Renewable Energy in Hawai‘i:
A Comparative Analysis of Wind, Solar, and Geothermal Energy Resources

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GG 499 (Undergraduate Thesis)

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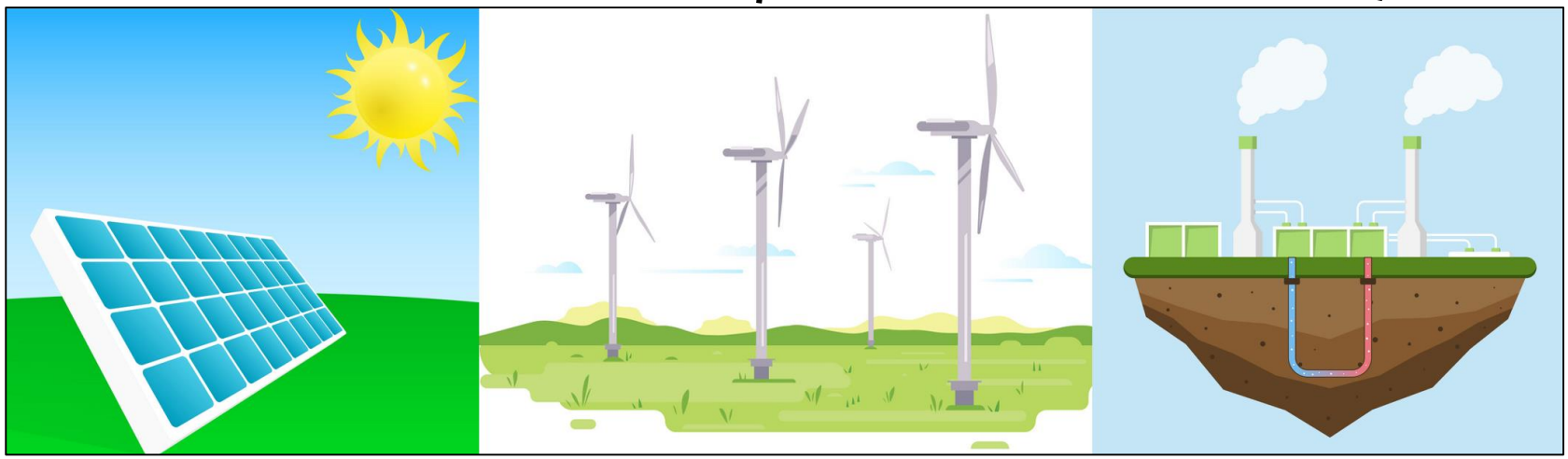
Outline

- Project Methodology
- Background
  - Power Supply Improvement Plan (PSIP)
  - Renewable Energy Forecast for Hawai‘i
- Renewable Energy Basics
  - Energy jargon
  - Overview of major renewables in the PSIP
- Findings – Renewable Energy Comparisons
  - Land use
  - Cost
  - Geothermal hazards
- Final Thoughts

Project Methodology

Compare the land use, cost and hazards of three hypothetical renewable resources with similar power delivery capabilities using **PGV** as the model for comparison



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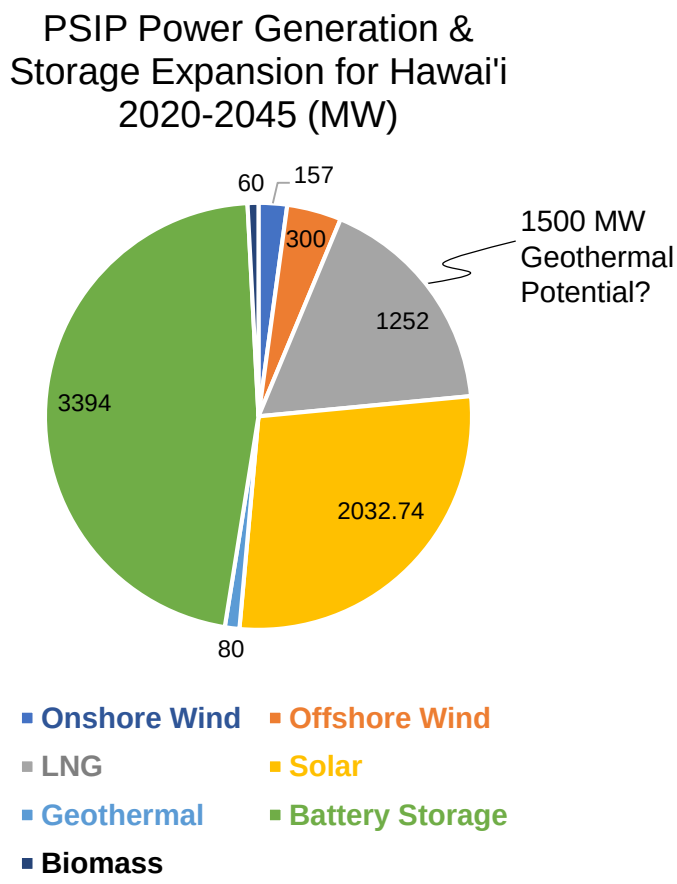
Hawaiian Electric Company Power Supply Improvement Plan

