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Salton Sea Geothermal Development

Nontechnical Barriers to Entry – Analysis and Perspectives

June 2022

Dave Goodman
Patrick Mirick
Kyle Wilson

U.S. DEPARTMENT OF ENERGY

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Abstract

Geothermal energy offers an opportunity to generate baseload, renewable energy that can help support the transition to an energy economy with reduced impacts on climate change and replace older, more expensive, nonrenewable, and more resource-impacting energy-generation facilities. The United States has the largest known geothermal resource in the world, with over 31 GW of conventional geothermal potential. However, due to market conditions, an inability to properly quantify both electrical grid benefits and resource stability, and the difficulty of exploring and developing the geothermal resource, few new geothermal projects have come online over the past three decades.

The Salton Sea, in Imperial County, California, provides a prime location and opportunity to develop new geothermal resources. The Salton Sea contains a robust, well-mapped, geothermal resource, with opportunities for concurrent development of lithium and other mineral resources. This report describes the history of geothermal development at the Salton Sea and compares geothermal to other renewable energy sources in the area. The report then uses a techno-economic analysis (TEA) model referred to as MAGE (Model for Analysis of Geothermal Economics) to analyze the relative benefits and costs of various challenges and opportunities and provides recommendations for streamlining geothermal development at the Salton Sea and elsewhere. The challenges and opportunities analyzed in MAGE were informed by stakeholder interviews and literature reviews.

Based upon the identified challenges and opportunities and the results of MAGE, primary findings are that certain nontechnical barriers such as permitting costs play only a minor role in determining the viability of development of the geothermal resource at the Salton Sea. Other barriers such as permitting timelines, government/agency coordination, and the potential co-location of lithium extraction with a geothermal plant may result in much larger impacts on project viability.

Executive Summary

Geothermal energy offers an opportunity to generate baseload, renewable energy that can help respond to the impacts of climate change and replace older, more expensive, nonrenewable, and more resource-affecting energy-generation facilities. The United States has the largest known geothermal resource in the world—more than 31 GW of conventional geothermal potential. However, due to market conditions, an inability to properly quantify electrical grid benefits and resource stability, and the difficulty of exploring and developing the geothermal resource, few new geothermal projects have come online over the past three decades.

The Salton Sea, in Imperial County, California, provides a prime location and opportunity to develop new geothermal resources. It contains a robust, well-mapped, geothermal resource, with opportunities for concurrent development of lithium and other mineral resources. However, most geothermal plants at the Salton Sea were built in the 1980s and while extensive undeveloped resources exist, there has been limited development since then (one new plant in 2012 and another planned for 2023). Future geothermal development in the area is generally supported by federal and state energy agencies, power buyers (utilities), the county planning and permitting agency, and by several environmental nongovernmental organizations.

The technology and history of geothermal development, current historical and economic conditions and various energy resources at the Salton Sea compared to geothermal resources are described, followed by a techno-economic analysis (TEA) model that attempts to quantify the nontechnical challenges and opportunities associated with new geothermal development at the Salton Sea. This model, referred to as MAGE (Model for Analysis of Geothermal Economics) can help explore impacts from reducing permitting costs or increasing tax subsidies, to support evaluations of how beneficial these actions may be for reducing the cost of geothermal electricity (help make it more competitive with other renewable energy sources) and increasing the profitability of a new power plant (e.g., reducing payback period durations).

MAGE starts with the development of a hypothetical baseline geothermal plant with status quo input parameters for capital costs, operation and maintenance costs, exploration/permitting and construction times, permitting times and fees, financing terms, taxes, federal subsidies, and more (see Table S.1 for assumptions). The baseline MAGE scenario was built upon research and guidance from power producers, utilities, and government regulators about what the proper input parameters should be for the hypothetical plant. The model will be provided to the public so that they can adjust the parameters to build their own hypothetical plant, customize the design (e.g., adjusting capital costs), and evaluate the benefits of their own potential solutions (e.g., increasing subsidies).

MAGE divides the geothermal process into three stages: exploration and permitting, construction, and operation. Exploration and permitting are the first steps in the process and may occur concurrently. Steps associated with exploration may include acquisition of the land and/or obtaining a lease, water sampling, exploration surveys, and drilling of exploratory and test wells. Permitting encompasses compliance with federal, state, and/or local environmental compliance requirements, along with acquisition of any land use, zoning, and/or construction permits. Construction involves the building of the plant, wells, and ancillary facilities. Steps may include drilling production wells, construction of the geothermal plant and support structures, and construction of offsite transmission lines necessary to transport the power to load centers.

The outputs of the baseline MAGE scenario denoting these three stages of the geothermal process are shown below in Figure S.1, the results of various MAGE sensitivity model runs are shown in Table S.2, and the effectiveness of different actions for geothermal are summarized below.

Table S.1. Input parameters used to establish the base model Salton Sea geothermal plant.

Parameter	Value
Geothermal Plant	
CAPX geothermal	$3,500/kW (171.5M for 49 MW plant)
OPEX geothermal	$3.25M/yr
Permit + habitat mitigation costs	$1,000,000
Plant lifetime	30 years
Plant size	49 MW
Capacity factor	330 days per year
Annual production loss	1%
Financial	
Discount rate	7.1% WACC for exploration and operation.
Power price	$80/MWh
Federal tax rate	21%
State tax rate	8.84%
Regulatory	
Construction time	4 years
Exploration time	4 years
Exploration cost	$10M
Investment tax credit	10%
Annual Property taxes	3.5M
Lithium	
CAPX lithium	$35M
OPEX lithium	$40M per year
Lithium harvest	8,350 tons per year
Wholesale lithium price	$13,000 per ton of lithium carbonate
CAPX = capital costs; OPEX = operations costs; WACC = weighted average cost of capital.	

