# Real Options for Geothermal Energy Lightning Dock Expansion

#### Chad Holmes IDS.330 Spring 2021

https://www.gannett-cdh.com/presto/2019/03/28/PNM2/a16b7b85-101a-4321-8bfa-bf49be1e27d4dju 20190224 Lordsburg 251.jpg?width=660&height=441&fit=crop&format=pjpg&auto=webp

### Cautionary Statement

The work presented here was completed by the author as an academic exercise in partial fulfillment of the requirements for MIT course IDS.330 and are not endorsed by any professional company, organization, or working group.

Information included in the models is based on publicly available data. Model inputs were determined from primary sources or selected as a best educated guess by the author when no suitable information source could be identified.

Although referenced directly in the report, neither Cyrq Energy nor Climeon was directly consulted on the content. Conclusions drawn within this report should not be considered a professional recommendation, but simply a hypothetical analysis for the purposes of educational training.

### Lightning Dock History

#### Lightning Dock KGRA: Hidalgo County, New Mexico

- 1948 Agricultural well struck boiling water at 26.5 m depth
- 1977 AMAX Exploration drilled 58 wells as part of an exploration campaign.
- 1977 Burgett Geothermal Greenhouses, Inc. began operating with direct use of geothermal waters.
- 1982 Burgett installed 40 kW and 100 kW plants, which failed after installation. Tried again with other designs in 1995 and 2008.
- 1986 Lightning Dock Geothermal, Inc. obtained lease to develop a power plant.
- 2013 Cyrq Energy (post-acquisition) brought <mark>4 MW plant</mark> online and formed a power purchase agreement (PPA) with Public Services of New Mexico (PNM).
- 2018 Turboden repowered Lightning Dock, increasing commercial capacity to 10 MW.



#### From Fig 1 in (Crowell and Crowell, 2014)

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## Geothermal in NM: Renewable Portfolio Standard (RPS)



Click below to search the NMPRC website

#### New Mexico Public Regulation Commission and Renewable Energy in New Mexico

The <u>Public Regulation Commission</u> reviews and approves renewable energy procurement plans and reports of <u>Investor Owned Utilities</u> ("IOU's") and <u>Rural Electric Cooperatives</u> ("Coops") pursuant to the <u>Renewable Energy Act ("REA"), §§ 62-16-1 et seq. NMSA 1978</u> and <u>Title 17.9.572</u> <u>NMAC</u> ("Rule 572"). IOU's in New Mexico are procuring renewable energy and renewable energy certificates from New Mexico renewable generation facilities to meet the Renewable Portfolio Standard (RPS) requirements of the REA and Rule 572.

#### **Investor Owned Utilities and the RPS**

The REA and Rule 572 established an RPS applicable to all investor owned electric utilities in New Mexico. In 2006, the RPS will be 5% of retail sales in <u>kWh's</u>, reaching 10% by the year 2011. Recent legislative changes to the REA (<u>SB418</u>, signed March 5, 2007 by Governor Bill Richardson) have increased the RPS percentages and extended the time lines - IOU's now must have in their portfolio as a percentage of total retail sales to New Mexico customers, renewable energy of no less than 15% (by 2015) and 20% (by 2020).

Resource Diversity and the RPS In addition to the RPS, Adde 572 requires within the total portfolio percentage requires Diversity requirements for IOU's as % of No less than 30% Wind No less than 20% Solar No less than 5% Other technologies

Mo less than *30% Wind* No less than *20% Solar* No less than *5% Other technologies* 

No less than 1.5% Distributed Generation (2011-2014) and 3% Distributed Generation by 2015

#### http://www.nmprc.state.nm.us/utilities/renewable-energy.html

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Geothermal energy uses heat from below the earth's crust to create steam that turns the turbine, ultimately generating electricity. Like wind and solar, geothermal energy emits no pollutants into the air; unlike wind and solar energy, it is available to serve customers around the clock.

#### PNM is the first customer to take energy

from the Lightning Dock Geothermal Plant,

#### https://www.pnm.com/geothermal

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### Enhanced Geothermal Systems (EGS)



IDS.330 Final Project

energy.gov/sites/default/files/2015/04/f22/EGS%20Infographic 0.pdf

ACKGROUND m

### Binary Cycle Power Plants



Image from U.S. Dept of Energy energy.gov/eere/geothermal/electricitygeneration IDS.330 Final Project Source: public domain. Used with permission.

- Primary fluid produced from the subsurface.
- Heat exchange between primary and secondary fluid with a low boiling point.
- Secondary fluid flashes to vapor and drives the turbines.
- Typically used for moderate to low temperature geothermal (≤180°C).