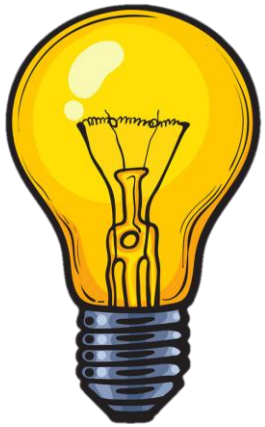
- Hawai‘i Clean Energy Initiative (HCEI) set goal to achieve 100% renewables by 2045
- Plan developed by Hawaiian Electric (HECO) and published in the Power Supply Improvement Plan (PSIP)
- PSIP development was collaborative – NREL
- PSIP review process was exhaustive



Energy Jargon

- kW vs kWh → rate vs quantity
- Watt = 1 Joule / second → **time included**
- When time is added as suffix → **quantity**
- kWh
- MWh
- GWh
- GWy

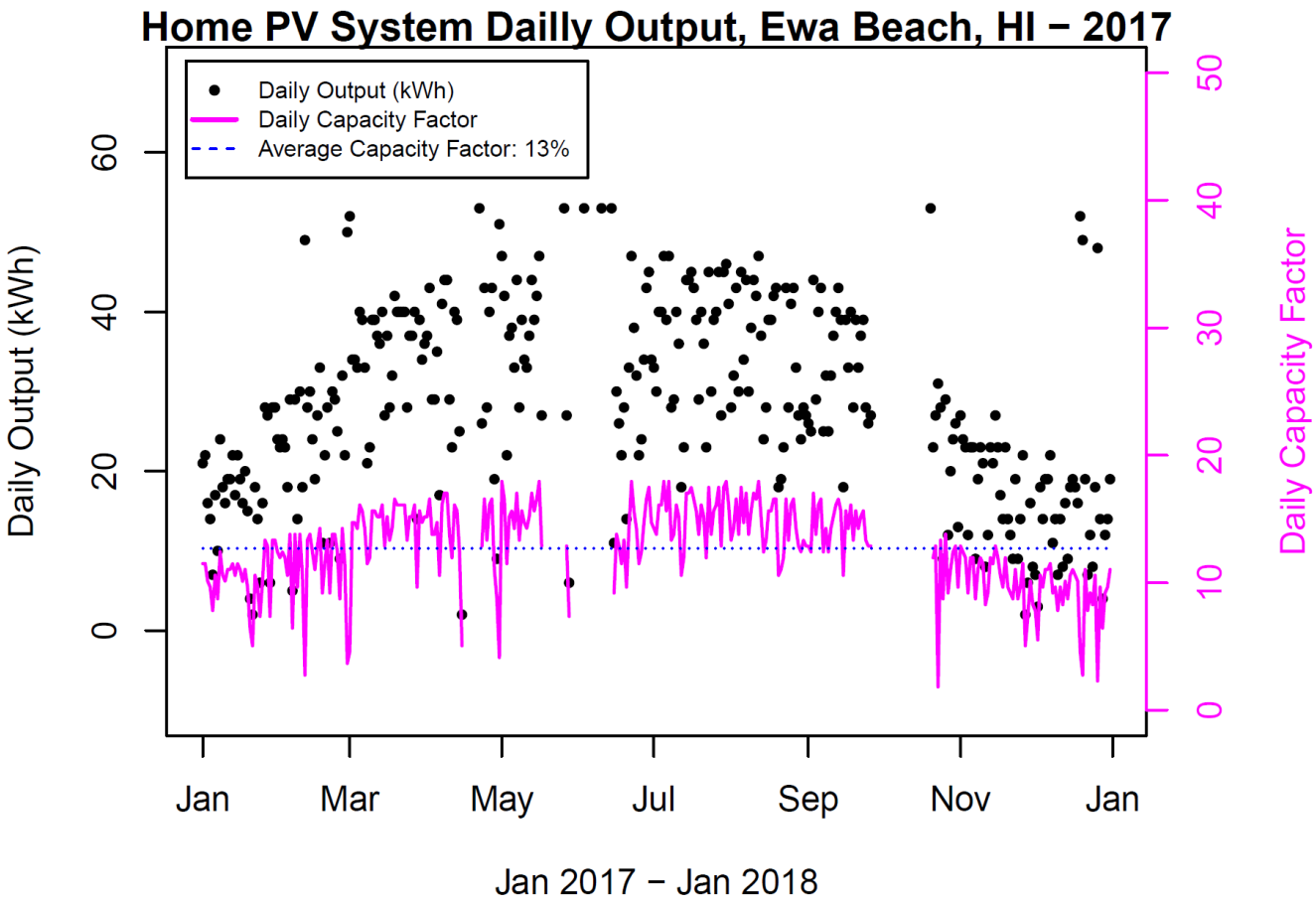
Joules

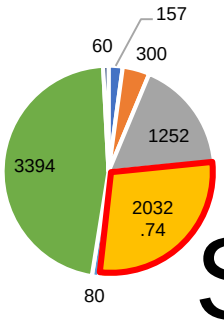
1 kWh =  **for 24 hours**

Energy Jargon

- Nameplate Capacity: **maximum** electricity output
- Capacity Factor: percent of maximum output for a year
  - Measure of the efficiency of a power plant
    - Powerplants usually publicly owned & financed
    - Sell more product (power) pay back debt & earn profit faster
- Baseload Energy: **minimum** power required over a given period
  - Wind and solar cannot provide baseload energy – at some point, due to season or time of day, most renewables will not generate any electricity
  - Major challenge with implementation of Hawai'i's PSIP