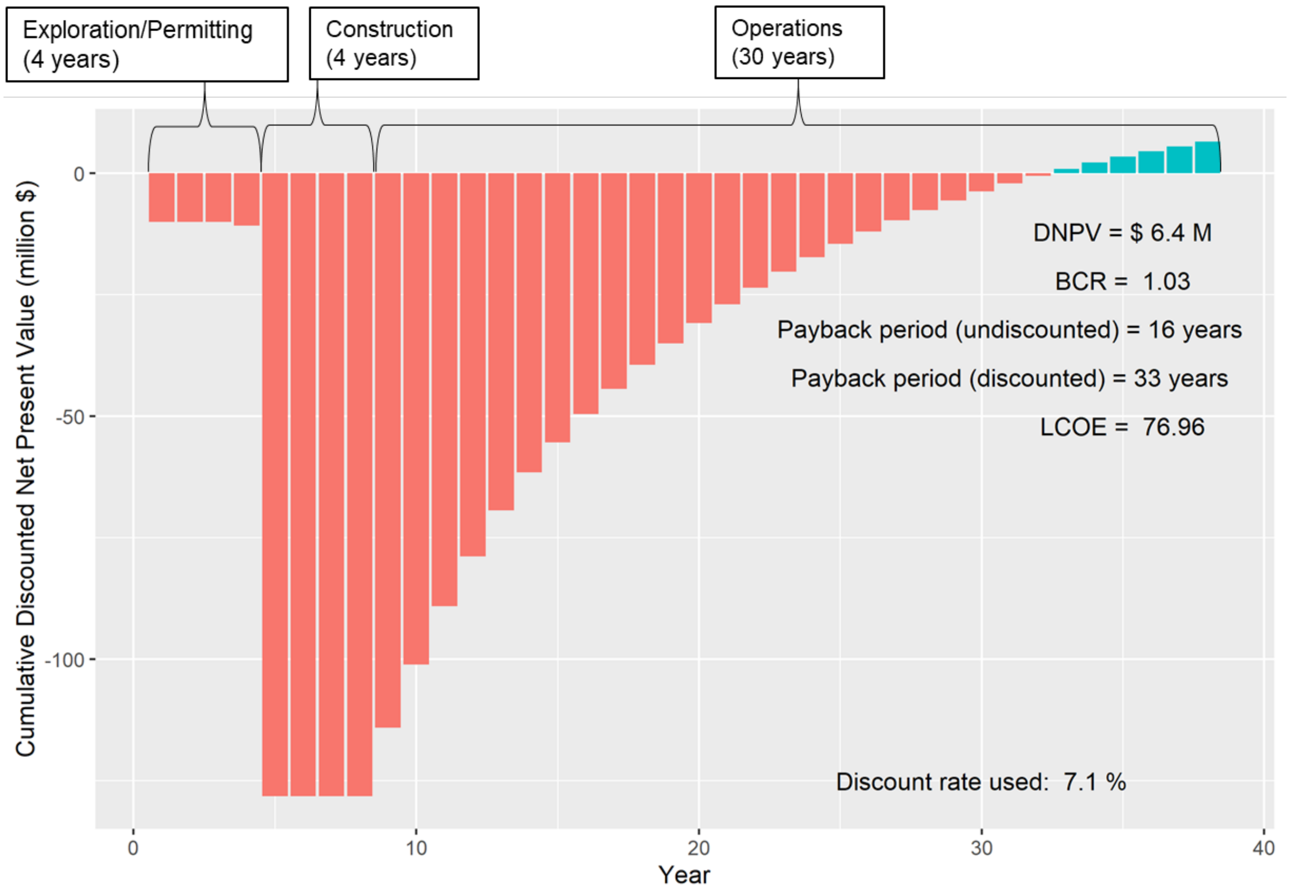

Figure S.1. Baseline MAGE outputs.

Table S.2. MAGE outputs associated with various scenarios.

Scenario	DNPV (M$)	BCR	Payback period (Discounted)	Payback period (Undiscounted)	LCOE ($/MWh)
Baseline (4 years exploration and permitting; 4 years construction)	**6.4**	**1.03**	**33**	**16**	**76.96**
Zero Permit Costs	7.2	1.03	32	16	76.57
Exploration and permitting time reduced 1 year	7.6	1.03	31	15	76.65
Exploration and permitting time reduced 2 years	8.4	1.04	30	14	76.52
Exploration and permitting time 6 years	4.3	1.02	36	18	77.66
Construction time reduced 1 year	16.0	1.07	27	15	72.93
Exploration and permitting time reduced 3 years, construction time reduced 1 year	21.43	1.08	23	12	72.27
Exploration and permitting costs increased to $20M	-3.60	0.98	NA	17	81.71
Construction costs reduced 20%	32.7	1.18	22	14	64.42
Construction costs reduced 33%	43.1	1.25	20	14	59.05
Capital costs increased 110%	-175.7	0.55	NA	NA	160.49
30% Capital Subsidy	31.1	1.17	22	14	65.17
26% Capital Subsidy	26.3	1.14	24	15	67.53
Property Tax Waiver	26.7	1.14	25	15	67.31
Discount rate reduced by 1%	24.1	1.11	27	16	70.20
3% Discount Rate	115.5	1.36	19	16	52.92
Equity financing - internal funding	-31.8	0.78	NA	16	108.78
Equity financing - external funding	-34.2	0.49	NA	16	188.46
EGS inputs	96.5	1.21	22	15	62.19
Lithium plant	350.1	1.52	11	12	N/A

BCR = benefit-cost ratio; DNPV = discounted net present value; EGS = enhanced geothermal system; LCOE = levelized cost of electricity.

Based upon the MAGE results, reducing capital costs and the discount rate show the largest gains in LCOE and other outputs. Reducing permitting and mitigation costs, reducing the regulatory timeframe, and reducing the exploration costs do not have as large of an impact.

Government policy has little direct influence over the capital or operating costs of a project. These can only be reduced via subsidies such as tax waivers. These types of subsidies result in a dollar-for-dollar gain for the project. Various state and federal subsidies existed in the 1980s when geothermal development was at its peak at the Salton Sea, but most of these have long since expired. Increasing the investment tax credit (ITC) for geothermal projects from 10%

to 30% has almost identical gains to reducing the capital costs by 20%. State property tax subsidies and waivers have a similar effect on operating and maintenance costs. Government policy can reduce costs associated with permitting and mitigation; however, these reduced costs provide relatively small benefits. Reducing the regulatory and approval timeline can result in some cost reductions. These reductions are greater for projects that require high discount rates for the early years of a project when there is greater uncertainty and risk.

Government policy can influence the discount rate by reducing the risk of a project. Minimizing the costs and/or timeline associated with the regulatory process and helping to ensure a successful exploration and construction process can help reduce the risk, and subsequently the required discount rate. Loan guarantees or loan subsidies could also directly reduce financing costs, thereby reducing the discount rate. Figure S.2 demonstrates that the most effective form of government intervention would be a federally backed loan program for new geothermal projects, which is consistent with industry feedback that high loan rates are a main barrier to entry.

The analyses shown in Figure S.2 help to represent the relative sensitivity of these changing variables and their resulting effect on the levelized cost of electricity (LCOE). These sensitivity analyses help indicate the types of actions that may meaningfully reduce the LCOE of geothermal electricity and help make it more competitive with other renewable energy sources.

The optimism for new lithium extraction projects linked to Salton Sea geothermal power plants is high. This emerging technology provides a means of extracting lithium from the geothermal brine, before reinjecting it back into the underground reservoir. As of 2020, the California Energy Commission estimates that the earth below the southern Salton Sea contains a unique brine that has the potential to supply 40% of global lithium demand, produce more than 600,000 tons of lithium carbonate per year, and produce up to $7.2 billion in annual revenue. MAGE projects that lithium extraction could be a financial gamechanger for geothermal power producers in the area, by substantially lowering the levelized cost of electricity, increasing the discounted net present value, and decreasing the payback period of the geothermal facility.

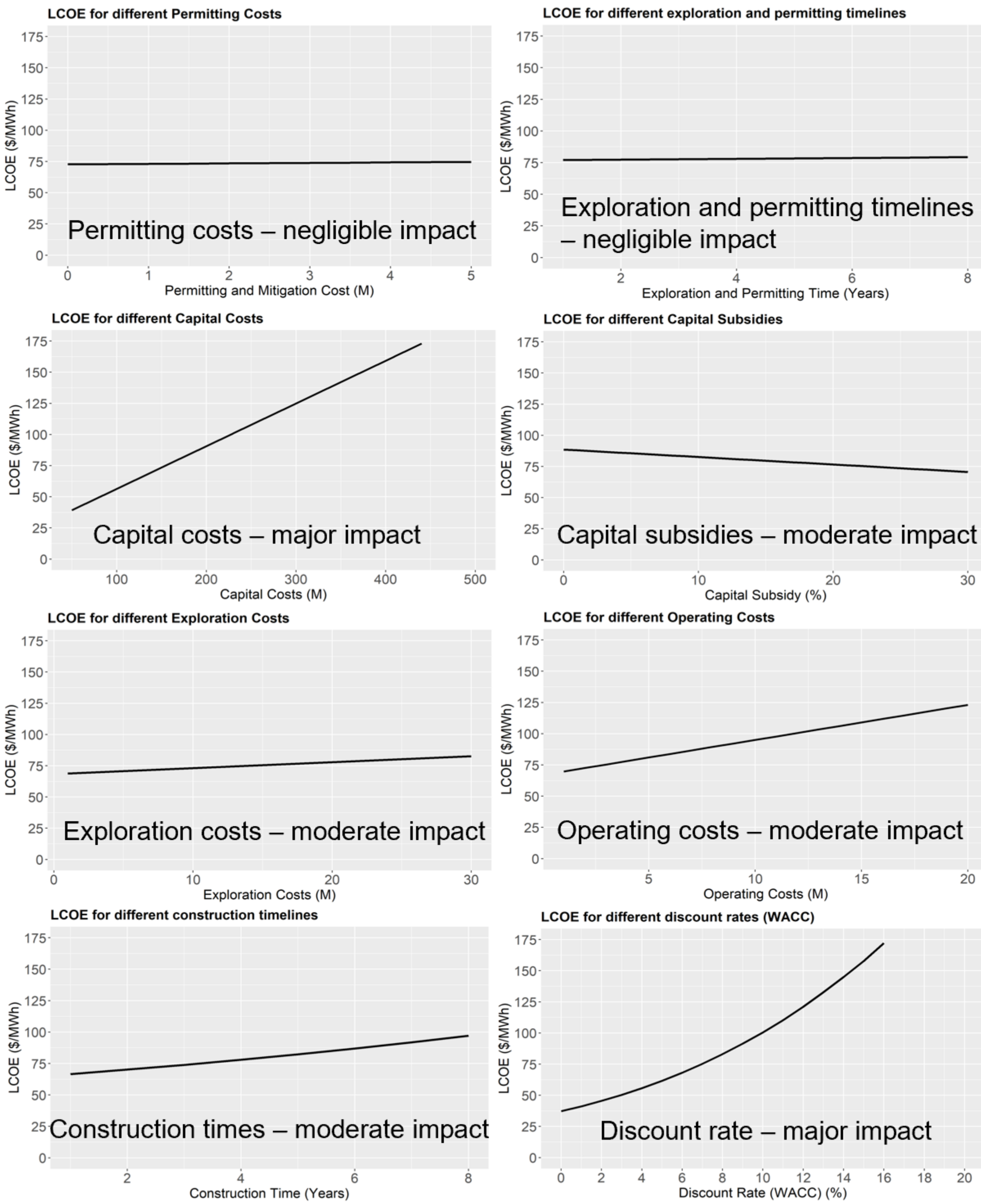

Figure S.2. Sensitivity of geothermal LCOE due to adjustments in key parameters for the baseline Salton Sea geothermal plant.

