of Operations (ConOps). This represented the most advanced and flexible FAA waiver obtained by PG&E at the time of the project.
- Staffed the control room with full-time personnel to fly dock systems
- Explored and tested use cases across various functional areas
- Objectively evaluated both drone system vendors' system offerings
- Material contribution to the maturation of one vendor's system offering to the benefit of both PG&E and the broader utility industry for a range of use cases
- Developed internal PG&E processes and procedures for remotely operated UAS

5.4 Key Recommendations

The recommendations for improvements to Vendor B's solution building upon this project to better enable PG&E's use cases are summarized below.

Range extenders

The current version of Vendor B's dock system relies on the drone having line of sight with the dock to maintain link. This limits the range the drone can have from the dock during flights. Equipment like repeaters for the dock system would help improve range by improving the line of sight around bends and obstacles. Connection via 5G LTE via a sim card onboard the drone is another way to improve connection by allowing the drone to fly and remain connected to the cloud when flying in areas that have cellular coverage without the need for repeaters with repeaters being necessary for areas without cell coverage.

Dock Hopping

To fully realize the benefits of improved range, the ability to take off from one dock and do a one-way flight in which the drone lands on another dock, would create the possibility of covering more ground inspection-wise more efficiently and effectively.

Improved Batteries

Improved drone batteries that can withstand more cycles before they are significantly degraded to the point where they are no longer suitable for flight would be desirable. The batteries used as part of this demonstration must be replaced within half the cycles originally advertised to prevent a battery failure in mid-flight.

Improved Payload (Camera)

The current dock system does not have a camera that meets the detailed inspection quality for small components often found on electric towers. A camera with the ability to adjust focus and zoom optically with a higher megapixel count would improve inspection capabilities of PG&E's electric assets.

5.5 Technology Transfer Plan

5.5.1 IOU's Technology Transfer Plans

A primary benefit of the EPIC program is the technology and knowledge sharing that occurs both internally within PG&E, and across the other IOUs, the CEC, and the industry. To facilitate this knowledge sharing, PG&E will share the results of this project in industry workshops and through public reports published on the PG&E website. Specifically, below is information sharing forums where the results and lessons learned from this EPIC project were presented or plan to be presented:

5.5.2 Adaptability to other Utilities and Industry

The following findings of this project are relevant and adaptable to other utilities and the industry:

- Beyond visual line of site flights via drone docking stations for asset inspections are possible and can be done so safely.
- Docking stations with a smaller footprint are more desirable than those with large footprints due to limited space in substations
- Using third party weather stations is a viable solution without having to rely on using just the docking station's weather system. It is recommended to use more than one weather station to

cross-check weather observations for accuracy, so pilots are not making flight decisions based off stale or inaccurate weather readings.

5.6 Data Access

Upon request, PG&E will provide access to data collected that is consistent with the CPUC's data access requirements for EPIC data and results.

6 Metrics

The following metrics were identified for this project and included in PG&E's EPIC Annual Report as potential metrics to measure project benefits at full scale.[4] Given the proof-of-concept nature of this EPIC project, these metrics are forward looking.

D.13-11-025, Attachment 4. List of Proposed Metrics and Potential Areas of Measurement (as applicable to a specific project or investment area)	Reference
1. Potential energy and cost savings	
a. Number and total nameplate capacity of distributed generation facilities	
b. Total electricity deliveries from grid-connected distributed generation facilities	
c. Avoided procurement and generation costs	
d. Number and percentage of customers on time variant or dynamic pricing tariffs	
e. Peak load reduction (MW) from summer and winter programs	
I	
g. Percentage of demand response enabled by automated demand response technology (e.g. Auto DR)	
h. Customer bill savings (dollars saved)	
i. Nameplate capacity (MW) of grid-connected energy storage	
2. Job creation	
a. Hours worked in California and money spent in California for each project	
3. Economic benefits	
a. Maintain / Reduce operations and maintenance costs	5.1
b. Maintain / Reduce capital costs	
c. Reduction in electrical losses in the transmission and distribution system	5.2
d. Number of operations of various existing equipment types (such as voltage regulation) before and after adoption of a new smart grid component, as an indicator of possible equipment life extensions from reduced wear and tear	
e. Non-energy economic benefits	5.2