  - PSIP answer: **lots of battery storage**

Baseload Energy & Capacity Factor





Solar Energy

- Electromagnetic radiation used to excite electrons and induce voltage
- Capacity factor: 20 – 25%
- Land use: 5 – 10 acres/MW
- Hazards:
  - Solar cells are made with silicon purified from high grade quartz which requires mining
  - A Single 4” solar wafer requires 0.77 kWh of energy and 8.9 grams of hazardous production chemicals

EE Waianae Solar Project LLC

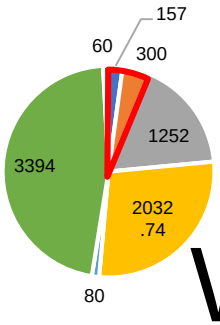
Silica sand mine in Ottawa, IL
Alex Garcia, Chicago Tribune, Nov. 20, 2013

This solar farm likely required

≈

70,000 gallons of chemicals
25,000 MWh of electricity

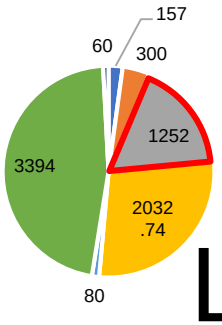
EE Waianae Solar Project LLC



Wind Energy

- Kinetic energy in air used to spin turbines and generate electricity
- Capacity factor: 35 – 45%
- Land use: 30 -113 acres/MW
- Hazards:
  - 2 MW turbine requires 700 tons of concrete which releases 500 – 700 tons of CO_2
  - 364 MW of wind on Oahu will release similar volume of CO_2 as 20,000 passenger cars over a year
  - Uncharacterized ecological and health impacts