While this report focuses on specific opportunities and economic scenarios at the Salton Sea, the final section contains recommendations and lessons learned for streamlining geothermal development, regardless of the geographic location of the project.

Table S.3 contains key findings and recommendations, with links to the locations of these discussions in the report.

Table S.4. Key Findings and Recommendations

Geothermal Resources at the Salton Sea • The Salton Sea has ideal conditions for geothermal growth because it contains a Known Geothermal Resource Area that has only been partially developed (700 MW of 2,950 MW capacity), is near major load centers/cities, and because there is high support for renewable energy expansion in California (Section 4.1). • Although the conditions are ideal for geothermal are ideal at the Salton Sea, most plants were built during from 1982-1990, only one has been built since 2000, and only one new plant is being developed (Section 4.1). • The Salton Sea has substantial potential for extracting lithium (needed for battery systems for both BESSs and electric vehicles) from geothermal brines. The CEC estimates that the Salton Sea has the potential to supply 40% of global lithium demand, produce more than 600,000 tons of lithium carbonate per year, and produce $7.2 billion in revenue at a price of $12,000 per ton (Section 7.6).	Geothermal Comparison to Other Renewables • Unlike solar and wind, geothermal energy is able to provide reliable baseload power at all times and also has the flexibility to ramp-up production when power demand is high. (Section 5.1). • Industry states that the lack of new development is primarily due to solar and wind being lower cost competitors (Sections 5.2 and 5.3). • While solar and wind energy development do generally have lower LCOEs and Power Purchase Agreement (PPA) values than do geothermal, these metrics do not account for ancillary services and benefits that geothermal provides (Section 5.3.3). • An emerging concern for the geothermal industry is that battery energy storage systems (BESSs) may be able to provide certain similar ancillary benefits at lower costs (Section 5.3.3).
Model for Analysis of Geothermal Economics (MAGE) • MAGE is a modeling tool that can be easily customized to evaluate how beneficial or costly certain actions would be at geothermal projects regardless of their location (Section 6.0). • MAGE can be adapted to evaluate other power sources such as solar, wind, hydro, and nuclear development (Section 6.0).	Streamlining Geothermal Development at the Salton Sea and Elsewhere • Decreased capital costs and lower discount rates result in the largest relative reductions in the geothermal LCOE (Section 7.1). • Permitting timelines are more impactful on geothermal viability than are permitting costs (Section 7.2). • Exploration timelines, costs, and associated risk are large factors in high geothermal LCOEs (Sections 5.2.3 and 5.2.4); these are most

	effectively mitigated through government intervention such as tax incentives and/or loan guarantees (Section 7.3). • Resource and transmission conflicts are generally not a limiting factor in geothermal development at the Salton Sea, but may be in other locations (Sections 7.4 and 7.5). • Lithium extraction can be added onto and work symbiotically with geothermal development, and has the opportunity to make geothermal development substantially more competitive with other renewables (Section 7.6).

General Recommendations

- Streamlining geothermal development is dependent on the specific resource and geographic location of a project, but the following recommendations are likely to be beneficial regardless of location (Section 9.0):
    - Understand and outline the permitting process and timeline
    - Acquire necessary water rights
    - Ensure that the transmission systems has capacity to support the project
    - Survey and avoid resource conflicts early in the process
    - Inform state/federal governments of the benefits of geothermal energy
    - Engage the public and stakeholders
    - Consider the availability and benefits of co-location with minerals development
- A beneficial future action would be to host collaborative workshops where stakeholders can work with the modeling team to brainstorm, evaluate, and compile potential future policy recommendations.

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Acronyms and Abbreviations

BCR	benefit-cost ratio
BESS	battery energy storage system
BLM	U.S. Bureau of Land Management
CalGEM	California Energy and Management Division
CAPX	capital expenses
CDFW	California Department of Fish and Wildlife
CEC	California Energy Commission
CEQA	*California Environmental Quality Act*
CESA	*California Endangered Species Act*
CO_2	carbon dioxide
Corps	U.S. Army Corps of Engineers
CPUC	California Public Utilities Commission
CSP	concentrating solar power
CTR	Controlled Thermal Resources
CWA	*Clean Water Act*
DNPV	discounted net present value
DOE	U.S. Department of Energy
EGS	enhanced geothermal system
EIA	U.S. Energy Information Administration
EIR	environmental impact report
EIS	environmental impact statement
ESA	*Endangered Species Act*
FWS	U.S. Fish and Wildlife Service
GEA	Geothermal Energy Association
GETEM	Geothermal Electricity Technology Evaluation Model
GTO	Geothermal Technology Office
GW	gigawatt(s)
GWe	gigawatt(s) electrical
GWh	gigawatt-hour(s)
ICBOS	Imperial County Board of Supervisors
IID	Imperial Irrigation District
ITC	investment tax credit
KGRA	Known Geothermal Resource Area
kW	kilowatt(s)
kWh	kilowatt-hour(s)
LCOE	levelized cost of electricity

MAGE	Model for Analysis of Geothermal Economics
Mg/L	milligrams/liter
MND	Mitigated Negative Declaration
MOU	Memorandum of Understanding
MW	megawatt(s)
MWh	megawatt-hour(s)
NEPA	*National Environmental Policy Act*
NREL	National Renewable Energy Laboratory
NWR	National Wildlife Refuge
O&M	operations and maintenance costs
OPEX	operational expenses
PG&E	Pacific Gas and Electric
PNNL	Pacific Northwest National Laboratory
PPA	power purchase agreement
PTC	production tax credit
PV	photovoltaic
RPS	Renewables Portfolio Standard
S.B.	Senate Bill
SCH	Species Conservation Habitat
SSMP	Salton Sea Management Program
TEA	techno-economic analysis
U.S.	United States
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation

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1.0 Introduction

Geothermal energy offers an opportunity to generate baseload, renewable energy that can help respond to the impacts of climate change and replace older, more expensive, nonrenewable, and more resource-impacting energy-generation facilities. The United States has the largest known geothermal resource in the world, with over 31 GW of conventional geothermal potential. However, due to market conditions, an inability to properly quantify electrical grid benefits and resource stability, and the difficulty of exploring and developing the geothermal resource, few new geothermal projects have come online over the past three decades.

New technologies, changing market conditions, economies of scale, and financial incentives have led to the proposal of new geothermal projects, with the potential for additional new future projects. The Salton Sea in Imperial County, California presents a strong opportunity for new future development. The Salton Sea presents one of the most accessible and high-potential geothermal resources anywhere in the world, but development has remained slow. Reasons for this include the relatively high cost of geothermal exploration and drilling, high startup costs, resource conflicts, the need for habitat restoration and mitigation and lack of suitable areas at which to do so, relatively high wholesale prices and inability to secure power purchase agreements, transmission constraints, permitting issues, land access issues, and a lack of government subsidies and incentives.