[4] 2015 PG&E EPIC Annual Report. Feb 29, 2016. http://www.pge.com/includes/docs/pdfs/about/environment/epic/EPICAnnualReportAttachmentA.pdf

f. Improvements in system operation efficiencies stemming from increased utility dispatchability of customer demand side management	5.2
g. Co-benefits and co-products (e.g. feed, soil amendment, lithium extraction)	
h. Energy Security (reduced energy and energy-related material imports)	
4. Environmental benefits	
a. GHG emissions reductions (MMTCO2e)	5, 5.2
b. Criteria air pollution emission reductions.	5, 5.1, 5.2
c. Water savings	
d. Water quality improvement	
e. Waste reductions	
f. Habitat area disturbance reductions	
g. Wildlife fatality reductions (electrocutions, collisions)	3.1, 5.2
5. Safety, Power Quality, and Reliability (Equipment, Electricity System)	
a. Outage number, frequency and duration reductions	4.3.1, 5.2
b. Electric system power flow congestion reduction	
c. Forecast accuracy improvement	
d. Public safety improvement and hazard exposure reduction	4.1.3, 3.1
e. Utility worker safety improvement and hazard exposure reduction	3.3
f. Reduced flicker and other power quality differences	
h. Reduction in system harmonics	
i. Increase in the number of nodes in the power system at monitoring points	
6. Other Metrics (to be developed based on specific projects through ongoing administrator coordination and development of competitive solicitations)	
a. Insert other metrics here	
b. Insert other metrics here	
c. Insert other metrics here	
d. Insert other metrics here	
e. Insert other metrics here	
7. Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy	
a. Description of the issues, project(s), and the results or outcomes	3, 4.1, 4.1.2 4.1.3
b. Increased use of cost-effective digital information and control technology to improve reliability, security, and efficiency of the electric grid (PU Code § 8360)	

c. Dynamic optimization of grid operations and resources, including appropriate consideration for asset management and utilization of related grid operations and resources, with cost-effective full cyber security (PU Code § 8360)	
d. Deployment and integration of cost-effective distributed resources and generation, including renewable resources (PU Code § 8360)	
e. Development and incorporation of cost-effective demand response, demand-side resources, and energy-efficient resources (PU Code § 8360)	5.1
f. Deployment of cost-effective smart technologies, including real time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices for metering, communications concerning grid operations and status, and distribution automation (PU Code § 8360)	3.2
g. Integration of cost-effective smart appliances and consumer devices (PU Code § 8360)	
h. Deployment and integration of cost-effective advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal-storage air-conditioning (PU Code § 8360)	
j. Provide consumers with timely information and control options (PU Code § 8360)	
k. Develop standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid (PU Code § 8360)	
l. Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services (PU Code § 8360)	
8. Effectiveness of information dissemination	
a. Web-based surveys of people viewing materials or participating in program reviews	
b. Number of reports and fact sheets published online	
c. Number of times reports are cited in scientific journals and trade publications for selected projects.	
d. Number of information sharing forums held	5.6.1
e. Stakeholders attendance at workshops	
f. Technology transfer	5.6
9. Adoption of EPIC technology, strategy, and research data/results by others	
a. Description/documentation of projects that progress deployment, such as Commission approval of utility proposals for widespread deployment or technologies included in adopted building standards	
b. Number of technologies eligible to participate in utility energy efficiency, demand response or distributed energy resource rebate programs	
c. EPIC project results referenced in regulatory proceedings and policy reports	
d. Successful project outcomes ready for use in California IOU grid (Path to market)	
e. Technologies available for sale in the marketplace (when known)	

10. Reduced ratepayer project costs through external funding or contributions for EPIC-funded research on technologies or strategies	
a. Description or documentation of funding or contributions committed by others	
b. Co-funding provided for solicitations	
c. Dollar value of funding or contributions committed by others	