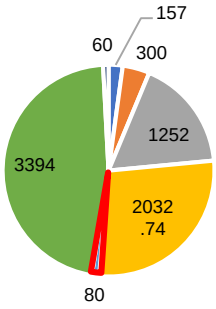
Kaheawa Wind Farm



Liquid Natural Gas

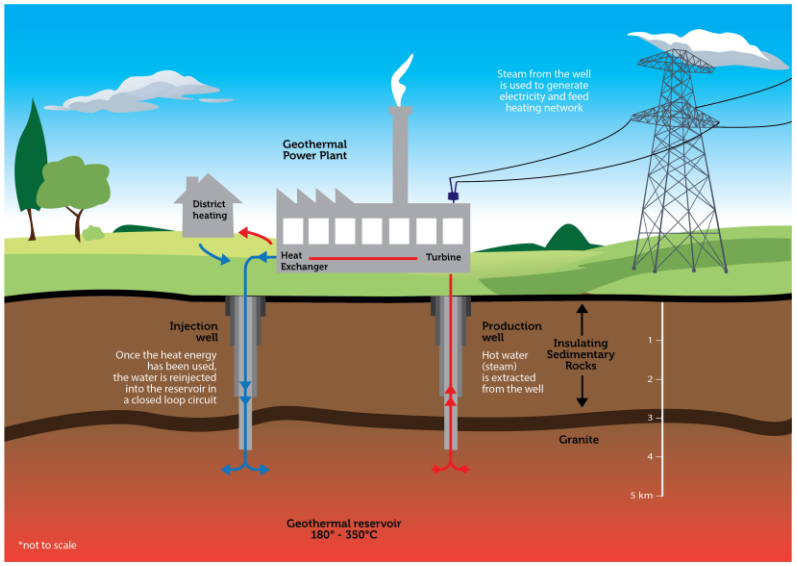
- Chemical energy in hydrocarbons used to generate heat and spin turbines
- Capacity factor limited only by demand
- Generating capacity generally an order of magnitude greater than renewable resources
- Hazards
  - Combustion emits CO_2
  - Storage and transportation
  - Water consumption