The U.S. Department of Energy (DOE)'s Geothermal Technologies Office (GTO) contracted with Pacific Northwest National Laboratory (PNNL) to develop this report. GTO noted that geothermal development is impacted by barriers related to permitting timelines for land access and environmental assessments and requested development of a techno-economic analysis of obstacles and impacts of state review timelines and how geothermal development integrates with environmental management. GTO highlighted the Salton Sea as a useful site for particular focus. PNNL coordinated with counterparts at the National Renewable Energy Laboratory (NREL) and Idaho National Laboratory (INL) in identifying issues and opportunities, coordinating with stakeholders, and in discussing preliminary findings and results. This report describes these issues in detail and presents opportunities and solutions to overcome these barriers.

In 2002, California established the Renewables Portfolio Standard (RPS) as a primary driver for increasing clean electricity generation (California S.B. 1078). The RPS had an initial target of 20% renewable energy by 2017, citing goals of "stable electricity prices, protect public health, improve environmental quality, stimulate sustainable economic development, create new employment opportunities, and reduce reliance on imported fuels." In light of the 2013 closure of California's San Onofre nuclear power plant, opportunities exist for renewable energy developments to help replace the lost generation (IID 2016) and meet the RPS for clean energy-generation. Furthermore, there are plans to close the Diablo Canyon nuclear power plant by 2025 (PG&E 2022), which is the last remaining nuclear power plant in California and produces ~9% of the electricity in the state. The Biden Administration is pushing California to keep Diablo Canyon (Reuters 2021) open because it is an important zero-carbon energy source in an era of climate change concerns. As of 2019, California was the largest net electricity importer of any state, importing 25% of the state's total electricity supply (EIA 2020). When expected energy imports do not materialize, rolling blackouts and other electricity emergencies can occur (Nikolewski 2020). Therefore, it is important for California to replace this imported electricity with baseload power generated within the state.

The Salton Sea provides an economically viable opportunity for replacing this lost energy with renewable energy from solar, wind, and geothermal (Figure 1-1). While renewable energy development in Imperial County has been substantial, a large undeveloped resource remains. If developed, this could help meet not only CA RPSs, but also provide economic and ecological benefits. One primary opportunity regarding geothermal development at the Salton Sea relates to the lithium contained in the geothermal brine, and the opportunities for extracting this lithium as a byproduct of geothermal development. Other opportunities include suggestions for streamlining the costs and timelines associated with the permitting and the regulatory process, potential subsidies, and government intervention techniques to spur development. Furthermore, as geothermal drilling technologies improve and become more efficient, the high potential of the geothermal resource at the Salton Sea can be increasingly tapped into and developed.

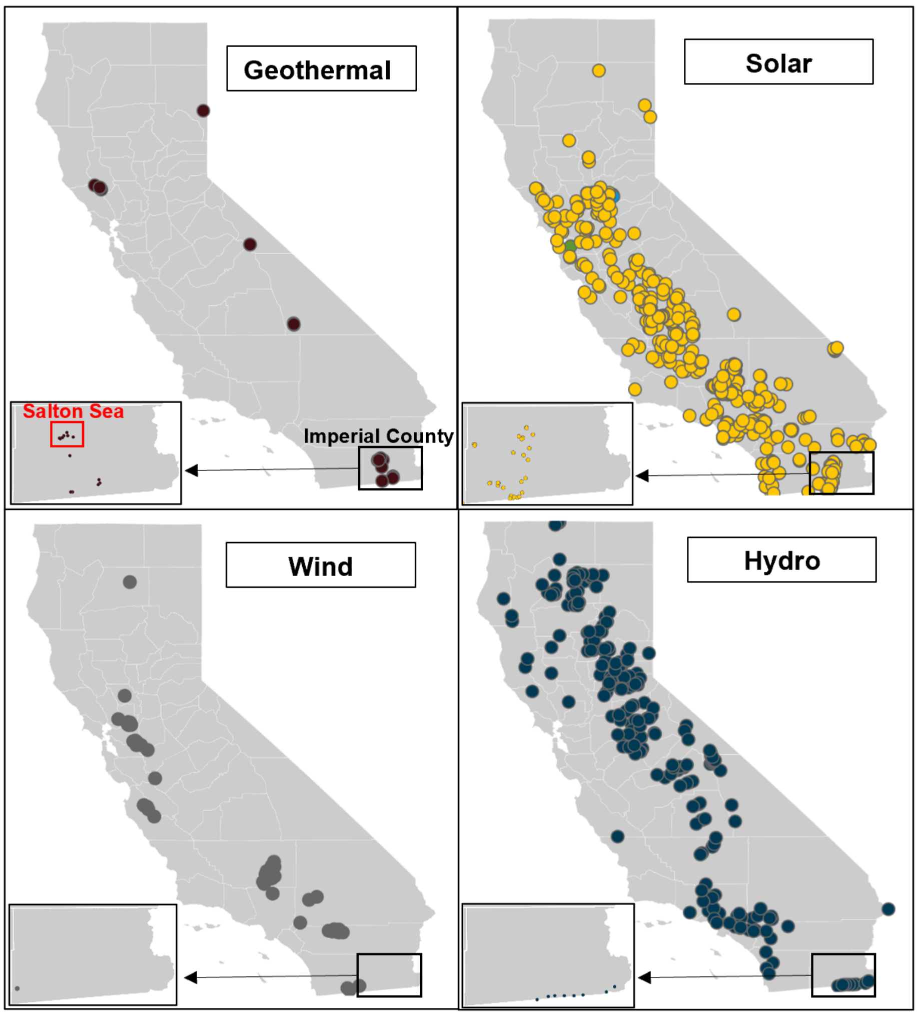


Figure 1-1. Map of renewable energy sources in California, Imperial County (side box), and the geothermal plants in the Salton Sea area that are the focus of this report (Source: EIA 2021c).

The Salton Sea allows evaluation of two main business components: (1) the traditional electricity generation component and (2) the emerging lithium extraction component. While the evaluation of the electricity component focuses on the Salton Sea area, these findings could be relevant to geothermal sites throughout the country. There is also high national attention on the

Salton Sea for new and environmentally friendly extraction methods that recirculate brine instead of using strip mines or evaporation pits. Unlike most other areas with geothermal resources, the Salton Sea could be a major domestic source of lithium to power electric cars and to provide grid reliability by storing power from intermittent renewable power sources, such as solar and wind energy.

This report also outlines various techno-economic scenarios that result in a decreased levelized cost of electricity (LCOE) associated with Salton Sea geothermal development. A primary purpose of this report is to use a technoeconomic analysis (TEA) model referred to as MAGE (Model for Analysis of Geothermal Economics) to contrast and compare the effectiveness of different types of solutions (model parameters) that could help the geothermal energy industry (e.g., permitting costs, tax credits, discount rates, lithium, etc.). Sensitivity analyses are used to compare how geothermal power prices and plant payoff schedules are affected by adjusting the model parameters. For example, these sensitivity analyses demonstrate that reducing the discount rate or capital costs would have higher benefits for geothermal than reducing permitting costs (see Section 6.3).

The ensuing sections of this report describe the technology and history of geothermal development (Section 2.0) and the current historical and economic conditions at the Salton Sea (Section 3.0); outline the various energy resources at the Salton Sea (Section 4.0); and compare geothermal to these other energy sources (Section 5.0). Section 6.0 introduces MAGE, which attempts to quantify the nontechnical challenges and opportunities associated with new geothermal development at the Salton Sea. Section 7.0 describes various challenges and opportunities at the Salton Sea, and uses MAGE to evaluate the relative benefits of certain actions that can reduce the price of geothermal electricity and improve the profitability of a hypothetical geothermal plant. The report concludes with a summary of the modeled MAGE scenarios (Section 8.0) and a user guide with recommendations that can help to facilitate geothermal development regardless of the geographic location (Section 9.0).

2.0 Geothermal Energy Background

The elements of geothermal development, types of geothermal power plants, the history of geothermal development, and enhanced geothermal systems are described in the following sections.

2.1 Characterization, Exploration, and Development

Geothermal development starts with project characterization, which involves field studies to identify the geothermal reservoir (Aragón-Aguilar et al. 2019). The first factor controlling the location of a potential geothermal resource is the geothermal gradient which corresponds to the increase in temperature with depth due to the conductive cooling of the Earth. Subsequently, the existence of a reservoir is confirmed through the drilling of deep exploratory wells, along with characterization of geothermal reservoir and the design of the systems to be used. Assuming the exploratory wells provide positive data, well drilling continues along with the development of geoscientific studies and a final project design (Aragón-Aguilar et al. 2019).