7 Conclusion

Through the EPIC 3.41 – Drone Enablement project, PG&E conducted a rigorous demonstration of two vendors' drone systems to assess the readiness and value of automated and BVLOS flight operations for multiple PG&E use cases. One of the vendor partners' solutions demonstrated significant promise, and PG&E collaborated closely with them to iteratively iron out numerous issues with their system over the course of the demonstration, and provided valuable feedback for their product roadmap, to the direct benefit of PG&E as well as the broader utility industry. During the project, PG&E's Aviation Services organization significantly increased its maturity around managing the company's drone operations. PG&E also successfully obtained a FAA BVLOS waiver to conduct operations leveraging the capabilities demonstrated in this project, and this marked the most advanced waiver PG&E had been granted to date at the time of the project. PG&E aims to continue more advanced demonstrations through its EPIC 4 program based on the learnings and recommended future improvements from this project, to position PG&E to unlock significant operational value by utilizing drones across a wide range of use cases.

8 Supplementary Technical Reference

Below is the 14 CFR Part 107 waiver issued to PG&E by the FAA per the Concept of Operations to conduct this project:

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

CERTIFICATE OF WAIVER

ISSUED TO

Pacific Gas and Electric Responsible Person: Kellen Kirk Waiver Number: 107W-2023-02551

ADDRESS –

1448 Sally Ride Dr Concord, CA 94520

This certificate is issued for the operations specifically described hereinafter. No person shall conduct any operation pursuant to the authority of this certificate except in accordance with the provisions contained in this certificate.

OPERATIONS AUTHORIZED

Small unmanned aircraft system (sUAS) operations beyond the visual line of sight of the remote pilot in command (PIC).

LIST OF WAIVED REGULATIONS BY SECTION AND TITLE

14 CFR § 107.31—Visual line of sight aircraft operation

STANDARD PROVISIONS

1. A copy of the application made for this certificate shall be attached to and become a part hereof.
2. This certificate shall be presented for inspection upon the request of any authorized representative of the Administrator of the Federal Aviation Administration, or of any State or municipal official charged with the duty of enforcing local laws or regulations.
3. The holder of this certificate shall be responsible for the strict observance of the terms and provisions contained herein.
4. This certificate is nontransferable.

NOTE—This certificate constitutes a waiver of those Federal rules or regulations specifically referred to above. It does not constitute a waiver of any State law or local ordinance.

SPECIAL PROVISIONS

Special Provisions Nos. 1 to 34, inclusive, are set forth on the attached pages.

This Certificate of Waiver is effective from October 3, 2023, to July 31, 2027, and is subject to cancellation at any time upon notice by the Administrator or an authorized representative.

	BY DIRECTION OF THE ADMINISTRATOR DEREK W HUFTY Digitally signed by DEREK W HUFTY Date: 2023.10.06 12:08:50 -04'00' **Emerging Technologies Division, AFS–700**

General.

SPECIAL PROVISIONS ISSUED TO
Pacific Gas and Electric

This Certificate of Waiver is an amendment which supersedes and replaces Waiver 107W-2023-00964 issued to Pacific Gas and Electric for operations under 14 CFR 107. Waiver 107W-2023-00964 is no longer valid.

The FAA's Flight Standards Service has reviewed your application to ensure compliance with the requirements of 14 CFR § 107.200 and § 107.205. Pursuant to these authorities, the Administrator finds that the proposed small unmanned aircraft (sUA) operation can be conducted safely under the provisions of this Certificate of Waiver (Waiver) as listed below because you have established adequate mitigations for risks involved with operating your sUA in the manner you described. Adherence to the provisions of this Waiver establishes the required level of safety within the national airspace system.

The Administrator may cancel this Waiver at any time. As a general rule, this Waiver may be canceled when it is no longer required, there is an abuse of its provisions, or when unforeseen safety factors develop. Failure to comply with any provision listed below is a violation of the terms of this Waiver and will serve as justification for cancellation.

List of Regulations Waived by Section and Title. The following regulations are waived:

> 14 CFR § 107.31, Visual line of sight aircraft operation, is waived to allow operation of the small unmanned aircraft (sUA) beyond the direct visual line of sight of the remote pilot in command (PIC).