Schofield Generating Station



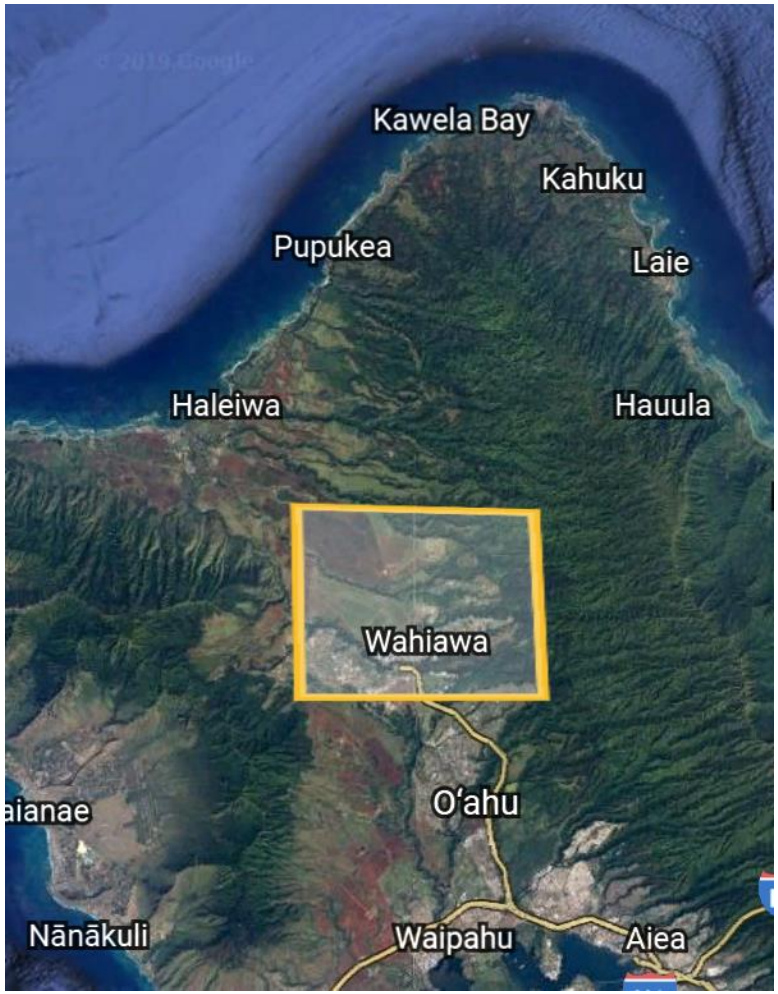
PGV Geothermal

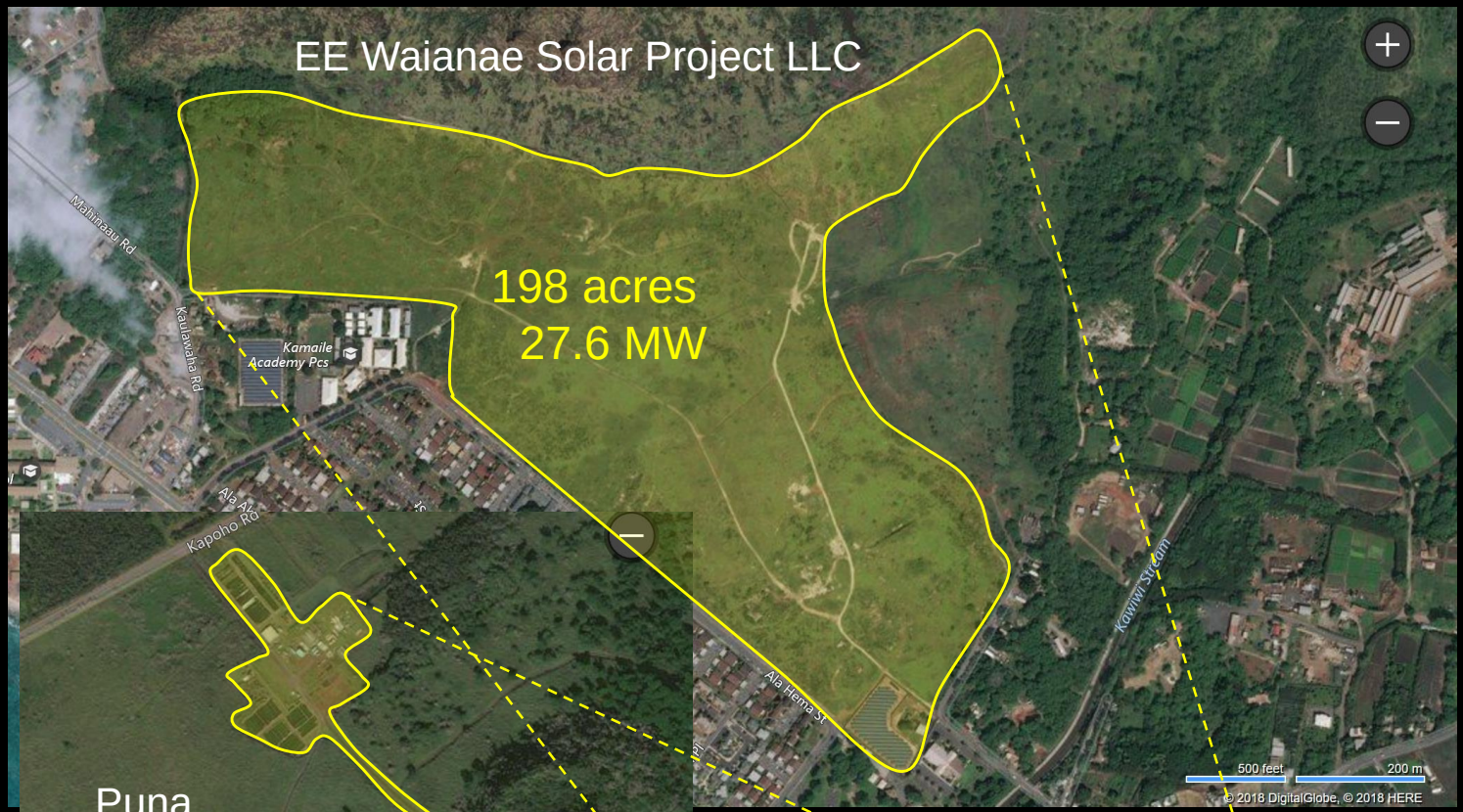
- Heat from the earth channeled to the surface with water and used to spin turbines
- PGV: 38 MW installed capacity
- 322,609 MWh in 2017
- Capacity factor:
  - **PGV: 97% in 2017**
  - General: 70-75%
- Land use:
  - PGV: 1 acre/MW
  - General: 1-8 acres/MW
- Hazards:
  - Blowouts and H_2S
  - Drilling
  - Motive fluids
  - Noise