A description of the phases associated with the geothermal resource characterization and development can be seen in Table 2-1.

The high risks, uncertainty, and cost of capital associated with the exploration phases are key challenges to geothermal plant development (NREL 2014). These risks are explored further in various modeled scenarios described in Section 7.0 of this report.

Table 2-1. U.S. Geothermal Energy Association's terms and definitions for geothermal resource development (adapted from NREL 2014).

Phase I – Exploration	Phase II – Permitting and Initial Development	Phase III – Resource Production and Plant Construction
• Literature survey • Geologic mapping • Geochemical and geophysical surveys • Internal transmission analysis • Land lease acquired • Permitting for exploration drilling • Temperature-gradient holes drilled • Slim hole approved and drilled • One full-sized discovery well drilled • Interconnection application submitted • Transmission feasibility studies • Permit for production well approved.	• At least one full-sized production well and one full-sized injection well drilled • Reservoir characterization complete • Interconnection feasibility study complete • System impact study • Interconnection facility study • Transmission service request submitted • Plant permit application • Power purchase agreement • Financing secured or being secured for power-plant construction.	• Plant equipment on order • Plant permits approved • Contract signed with construction contractor • Plant construction under way • Production and injection well drilling • Interconnection agreement signed • Transmission system service request studies complete • Plant permits approved • Power purchase agreement secured.

2.2 Geothermal Power Plants

Three basic types of geothermal power plants predominate: dry steam, flash steam, and binary, as depicted in Figure 2-1 and described below.

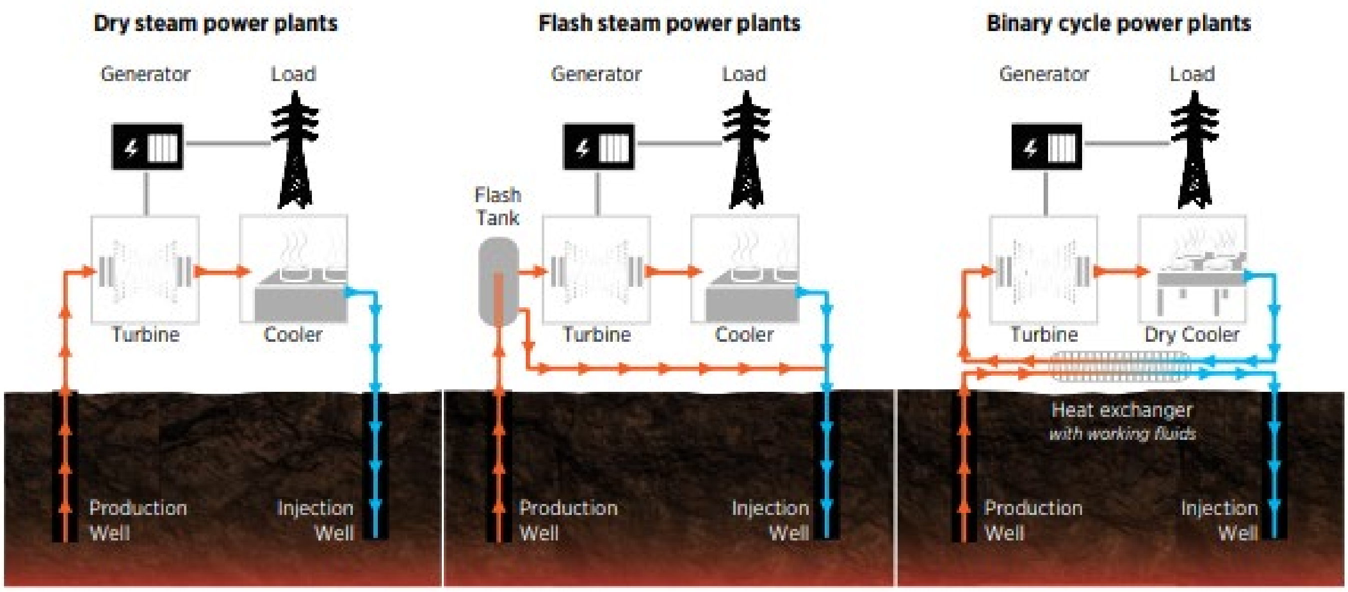


Figure 2-1. Geothermal power-plant configurations (DOE 2019).

2.2.1 Dry Steam Power Plant

Dry steam power plants collect steam from multiple wells as input to turn a turbine. They were the first type of geothermal power plant. They are rare due to the limited availability of dry steam resources and because they require relatively high reservoir temperatures (Fazal and Kamran 2021).

2.2.2 Flash Steam Power Plant

Flash steam power plants are the most common type of geothermal plant, and involve separation of steam from water through flashing. The steam feeds a turbine, and the water is pumped back to the geothermal reservoir. Double- and triple-flash systems can provide higher utilization of the geothermal energy for multiple stages of steam separation before reinjection of the water to the geothermal reservoir. Flash steam power plants require reservoirs with temperatures greater than 180°C. As discussed in Section 7.7, higher reservoir temperatures can lead to exponentially greater productivity (Fazal and Kamran 2021).

2.2.3 Binary Cycle Power Plant

Binary cycle power plants collect head from the geothermal fluid, which is used to boil a second fluid that has a lower boiling point. Binary cycle power plants are effective for geothermal reservoirs with lower temperatures, between 107°C and 180°C, and are generally lower-capacity plants (Fazal and Kamran 2021).

2.3 Geothermal Development History

Geothermal resources have been used by humans for thousands of years. In the US, the first large-scale development of a geothermal resource occurred in the 1850s at Geysers, in Northern California, where a spa resort was developed. Geothermal energy was used for heating in the 1890s in places such as Boise, Idaho, and Klamath Falls, Oregon, and the first geothermal power plant was developed at the Larderello dry steam field in Tuscany, Italy in 1904. In the 1920s, exploratory wells were drilled at the Geysers and in Imperial County with the intention of generating electricity. The first large-scale geothermal electricity-generating plant began operation in 1960 at the Geysers (DOE undated).

The *Geothermal Steam Act* of 1970 provided the Secretary of the Interior with the authority to lease lands for geothermal exploration and development. The 1974 *Geothermal Research, Development, and Demonstration Act* created the Geothermal Loan Guarantee Program, which provided over $136 million in loan guarantees to geothermal projects from 1974 to 1982 (Yonk et al. 2017). The *Public Utility Regulatory Policies Act* of 1978 (PURPA) encouraged cogeneration and renewable resources (APPA 2020), by requiring that utilities purchase power from independent power producers (Yonk et al. 2017).

In California, the Geothermal Grant and Loan Program was created in 1980, promoting the development of California’s geothermal resources and supporting technologies by offering grant opportunities and other resources. The program is funded by royalty and lease payments by geothermal developers operating on private lands in California. The intent of these funds is to “promote and maintain development of California's vast geothermal energy resources, mitigate any adverse impacts caused by geothermal development, and help local jurisdictions offset the costs of providing public services necessitated by geothermal development” (CEC 2022a). The combination of PURPA and the 1970s global oil crisis encouraged renewable energy development, including geothermal. After PURPA was passed, the renewable energy sector, including the geothermal industry, grew dramatically through the 1980s. In the 1990s, natural gas prices decreased to the point that geothermal generation could not compete, leading to stagnant new geothermal development (Yonk et al. 2017). As discussed in Section 4.0 of this report, very few new geothermal projects have been developed in Imperial County since the boom of the 1980s; however, new market conditions, technologies, enhanced geothermal systems, and reduced barriers to entry have begun to re-encourage geothermal development.

As of 2020, geothermal power was generated in seven states in the United States (see Table 2-2).

