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Good morning Chair Murkowski and members of the committee. Thank you for inviting me to testify before you today about Hawaii's energy ecosystem and the challenges and opportunities faced in operating islanded energy systems in the Hawaiian archipelago. While there are discreet distinctions between islanded and interconnected systems, many of the solutions Hawaii has explored, and in some cases has pioneered, may be broadly applicable to all energy systems and accordingly inform future policies and expenditures at the federal level.

Hawaii's geographic isolation -- roughly 2,500 miles from the nearest land mass -- has played a central role in the evolution of the state's energy system. Even with the recent rapid growth of renewable energy in our electricity sector, more than eighty percent (80%) of Hawaii's energy still comes from petroleum, making us the most oil-dependent state in the nation. For much of the post-war era, Hawaii's over-reliance on oil for power generation had a relatively modest impact on the state's economy and energy security, as crude prices were generally stable. But as global crude markets became more volatile starting with the Arab oil embargo of the early 1970s, Hawaii's dependence on oil became a significant economic liability. Today, Hawaii spends about $5 billion a year to buy foreign oil to support its energy needs. As a result, Hawaii has the highest energy costs among the fifty states. This represents a tax on growth in Hawaii that imposes a significant burden on our residents and businesses.

Economics and energy security were the initial drivers for clean energy plans nearly 40 years ago, but it took more than 30 years for those plans to become actionable policies for greater energy self-sufficiency. There was considerable inertia from Hawaii's historic reliance and interdependence on petroleum as the predominant fuel in all sectors. This was due to the knowledge that downward pressure on petroleum demand in Hawaii's small energy market would adversely affect the delicate product balance of the two local refiners supplying jet fuel, gasoline, diesel, and low sulfur fuel oil. However, increasing calls for greater food and energy security along with a rising sense of the harmful impact of climate change on Hawaii's island communities created the urgency and momentum for change.

An important best practice pursued by Hawaii was the establishment of its first renewable portfolio statute in 2001, requiring renewable energy as a certain percentage of utility sales. The first major milestone in this regard was achieved in 2009 when the Hawaii Legislature passed a forty percent (40%) renewable portfolio standard (RPS) to be achieved by 2030 and an energy efficiency portfolio standard (EEPS) equivalent to a thirty percent (30%) reduction in electricity use through efficiency and conservation. An important distinction from previous plans was the bipartisan coalition of policymakers in Hawaii's congressional delegation and statehouse, which was embodied in a 2008 Memorandum of Agreement between the U.S. Department of Energy and Hawaii, and was subsequently reconfirmed in 2014.

The new policy agenda and roadmap for action was bolstered by an unprecedented partnership of energy stakeholders, all of which became known as the Hawaii Clean Energy Initiative. The Initiative received a significant amount of financial and technical support for resource assessments, scenario analyses, and wind and solar integration studies from the Department of Energy, the National Renewable Energy Laboratory, Office of Naval Research, and the Hawaii Natural Energy Institute. Knowledge gained by this body of challenging work during the past six years provided greater understanding on how Hawaii's islanded grid systems could operate safely and reliably in Hawaii with unprecedented levels of intermittent renewable power. Also, long-term funding for clean energy and energy efficiency technical assistance at the state level was established through a 25 cent fee on each barrel of petroleum product sold in the state, excluding aviation fuel.

In 2013, the Governor established five Energy Policy Directives to offer guidance and clarity for future policy, regulatory and financial actions necessary to fulfill Hawaii's energy transformation. Under the policy directives, Hawaii's new energy ecosystem should consist of a diversified energy portfolio, anchored in indigenous renewable resources, and supported by an integrated and interconnected energy infrastructure. In addition, clean energy development should balance economically and technologically sound solutions and Hawaii's unique environment and culture. Hawaii should also leverage its role as an emerging international clean energy test bed to attract innovation and investments in the new clean energy sector. Finally, Hawaii's renewable future should not be pursued at any cost, but in an environment in which energy efficiency and clean energy can prevail on the basis of providing superior value to conventional energy sources and systems.

Perhaps because of Hawaii's isolation and vulnerability, these common themes have been universally embraced, and the Hawaii Clean Energy Initiative has grown stronger during the course of three gubernatorial administrations and four biennial legislative sessions. Most importantly, energy consumers and other stakeholders have enabled a growing clean energy market that has expanded at such a rapid pace that Hawaii has greatly exceeded its interim RPS and EEPS statutory targets. The RPS topped twenty-one percent (21%) at the end of last year, well ahead of the 2015 interim target of 15 percent. On the energy efficiency side, the state has reduced electricity demand by more than 1,500 gigawatt-hours. Energy efficiency and demand response are playing a crucial role in benefiting both consumers and electric utilities in a number of ways, including with respect to integration of additional renewable energy resources and improving the efficiency of the State's electric grids.