No part of this waiver will function as an airspace authorization under 14 CFR § 107.41. The FAA's Air Traffic Organization responds directly to requests for such authorizations.

Common Special Provisions. The Responsible Person is directly responsible for safety of operations conducted under this Waiver and will ensure the Remote Pilot in Command (remote PIC), manipulator of the controls, and visual observer(s) (VO)[1] comply with all provisions of this Waiver.

1. The Responsible Person listed on the Waiver is responsible to the FAA for the safe conduct of the operations. Prior to conducting operations that are the subject of this Waiver, the Responsible Person:
   a. Must ensure the remote PIC, manipulators of the controls, and VO(s) are informed of the terms and provisions of this Waiver and strictly observe the terms and provisions herein;
   b. Must ensure the remote PIC, manipulators of the controls, and VO(s) are informed and familiar with part 107 regulations; and
   c. Evidence of the above (a and b) must be documented and must be presented for inspection upon request from the Administrator or an authorized representative;
2. This Waiver may not be combined with any other waiver(s), authorizations(s), or exemption(s) without specific authorization from the FAA;

[1] Title 14 CFR § 107.3 defines the term "visual observer." Any VO participating in operations conducted under this Waiver must meet the requirements listed in § 107.33 throughout the duration of flight operations.

3. The FAA has the authority to cancel or delay any or all flight operations if the safety of persons or property on the ground or in the air are in jeopardy or there is a violation of the terms of this Waiver;
4. A copy of this Waiver must be accessible and available to the remote PIC at the ground control station during sUA operations that are the subject of this Waiver;
5. The Responsible Person listed on this Waiver must maintain a current list of pilots by name and remote pilot certificate number used in operations under this Waiver. This list must be presented for inspection upon request from the Administrator or an authorized representative;
6. The Responsible Person listed on this Waiver must maintain a current list of sUA by registration number(s) used in operations under this Waiver. This list must be presented for inspection upon request from the Administrator or an authorized representative;
7. For the purposes of this Waiver, direct participants are the remote PICs, persons manipulating the controls, VOs, and any persons whose involvement is necessary for safety of the sUA operation. All other persons are considered non-participants;

Visual Line of Sight Operations Special Provisions The remote PIC may conduct sUAS operations without the ability to see the unmanned aircraft throughout the entire flight, provided:

OPERATIONAL PROVISIONS

8. Operations may not be conducted at night, as defined in 14 CFR § 1.1;

9. The remote PIC must use the strategies described in the waiver application to contain the sUA to the intended flight volume;

10. The RPIC must be located in the continental United States;

11. Return to Home feature must be programmed to contain the sUA to flight paths within the intended flight volume;

12. The sUA must not exceed
    a. 50 feet above ground level (AGL); or
    b. Within a 50 foot radius from any natural obstruction or manmade object;

13. The area of operation must be remote and safeguarded as described in the waiver application;

14. Prior to conducting operations under this Waiver, the remote PIC must identify operational area obstacles and boundaries so as to avoid collision with, or damage to property

15. The Responsible Person must ensure all operations conducted under this Waiver follow the procedures outlined in the waiver application. If a discrepancy exists between the provisions in this Waiver and the procedures outlined in the Waiver application, the Waiver takes precedence and must be followed;

16. The Responsible Person must ensure a copy of the Waiver application and Waiver is available to the remote PIC and all other direct participants prior to and during sUAS operations that are the subject of this Waiver;

17. Prior to operations under this Waiver, all direct participants must attend a safety briefing that addresses at minimum, the following items:
    a. Designated positions, physical locations, responsibilities, and Crew Resource Management,
    b. Planned flight operating area,
    c. Designated launch and recovery areas,
    d. Verification of geo-fence boundaries,
    e. Verification of return home and land flight profile, and course,
    f. Verification of emergency landing site(s), land profile, and course,
    g. Procedures for avoidance of other aircraft,
    h. Procedures for operating under this Waiver;