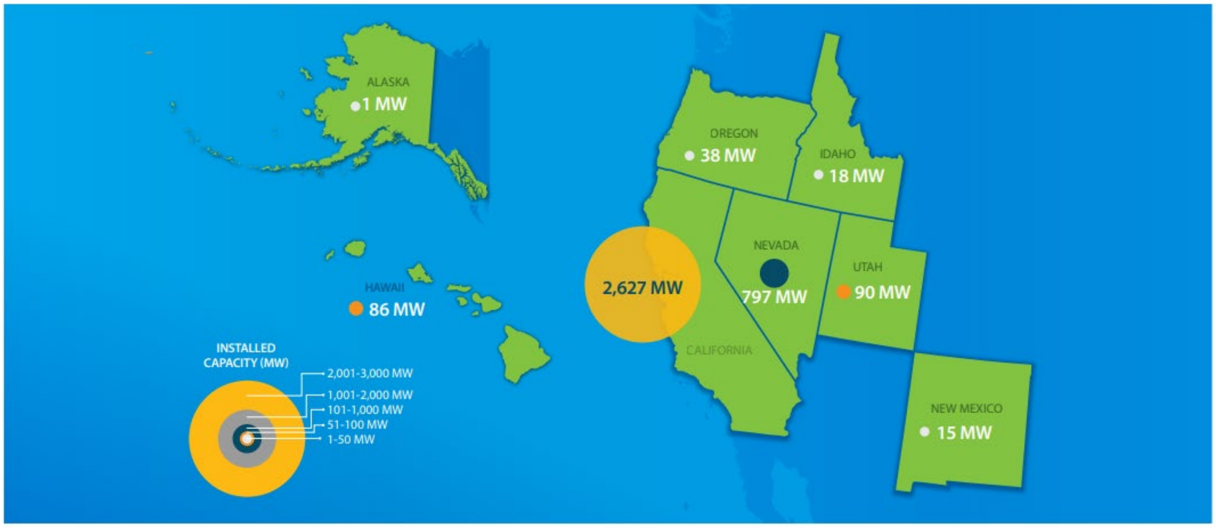


Figure 2-2. 2021 geothermal nameplate capacity by state (from NREL 2021a)

As seen below, geothermal resources in California represent a majority of total U.S. geothermal electricity generation. However, the share of total state electricity generation of geothermal power is lower in California than it is in Nevada (EIA 2021a).

Table 2-2. States with geothermal power plants in 2020 (EIA 2021a).

State	State Share of Total U.S. Geothermal Electricity Generation	Geothermal Share of Total State Electricity Generation
California	70.5%	6.1%
Nevada	24.5%	10.2%
Utah	2.1%	1.0%
Hawaii	1.2%	2.2%
Oregon	0.9%	0.2%
Idaho	0.5%	0.5%
New Mexico	0.3%	0.2%

2.4 Enhanced Geothermal Systems

Enhanced geothermal systems (EGSs) encompass a variety of technologies implemented to improve geothermal productivity within known, unexplored, and undeveloped resources. These improved technologies can help to tap into in-field, near-field, and deep resources that are otherwise uneconomic to develop. In general, an EGS is "a man-made reservoir, created where there is hot rock but insufficient or little natural permeability or fluid saturation. In an EGS, fluid is injected into the subsurface under carefully controlled conditions, which cause pre-existing fractures to re-open, creating permeability." While EGS technologies continue to be developed, they present an opportunity to access as much as 100 GWe of geothermal energy (DOE 2016a). Section 7.8 of this report explores some techno-economic scenarios associated with EGSs and other technological improvements.

3.0 Salton Sea Background and Context

The sections below describe the history and background of the Salton Sea, the energy resources at the Salton Sea, and various opportunities and challenges associated with Salton Sea geothermal development.

3.1 History

Located in southern Riverside and northern Imperial Counties in Southern California, the Salton Sea is California's largest lake, (Associated Press 2015).

Historically, nine different Native American groups occupied the Salton Sea area. In 1876, the U.S. Government established the 24,800 Torres Martinez Desert Cahuilla Indian Reservation (SSRP undated).

In the 1850s, the Imperial Valley was recognized as an area that, if irrigated, could be productive farmland (SSRP undated). The Imperial Canal was constructed in 1901, bringing an agricultural boom and land speculation. The modern Salton Sea was created in 1905 when the Colorado River breached a temporary diversion of the Imperial Canal, flowing into the Salton Sink for 2 years before being stopped. The Salton Sink is a basin that was historically filled every 400–500 years (creating a saline lake called Lake Cahuilla) and dried due to cyclical natural river flows, flooding, and evaporation (Kennan 1917). The creation of the lake allowed for agricultural development and tourism in the Imperial Valley, and the lake became one of the most important wetlands and habitats for migrating and resident bird species. The Sonny Bono Salton Sea National Wildlife Refuge (NWR) was established when 32,766 acres were set aside in 1930 (FWS 2020) as a sanctuary and breeding ground for birds and other wildlife.

In the 1950s, the Salton Sea became an area of high recreation and tourism, with attractions such as the North Shore Yacht Club hosting visitors such as the Beach Boys and the Rat Pack for parties, dances, fishing, water sports, and boat races. The California Department of Fish and Game stocked the sea with game fish; and hotels, resorts, restaurants, and marinas were created in towns around the sea. Tourism plummeted in the 1970s and 1980s due to various factors, including multiple tropical storms, rising salinity, pollution, and a receding shoreline. The sea is maintained by agricultural runoff (SSA 2017), but evaporates faster than it is filled, particularly due to a lack of inflow. As a result, the sea has shrunk over time. Because the sea has no natural outflows, it has become a saline lake, with a salinity that is currently 50% greater than that of the ocean (CDFW 2022). "Salinity in the Salton Sea increased from approximately 45,600 milligrams/liter (mg/l) in 2003 to 69,000 mg/l in 2019" (CRS 2021). The salinity level continues to rise and will increase significantly without application of restoration and mitigation measures.

3.2 Climate and Economy

Today, Imperial County, in which most of the Salton Sea lies, has the lowest per capita income of any county in Southern California, and the highest unemployment rate in the state. As of 2020, the total population of the county was 190,624 (up from 174,528 in 2010) (ICCED 2020). Population within the county is increasing due to immigration and home affordability. Tourism has increased and is expected to continue to increase in Imperial County, with areas of interest including the Salton Sea itself, the Algodones Sand Dunes, Slab City, Salvation Mountain, the

Sonny Bono Salton Sea NWR, and Ports of Entry to Mexico. Today, tourism accounts for about 7% of total employment in Imperial County (ICCED 2020).

The Imperial County economy is dominated by agriculture, which accounts for 48% of all employment. Other major industry sectors in Imperial County include government, retail trade, and health care. Imperial Irrigation District (IID) is a locally owned water and power utility, which operates more than 3,000 miles of canals and drains, delivering 3.1 million acre-feet of water for agricultural, municipal, and industrial use (ICCED 2020). The IID is also a major landowner in the Salton Sea area.

Imperial County's Latino population represents 83% of the total population. The Council on Environmental Quality has designated 27 of Imperial County's 31 census tracts as "disadvantaged" in at least one of 15 criteria in the Climate and Economic Justice Screening Tool, including the immediate vicinity of the Salton Sea (CEQ 2022).

Imperial County is characterized as a semiarid desert with hot, dry summers and warm winters. Total rainfall averages approximately 2.63 in annually (ICPDSD 2015), and the heaviest precipitation occurs in January to March. The hot temperatures and warm winters make the county attractive for solar development, and wind development in certain locations.

Based on the warm climate and the availability of irrigation water from the Colorado River, it is estimated that over two-thirds of all winter vegetables (ICCED 2020) consumed in the United States are grown in Imperial County.

IID has expressed a desire to provide high-paying, skilled, and stable jobs in Imperial County. New energy development, including geothermal, provides an opportunity to meet these economic goals, while also increasing the property and income tax bases for the county.

3.3 Salton Sea Habitat

As the Salton Sea has receded, its increasing salinity has led to massive die-offs of fish and the avian populations that depend on the fish for their food. Communities surrounding the lake, including Bombay Beach and Salton City, have lost most of their businesses and population. The receding lake has also exposed previously underwater lake beds; these areas, called playas, contain various toxic substances and result in toxic dust being carried by winds across Imperial County (CRS 2021). As described below, these playas also contain high potential for geothermal development. In 2019, Imperial County issued a local emergency proclamation for the Salton Sea due to dust particulate matters (Imperial County 2019).