### Modular Concepts

- Climeon offers a compact binary cycle geothermal unit (HP150).
- Units cluster to form a Power Block.
- Power Blocks can be independently installed to build a larger-capacity aggregate facility.



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### Deterministic Case

- Excel-based model for NPV calculation
- NPV (discount rate = 9%) components:
  - Income = electricity generated times PPA pricing (kWh\*\$/kWh)
  - **CAPEX** = wells + power plant + fluid distribution + stimulation + exploration
  - OPEX = power plant O&M + field O&M + water O&M + labor
- Assumes a **30-year life span**
- Assumes a <u>50</u>% above wholesale electricity price for power purchase agreement (PPA)
  - Similar to current value of Cyrq/PNM PPA
  - Can be easily adjusted on cover sheet with alternate values

Deterministic Model		Case Study, Light	ning Dock, INNI			
RESOURCE	VALUE	UNITS	REFERENCE		NOTES	
Surface Temperature (2020)	15.8	degrees C	Dahal 2012		10120	
Austrana Casthermal Cradient	10.0	degrees C / km	Crewell 2014: een he hi	hanad on hele TC FF 14	A lon CW of an amaly	
werage Well Depth (near verical MD)	11	legiees C / Kill	Crowell, 2014, Call be In	pased on hore 10 50-14,	, 4 Kill Svy of allohidiy	
nitial Average Reservoir Temperature	126	dagroop C		calculated based on res	Elvoir temperature Els of Climoon (max: 120)	C)
Production Well Temperature Loss	5	degrees C	Beckers 2013: GETEM	aggressive value. Becke	rs uses 10deg w/ 5km we	<ul> <li>GETEM calculates</li> </ul>
Production Temperature (at well head)	120	degrees C		re-compute with equation	n from Beckers 2016 onc	e other variables defi
Nater Loss Rate	2%	% of injected water	SAM	for open loop		
Production Flow Rate per Well Pair	35	ka/s	GETEM NREI	https://atb.nrel.gov/elect	ricity/2020/index.php?t=a	t
		-			, , , , , ,	
CAPEX (per module)	VALUE	UNITS	REFERENCE		NOTES	
Drilling & Completions Costs	\$ 1,305,956	16 USD (1 well)	Beckers 2013	Lukawski, 2016		
Vells per module		2 well count per unit		doublet		
Surface Plant Costs	\$ 1,000	00 \$/kWe	Beckers 2013	waiting on reply from Ba	seload Cap., stick with th	is for now
Reservoir Stimulation per injection well	\$ 1,250,000	00 USD	Lowry, 2017	\$1,250,000 per injector s	stimulation, recent ballpar	k figure so no cost a
-luid Distribution Costs	\$ 279,300		Beckers 2013	also ballpark figure, need	ds additional study based	on New Mexico for r
Redevelopment Factor		.05	pers. conversation, Pres	could be cheaper to redr	ill than drill from scratch	
hermal Drawdown Threshold		3.0 degrees C	GETEM	0.2111-12.2		
hermal Drawdown Rate	(	5%	GETEM	varies from author-to-aut	hor (up to 4%)	
Redevelop Every		24 years				
Exploration Success Rate	100	0%		assumed 100% since ar	ea is already developed, i	normally ~20% (Glas
otal Capital Costs (exploration)	\$ 2,133,542	54 USD	Beckers 2016	Ccap = Ccap;well + Cca	p;pp + Ccap;stim + Ccap	;distr + Ccap;expl
otal Capital Costs (drilling)	\$ 2,611,912	33 USD	Beckers 2016			
otal Capital Costs (non-drilling)	\$ 3,121.310	00 USD	Beckers 2016			
POWER PLANT (modules)	VALUE	UNITS	REFERENCE		NOTES	
Plant Type	Binary ORC			governs system physics		
Plant Useful Life	30	years	Augustine, 2009	basis for cost analysis		
leat Inlet Temperature	120	degrees C		simplifying assumption,	ignoring secondary fluid h	eat exchange
Cool Inlet Temperature	50	degrees C		backing out from known	Climeon Mwe	
leat Capacity	2.28	kJ/kg-K	Dincer, 2010	isobutane, not sure if thi	s is their fluid	
femperature Drop	70.0	degrees C (or K)				
nthalpy Drop	5.6	MWth		Q = q x Cp X delta T		
Panacity Eactor	95%		Glassly 2015, GETEM			
Jupucity Fuctor						
Degradation Factor	0.5%		NREL, 2002	using 0.5% NREL degra	dation per year	
Degradation Factor Generation Efficiency (2nd Law Efficiency)	0.5%		NREL, 2002 Beckers 2019, Glassley	using 0.5% NREL degra relates power production	dation per year ı (Mwe) to exergy of geoth	nermal fluid
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Selle value. SS. Olvily



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IDS.330 Final Project

### **Electricity Price**

- Price step change inserted on a random date (uniform selection) and magnitude sampled from PDF
- Volatility added by sampling from normal distribution determined from forecast and confidence intervals.