18. Operations subject to this waiver must cease as soon as possible in a manner that does not jeopardize the safety of human beings, property or other aircraft, if, at any time:

a. Safety of human beings or property on the ground or in the air is in jeopardy,
b. Any failure to comply with the provisions of this Waiver exists,
c. sUAS control link is lost,
d. A non-participating aircraft or person enters the designated flight operating area,
e. GPS signal is lost, or sUA GPS location information is degraded or uncertain,
f. any part of the DAA strategy is not functioning or unavailable;

19. No sUA flight that occurs under this waiver may carry the property of another for compensation or hire;

20. The Responsible Person must file a Notice to Air Mission (NOTAM) no more than 72 hours and no less than 24 hours prior to operating under this waiver. A NOTAM can be filed by calling 1-877-487-6867 (1-877-4-US-NTMS) or online at https://www.1800wxbrief.com/Website/login#!/ and must include the location and/or operating area, altitude, and time and nature of the activity. The Responsible Person must verify the NOTAM has been issued prior to conducting waivered operations;

TECHNICAL PROVISIONS

21. Operations conducted under this Waiver may only occur with the make and model sUAS described in the waiver application Proposed operations of any other manufacturer, make or model of sUAS will require a new waiver application or a request to amend this Waiver;

22. All sUAS operations conducted in accordance with this Waiver must comply with all manufacturer recommendations and limitations for the sUAS;

23. The Responsible Person must maintain each sUAS and its components in accordance with manufacturer's instructions and recommendations. sUAS maintenance includes scheduled and unscheduled overhaul, repair, inspection, modification, replacement, and system software upgrades of the sUAS and its components necessary for flight. A log of all maintenance performed must be kept for each aircraft operated under this waiver. This log must be available to the remote PIC for review prior to conducting operations that are the subject of this waiver. Each sUAS maintenance log must be presented to the Administrator when requested. The log must contain the following information for each maintenance activity:
    a. A description (or reference data acceptable to the Administrator) of work performed,
    b. The date of completion of the work performed,
    c. The name of the person who performed the work, and
    d. The signature of the person who performed the work;

24. Any sUAS that has undergone maintenance must undergo a functional test flight prior to conducting operations under this Waiver. A log entry must be made for each functional test flight. The log entry must contain at minimum the:
    a. Calendar date,
    b. sUAS registration number,
    c. Remote PIC who performed the functional test flight,
    d. Duration of the flight, and
    e. The result of the functional flight test;

25. A functional test flight may only be conducted under the standard requirements of part 107 (without waiver);

26. sUAS must be equipped with high visibility markings and/or lighting to increase conspicuity of the sUA in order to be seen by crewmembers in other aircraft from a distance of no less than 1 statute miles (sm) during the day;
27. sUAS ground control must display in real time the following information: sUA altitude, sUA position, sUA direction of flight or attitude, sUAS flight mode, battery life, DAA status and C2 status. This information must be available at all times to the remote PIC;
28. The sUAS must alert the remote PIC of degraded system performance, sUAS malfunction, or loss of Command and Control (C2) link between the ground control station and the sUA as described in the waiver application;
29. Launch or recovery areas must be pre-designated and monitored to keep any human being who is not directly participating in the operation out of the areas prior to, during, and immediately following flight operations;

30. Prior to conducting operations under this Waiver, the remote PIC must determine all control links used in the sUAS, will maintain the ability to control the sUA at the maximum planned distance for the proposed operation. At all times during operations that are the subject of this Waiver, the remote PIC must maintain the ability to direct the sUA to ensure compliance with the applicable provisions of this waiver;

31. If the remote PIC loses command or control link with the sUA, the sUA must follow a predetermined route to either reestablish link or immediately recover/land at a predesignated location;

32. ADS-B OUT (1090/978 MHz) may not be transmitted from the sUAS when operating pursuant to this Waiver. ADS-B IN is required for operations under this waiver;

33. All emitters used in sUAS must be in compliance with all applicable FCC regulations and all provisions of the FCC authorization granted for the emitter. A FCC experimental authorization may not be used for sUAS operations under this Waiver; and

ENVIRONMENTAL PROVISIONS

34. Operations conducted under this waiver are limited to the locations meeting the performance requirements of this Waiver.