> The county also issued notices of violations of county regulations in 2020 to state agencies, federal agencies, and the Imperial Irrigation District (IID) for not adequately controlling dust during the construction of the Red Hill Bay Restoration Project and for not adequately implementing dust control activities on exposed playa around portions of the Salton Sea. (Imperial County 2019)

The State of California has made substantial efforts to stabilize playas and restore habitat used by fish and wildlife at the Salton Sea. California's 2017 Salton Sea Management Program (SSRP) outlined various efforts to restore Salton Sea habitat, which included a 10-year plan focused on construction up to 30,000 acres of habitat and dust suppression projects. The first large-scale project associated with the SSRP is the Species Conservation Plan, which involves the construction of ponds and wetlands on the south end of the Salton Sea to create fish and bird habitat (CNRA 2022). However, funding to support all the projects described in the SSRP is lacking.

The federal government has also recognized the need for habitat restoration at the Salton Sea. The federal nexus to the Salton Sea involves the construction and maintenance of irrigation canals from the Colorado River that flow into the area. Congressional bills such as H.R. 3877, the *Salton Sea Projects Improvement Act*, which was introduced in the House Natural Resources Committee in 2021, would authorize $250 million for federal agencies such as the U.S. Bureau of Reclamation (USBR) to develop habitat restoration and mitigation projects in and around the Salton Sea. However, no federal habitat restoration bill has been approved to date.

The U.S. Department of Interior did enter into a Memorandum of Understanding (MOU) with the Salton Sea Authority in 2014, with the intent to:

> improve collaboration between federal, tribal and local entities on natural resource issues involving the Salton Sea. The MOU is a key step in cementing each party's commitment to find collaborative solutions to resource challenges, to share available technical and scientific information and expertise, and to prioritize partnerships to improve resource conditions in and around the Sea. (DOI 2021)

Federal and state incentives to construct and operate large-scale energy projects may symbiotically benefit habitat restoration needs, as identified in the SSRP. As an example, state subsidies for geothermal projects constructed on the exposed Salton Sea playa could conditionally require implementation of dust suppression techniques to mitigate for both the direct impacts of the construction and operation of the project, meeting both the goals of the SSRP and CA's RPS. Section 7.2.4 discusses the potential for and benefits of government subsidies in more detail.

3.4 Land Ownership and Infrastructure

Land at the Salton Sea is checkerboarded and owned by various entities including the USBR, U.S. Fish and Wildlife Service (FWS), U.S. Bureau of Land Management (BLM), the California State Lands Office, the Torres Martinez Tribe, and private entities (Figure 3-1). IID is the primary landowner in the areas proposed for geothermal development. Federally, the USBR has potential jurisdiction over the playa exposed as the Salton Sea recedes, FWS owns and manages the Sonny Bono Salton Sea NWR, and the BLM is responsible for subsurface mineral management on the federal estate. Private lands in the area consist of various agricultural and residential parcels.

The receding Salton Sea has created large portions of playa that have been cut off from the transportation and transmission grid and that contain no infrastructure. Various irrigation canals and drainages supporting the agriculture in the area historically drained into the Salton Sea; with the receding sea, this drainage must cut through the playa to reach the sea. Many of these drainages have created new wetlands on the playa. These drainages raise potential issues of federal jurisdiction associated with waters of the United States, as discussed further in Section 7.2.2 of this report.

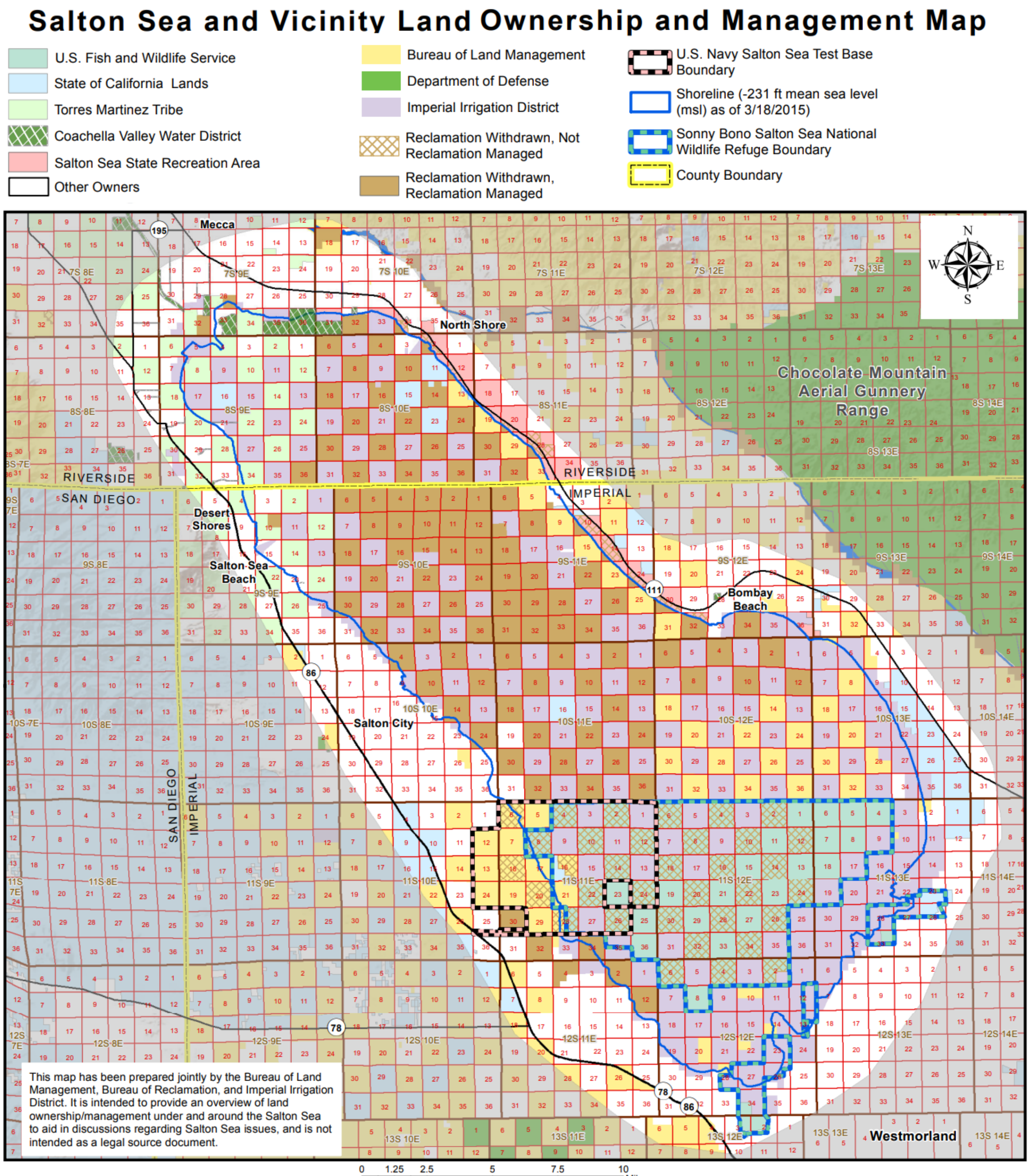


Figure 3-1. Land ownership map of the Salton Sea area (from DOI and IID 2015).

4.0 Energy Resources at the Salton Sea

Most geothermal resources are found along tectonic plate boundaries, which is where most volcanoes are located. The magma from these volcanoes heats water running along fault lines (EIA 2022). The geothermal potential is high at the Salton Sea because of its location in the Salton Trough, located at the southern end of the San Andreas fault system where the Pacific and North American tectonic plates meet (Kaspereit et al. 2016). The Salton Sea geothermal resource has been explored since 1927, and the U.S. Geological Survey (USGS) has identified nine Known Geothermal Resource Areas (KGRAs) in Imperial County, constituting approximately 326,928 acres. The National Renewable Energy Laboratory (NREL) found that roughly 232,000 acres of developable land exist within these KGRAs, and approximately 50,000 acres are within 5 miles of a 138kV to 230kV substation. This report focuses on the Salton Sea KGRA, which covers much of the southern portion of the Salton Sea, as illustrated in Figure 4-1.