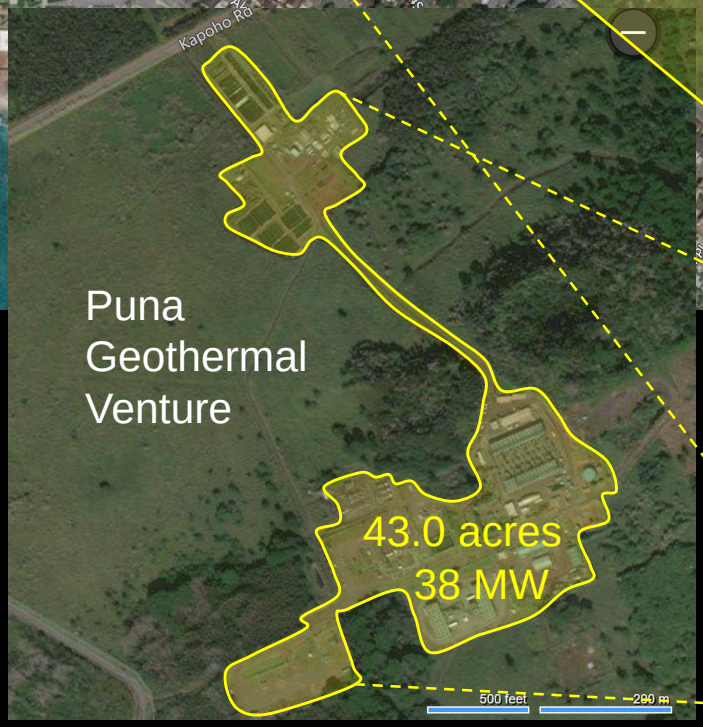


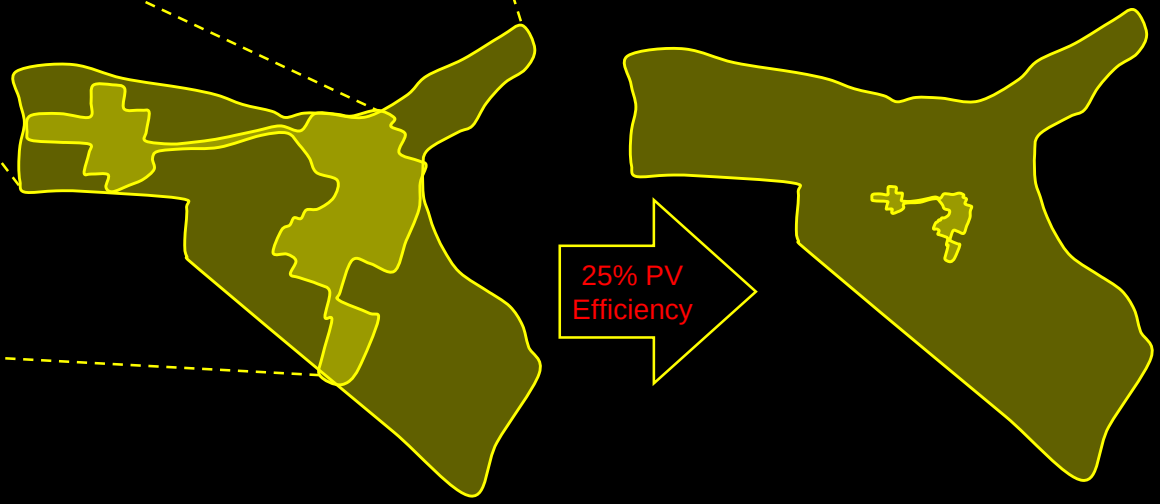
Renewable Energy Comparison: Land Use

- PGV produced 322,609 MWh in 2017
- Comparable Wind: **2,500 – 12,000 acres**
- Comparable Solar: **700 – 1900 acres**
- PSIP projects 364 MW of wind and 1904 MW of solar on O‘ahu
- **30 – 90** square miles of land and/or sea