When examining the costs of generation, producing electricity by tapping our world class trade winds, abundant sunshine and other renewable resources compares favorably with producing electricity from oil. While clean energy goals in other jurisdictions may conflict with economic goals to lower the cost of electricity, in Hawaii it is clear that the transformation to a clean energy future is entirely consistent with the economic goals of lowering the cost of electricity. Recent utility-scale renewable energy contracts procured by Hawaii's electric utilities for wind, solar and geothermal are below the avoided cost of oil-fired generation. Power purchase agreements negotiated by Hawaiian Electric Company over the past year for utility scale solar and wind range from 14 cents per kilowatt hour to 15 cents per kilowatt hour. That compares with an average oil-fired price of generation of 20.1 cents per kilowatt hour over the past five years. Also, the tens of thousands of Hawaii residents and businesses who have installed distributed PV systems have been able to slash their electricity bills, with some using the savings to pay off their investments in as little as five to six years.

Hawaii has also led the nation for three consecutive years in the per capita value of energy saving performance contracts. These agreements are between a building owner and a private energy services company specifying that future operational cost savings can be used to pay for the entire cost of a building's energy and water efficiency retrofits. These contracts assist Hawaii in mobilizing investments in high-impact energy efficiency projects to help the State achieve its energy targets.

Hawaii's transition to clean energy has not been without its share of technical challenges and costs associated with incorporating increasingly large percentages of intermittent renewable energy, which was most recently experienced by the rapid growth of distributed solar. Today, I cite three examples of how Hawaii is dealing with these challenges, including the interconnection of intermittent power, integrated resource planning, and the growing integration of the electricity and transportation sectors. A final example also discusses energy assurance and reliability challenges in Hawaii's changing energy ecosystem.

Hawaii is leading the nation in customer adoption of distributed solar. The national average is less than 1 percent. Today, Oahu leads the nation at 12 percent, with Maui a close second at 10 percent, Hawaii island at 9 percent and Kauai at 7.3 percent.

The result of this unprecedented growth in solar is that one-third, or 136 of Hawaiian Electric Company's 416 circuits in Oahu are said to exceed 120 percent of daytime minimum load, with 10 percent exceeding 250 percent. At 250 percent, that means that on any given day, there is 2.5 times the amount of electrical generation capacity on a circuit at certain times of the day than the minimum load requirements. This is a particularly challenging problem given that one of the main jobs of an electric utility is to match load with demand.

When one considers that Hawaii also leads the nation in solar capacity per capita, the rates of renewable penetration are even more impressive because Hawaii's isolated grid cannot absorb the percentage of renewables that can be interconnected in states that are attached to a regional grid. Consequently, often at the firm prodding of the Hawaii Public Utilities Commission and other energy stakeholders, Hawaii's utilities have had to act in real time to propose, deploy and confirm solutions for integrating such high levels of renewables. Among the current strategies deployed by Hawaiian Electric Company are:

- Testing and working on specifications of "fast trip" inverter functionality to avoid transient over-voltage events;
- Computer modeling each individual distribution circuit to determine proactively the DER "hosting capacity" of each circuit; and
- Working with inverter manufacturers to bring to market advanced inverter functionality to manage voltage levels to customers.

These solutions are having an immediate and profound effect on reducing the interconnection queues that were established by the utilities to manage the pace of distributed solar interconnections in the name of system reliability and safety.

A second example is what Hawaii is doing to optimize its energy systems to achieve the new 100 percent RPS by 2045. By becoming the first state in the nation to adopt a 100% renewable portfolio objective by a certain time, Hawaii has effectively defined the end state objective for all future investments in Hawaii's electricity sector.

This allows the planning of systemic change, not incremental change, towards a new clean energy future that is structurally different than the present model. While interim objectives drive investment, all of the steps must be taken in support of the long-term goal. As an example, there may be numerous generation and grid design configurations that support the development of 20% or 40% renewable energy. However, given the type and quality of known or presumed renewable energy options throughout Hawaii, there are clear paths to support a renewable mix at 70% or 100%.

By modeling an even mix of wind, solar and dispatchable renewables such as biomass, geothermal or ocean thermal energy conversion, storage requirements can be reduced by half or more when compared to higher proportions of intermittent renewables, which will result in significant cost savings to ratepayers. The lesson here is that planned optimization at an early stage may limit overbuilding costly solutions and is critical in the long-run containment of costs to upgrade the electrical system.

For these reasons, the Hawaii State Energy Office is focusing on utility resource planning, rate design and price signals to collaborate and inform Hawaii's electric utilities and the Public Utilities Commission on optimal configurations to achieve a growing portfolio of renewable resources, as well as to achieve equitable rates of compensation for installed systems. The goal is simple: working towards 100 percent renewables in a manner that achieves the greatest value for the lowest total cost to all customers.