#### Base Case

#### Uncertainties

- Drilling & completions costs
- Pricing (future step change)
- Thermal drawdown rate
- Geothermal gradient

#### Flexibilities

• None

N=2000
-\$4.0MM
\$8.7MM
-\$19.8MM
-\$2.3MM
\$6.6MM
-207%





## Redevelop Only

Uncertainties

• Same as Base Case

Flexibilities

 Redrill after 13°C thermal drawdown. Temperature gets reset for primary fluid entering plant.

REDRILL



<b>Redevelop Only Statistics</b>	N=2000
ENPV	-\$1.8MM
STD(NPV)	\$6.5MM
P05 NPV	-\$14.3MM
P50 NPV	-\$0.7MM
P95 NPV	\$6.5MM
% Difference from NPV Det	-150%

### Redevelop and Grow

Uncertainties

• Same as Base Case

Flexibilities

CENARIOS

- Redrill after 13°C drawdown.
- Increase capacity 25% if prices up ≥20% compared to time of PPA signing.

REDRILL

BUILD

• PPA rate "renegotiated" with each capacity increase.

<b>Redevelop Grow Statistics</b>	N=2000
ENPV	\$9.7MM
STD(NPV)	\$10.3MM
P05 NPV	-\$6.6MM
P50 NPV	\$9.4MM
P95 NPV	\$27.0MM
% Difference from NPV Det	162%



## Full Flexibility

Uncertainties

• Same as Base Case

#### Flexibilities

- Redrill after 13°C drawdown.
- Increase capacity 25% if prices up ≥20% compared to time of PPA signing.

REDRILL

BUILD

SHRINK

 Shut down 25% of modules if prices suddenly drop by ≥20%.

Full Flexibility Statistics	N=2000
ENPV	\$8.2MM
STD(NPV)	\$10.3MM
P05 NPV	-\$8.8MM
P50 NPV	\$8.1MM
P95 NPV	\$25.2MM
% Difference from NPV <sub>Det</sub>	121%



## Key Insights

- Redevelop and Grow case dominates all other scenarios.
   Best model.
- Full Flexibility less attractive likely due to the loss of income as modules taken offline.



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## Sensitivity Test for Full Flexibility Case

- Increasing **reduction amount** (RA) leads to greater downside risk and lower ENPV.
- Redevelop and Grow scenario is the natural limit as  $RF \rightarrow 0$ .

#### **General Parameters**

Contract rate over wholesale	50%
Drilling learning rate	6%
Discount rate	9%
Price trigger for flexibility	20%
Expansion amount	25%
Reduction amount	50%



**RESULTS GET WORSE** 

## Sensitivity Test for Full Flexibility Case

- Decreasing **reduction amount** (RA) reveals a window where downside risk is lower and ENPV is maximized.
- Full Flexibility with RA=10% is the preferred model.

#### **General Parameters**

Contract rate over wholesale	50%
Drilling learning rate	6%
Discount rate	9%
Price trigger for flexibility	20%
Expansion amount	25%
Reduction amount	10%



#### Learnings and Recommendation

- **Deterministic model** overpredicts NPV compared to the Base Case Monte Carlo model (Flaw of Averages). The deterministic predicted profit nearly matches the Base Case predicted loss.
- Base Case scenario has significant downside with >60% of modeled realizations ending in losses.
- Redevelop Only scenario limits downside risk. ~56% of model realizations still result in a net loss, but the losses are not as extreme as in the Base Case.
- Redevelop and Grow scenario significantly improves upside capture by increasing capacity and renegotiating PPAs when electricity prices surge. Also reduces downside risk and has an ENPV of just under \$10MM.
- Full Flexibility scenario performs worse than Redevelop and Grow when 25%+ of existing power plant modules are shut down in response to a downturn in electricity prices. 10% reduction produces the recommended model with twice the ENPV of the deterministic case and the least downside risk among all scenarios. This model correctly balances cost savings of lower O&M expenses with income loss from reduced capacity.

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IDS.333 Risk and Decision Analysis Fall 2021

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