- EE Waianae Solar Project is the largest PV plant in the state [1]
- PV farms operate at 20-25% of max capacity [2]
- PGV operated at **97%** capacity in 2017 [3]
- 27.6 MW → 6.6 MW
- 38 MW → 37 MW
- ~1100 acres of PV to match PGV output

References
1 – Star Advertiser, January 25, 2017
2 – Hawaii Energy Facts & Figures 2016, page 3
3 – Renewable Portfolio Standard (RPS) Report 2017, pg 3

Renewable Energy Comparison: Cost

Resource		Utility Scale Solar	Onshore Wind	PGV
Capacity factor		20-25%	35-45%	97%
Installed capacity to match PGV 2017 output (322,609 MWh)		147-184 MW	82-105 MW	38 MW
Cost per installed kW ($/kW)		$2,057	$2,867	$11,302
Plant construction cost in 2030		$302,379,000 – 378,488,000	$235,094,000 – 301,035,000	$429,476,000
Energy storage cost ($/kWh)		$ 250		NA
Daily kWh storage at 25%		220,965 kWh		
25% energy storage cost		$55,241,267		
Daily kWh storage at 50%		441,930 kWh		
50% energy storage cost		$110,482,534		
Daily kWh storage at 75%		662,895 kWh		
75% energy storage cost		$165,723,801		
Fixed Annual O&M costs ($/kW)		$31.80	$43.38	$202.97
Total Annual O&M Cost		$4,674,600 – 5,851,200	$3,557,160 – 4,554,900	$7,712,860
Total Capital Cost	25% storage	$357,620,267 – 433,729,267	$290,335,267 – 356,276,267	**$429,476,000**
	50% storage	$412,861,534 – 488,970,534	$345,576,534 – 411,517,534	
	75% storage	$468,111,801 – **544,211,801**	$400,817,801 – **466,758,801**	

Renewable Energy Comparison: Cost

- Subsidies
  - Net Energy Metering Program
  - Hawai‘i Renewable Energy Technology Income Tax Credit
    - **$673.3 million** from 2011 to 2016
  - Renewable Energy Property Tax Exemption
- Geothermal Royalties
  - **$24.7 million** to State of Hawai‘i from 2007 to 2018
- **Geothermal costs are competitive with other renewables when necessity of energy storage and subsidies are considered**

PGV Emissions

- OSHA H_2S standards
  - Toxic above **100 ppm**
  - Irritant above **10 ppm**
- The Hawai‘i DOH limit for H_2S emissions during any one-hour period at PGV is **25 ppb**
- Research from UH Hilo showed that H_2S emissions over seven-year period never exceeded 23 ppb
- $H_2S + O_2 \rightarrow SO_2 + H_20$
- 1991 blowout released ~ 1 ton of H_2S over a short period
- Kīlauea Volcano releases 2,000 tons of SO_2 every day (~1065 tons of H_2S)

PGV during construction

Kīlauea Volcano, Halema‘uma‘u Crater

Final Thoughts

- Geothermal has the lowest land use of all non-nuclear, non-hydrocarbon renewable resources
- Geothermal is competitive with other renewables in terms of costs and hazards
- Geothermal provides clean, renewable baseload energy
- Geothermal potential through most of the state is **unknown**
- Limited research efforts to determine geothermal potential because its not a priority
- **Our lives are energy intensive…**
- Not in my backyard…but in someone else's?

“To achieve our goal of getting off fossil fuels, these reductions in demand and increases in supply must be big. **Don’t be distracted by the myth that “every little helps.” If everyone does a little, we’ll achieve only a little. We must do a lot.”**

Dr. David JC McKay, “Sustainable Energy – without the hot air”:

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