The third example is how Hawaii is looking beyond the electricity sector by expanding its focus to transportation which accounts for nearly two-thirds of the state's energy mix. Hawaii has just completed a comprehensive analysis on tactics that can be implemented to materially reduce fossil fuel consumption in Hawaii, and has developed a broader energy-transportation stakeholder alliance to collaborate on an energy road map that takes into consideration the growing interdependencies between the transportation and electric sectors.

To best take advantage of tactics dealing with electric drive vehicles, the state is beginning to model load balancing and storage resources for the electricity sector from higher penetrations of electric vehicles. For example, presuming attainment of a 70% renewable portfolio, the addition of 120,000 electric vehicles on the road would increase peak electricity demand by as much as 20 percent, resulting in a corresponding 10 percent increase in energy storage requirements.

However, if the 120,000 electric vehicles are supported by smart charging and advanced systems to be connected to the grid, energy storage requirements might actually be decreased by 10 percent, despite increasing the amount of renewable energy on the electric system.

Hawaii is also investigating the possibility of hydrogen vehicles to offer similar potential as a form of energy storage since hydrogen can be produced at times when renewable energy is abundant and stored for fueling vehicles at appropriate times of the day.

The fact that Hawaii is the most isolated population concentration in the world makes energy resiliency and disaster recovery an even greater concern and all the more valuable. Catastrophic events such as Hurricanes Katrina and Sandy have reminded the nation of the critical value of energy resiliency and disaster preparedness.

The development of micro grids that leverage renewable energy and distributed energy resource investments can provide additional value by providing emergency energy supply to homes, emergency response centers, hospitals, etc. Given Hawaii's commitment to transform its energy sector, and the unique value that such systems bring to Hawaii given its location, make it a prime candidate to develop resilient energy systems.

The search for solutions is helping fuel the growth of innovation in Hawaii. In fact, the very existence of isolated, islanded grids, along with the high energy costs and connections to the Asia-Pacific region has made Hawaii a uniquely attractive laboratory for clean energy solutions. Hawaii's strong commitment to clean energy, evidenced by progressive policies and high rates of deployment and integration has attracted entrepreneurs from around the world, looking to develop, test and prove emerging technologies and strategies before going to market, such as energy storage and smart inverters.

Yet, policy makers in Hawaii have been aware that the clean energy revolution, particularly the ability to install rooftop solar, has not taken place among all demographics and communities throughout the state. As a result, the Hawaii Legislature adopted a plan developed by the Hawaii Department of Business, Economic Development, and Tourism to combine securitized rate reduction bonds and on-bill repayment in the form of a green financing program that targets the underserved among residential customers, renters and nonprofits. This Green Energy Market Securitization (GEMS) program with its initial $150 million issuance of "AAA" bonds and roll-out of loan products has elicited international attention for its innovative approach to funding clean energy projects that can reach a broader clean energy market.

Hawaii's holistic view of its energy systems becomes even more attractive when considering the impact of removing carbon from the environment. The successful push for energy efficiency under the Hawaii Clean Energy Initiative is yielding unprecedented reductions in greenhouse gases. The State Energy Office estimates that at the current rate, the amount of CO2 reductions will bring Hawaii into compliance with the state's greenhouse gas law well in advance of the

2020 requirement to meet 1990 CO2 levels. The analysis demonstrates that the 2020 emissions levels will be lower than the 1990 levels by approximately four percent based on conservative assumptions. Hawaii's efforts to reduce greenhouse gas emissions through a forward-looking energy policy has provided an option to employ a systems approach to carbon reduction that relieves the burden for all large emitters to develop reduction plans and strategies as long as the aggregate CO2 reduction levels are achieved, which should be of particular interest to anyone who lives on an island. With 750 miles of coastline in Hawaii, rising sea levels are a growing concern. Anything that can be done to mitigate greenhouse gas emissions will benefit the coastal communities in Hawaii, including iconic Waikiki Beach.

In conclusion, Hawaii has been able to leverage its isolation and the challenges faced in the arena of clean energy to great advantage. Hawaii has been able to attract international investment from governments and corporations that see Hawaii as a bellwether for renewable energy, and a place where the next generation of energy solutions will be born. This success prompted both the administration of Governor David Ige and the Hawaii Legislature to rethink the potential of Hawaii's clean energy transformation. The upshot was the passage of a bill -- signed by Governor Ige in June of this year -- calling for Hawaii's electric utilities to accelerate the 2020 interim RPS target for renewables from 25% to 30%. Hawaii's continual refinement of its RPS targets assists in resource optimization, prevents costly overbuilds, and sets a clear, unambiguous goal of generating one hundred percent (100%) of electricity sales from its renewable sources by 2045. Hawaii's approach of setting targets for its utilities is a practical approach to further the state's energy policies.

Thank you for this opportunity to highlight Hawaii's clean energy leadership and share some of the lessons we have learned in pursuing our clean energy transformation.