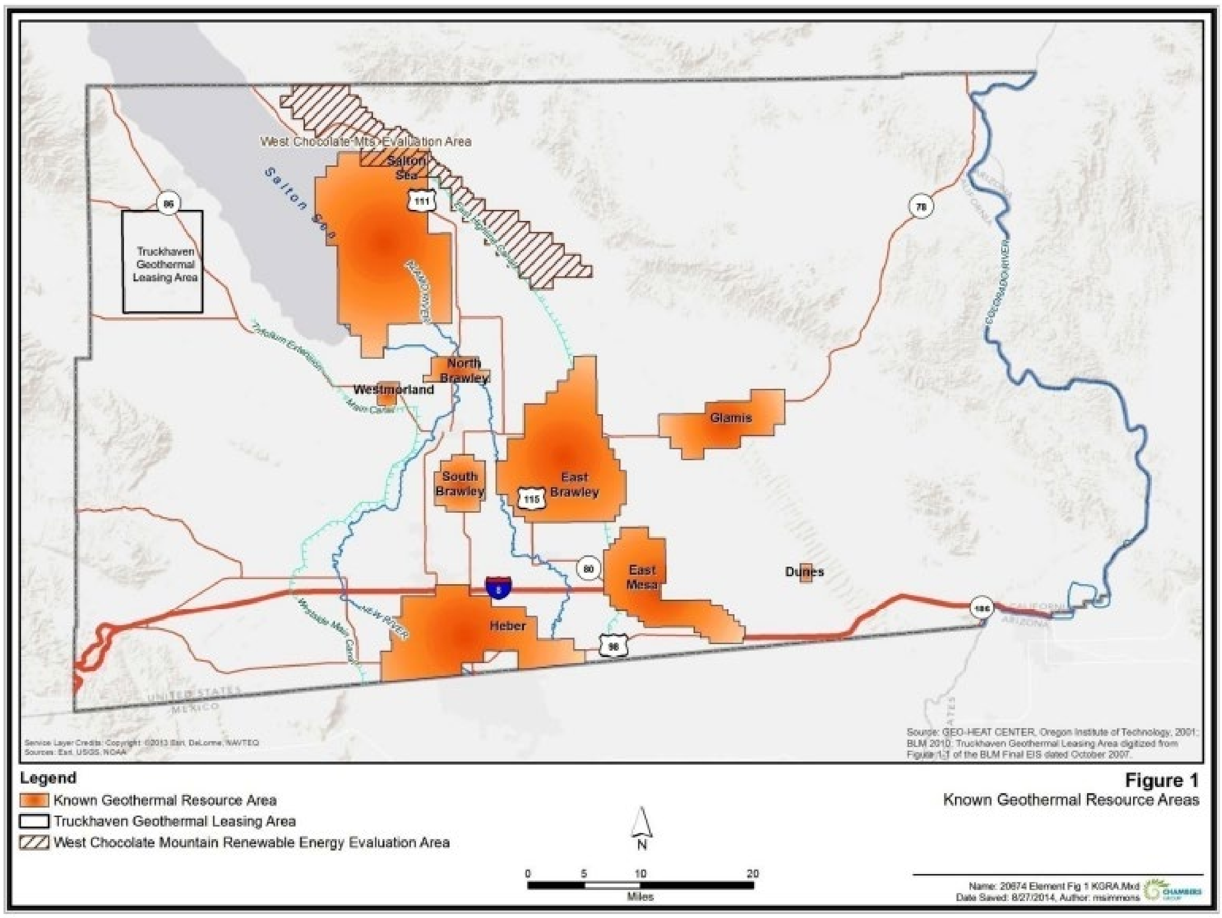


Figure 4-1. Imperial County KGRAs (ICPDSD 2015).

The Salton Sea KGRA is made up of lands covered by and near the Salton Sea, is slightly more than 100,000 acres in size (ICPDSD 2015), and is estimated to contain between as much as 2,950 MW (Kaspereit et al. 2016) of potential geothermal energy.

Much of the Salton Sea KGRA is currently covered by the Salton Sea. However, as the Salton Sea recedes, the newly exposed lakebed creates areas with high geothermal potential, estimated in 2016 to be more than 1,000 MW with an additional 700 MW over the years 2016–2028 as the lake continues to recede. NREL estimated that between 2020 and 2030, approximately 30,000 acres of playa around the Salton Sea would be exposed, with approximately 11,000 of these acres within the Salton Sea KGRA (NREL 2015).

4.1 Geothermal Energy

4.1.1 Past Development

As of 2020, total geothermal electric generation in California totaled 2,782 MW (CEC 2021b). However, very few projects have been constructed during the past 20 years. In the year 2000, the total geothermal electric generation in California was 2,689 MW. Figure 4-2 shows the relative lack of new geothermal development over the past two decades.

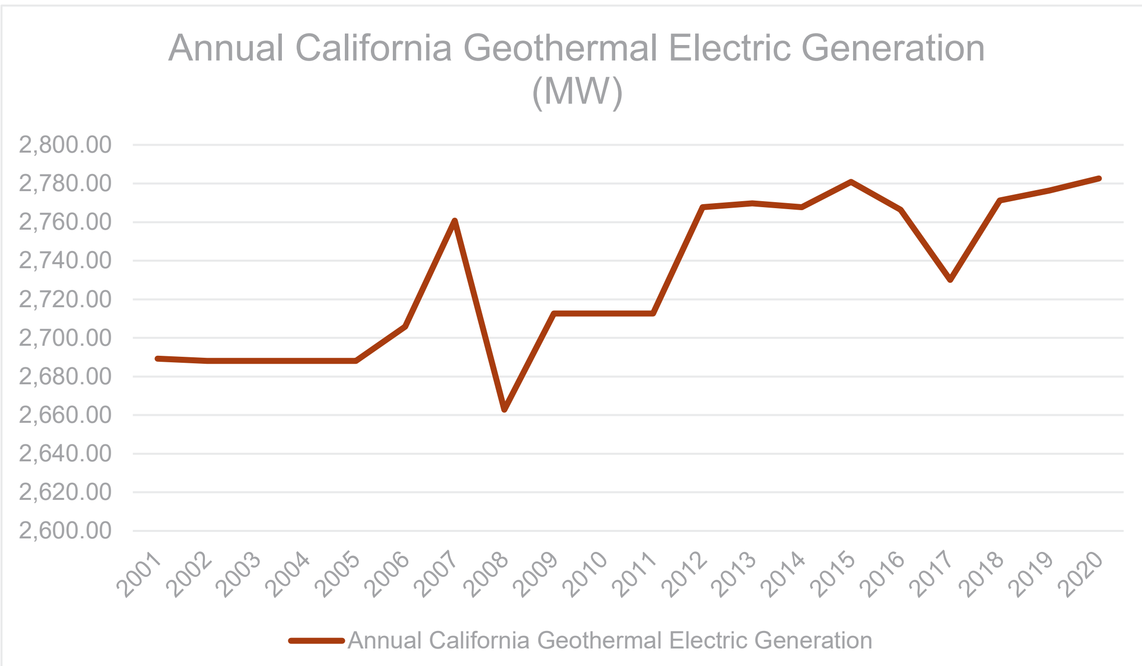


Figure 4-2. California Geothermal Electric Generation (MW) (Annual totals; includes imports).

A total of 717 MW of geothermal energy are generated in Imperial County (CEC 2021b), which includes projects outside the Salton Sea study area. Between 1982 and 2000, Cal Energy developed 10 projects in and around the Salton Sea (Table 4-1, Figure 4-3). These projects produce power that is delivered to various utilities and cities in Southern California and Arizona.

Table 4-1. Salton Sea KGRA Geothermal Plants (GDR 2019).

Facility	Units	Date of Commercial Operation	Nameplate Capacity (MW)	Owner
Salton Sea Unit 1	1	1982	10	CalEnergy/ Berkshire Hathaway
Salton Sea Unit 2	3	1990	20	
Salton Sea Unit 3	1	1989	54	
Salton Sea Unit 4	1	1996	47.5	

Facility	Units	Date of Commercial Operation	Nameplate Capacity (MW)	Owner
Salton Sea Unit 5	1	2000	58.3	
J.J. Elmore	1	1989	45.5	
J.M. Leathers	1	1990	45.5	
Del Ranch		1989	45.5	
Vulcan	2	1986	39.6	
CE Turbo	1	2000	11.5	
J.L. Featherstone (formerly Hudson 1)	1	2012	55	EnergySource
Total			432	

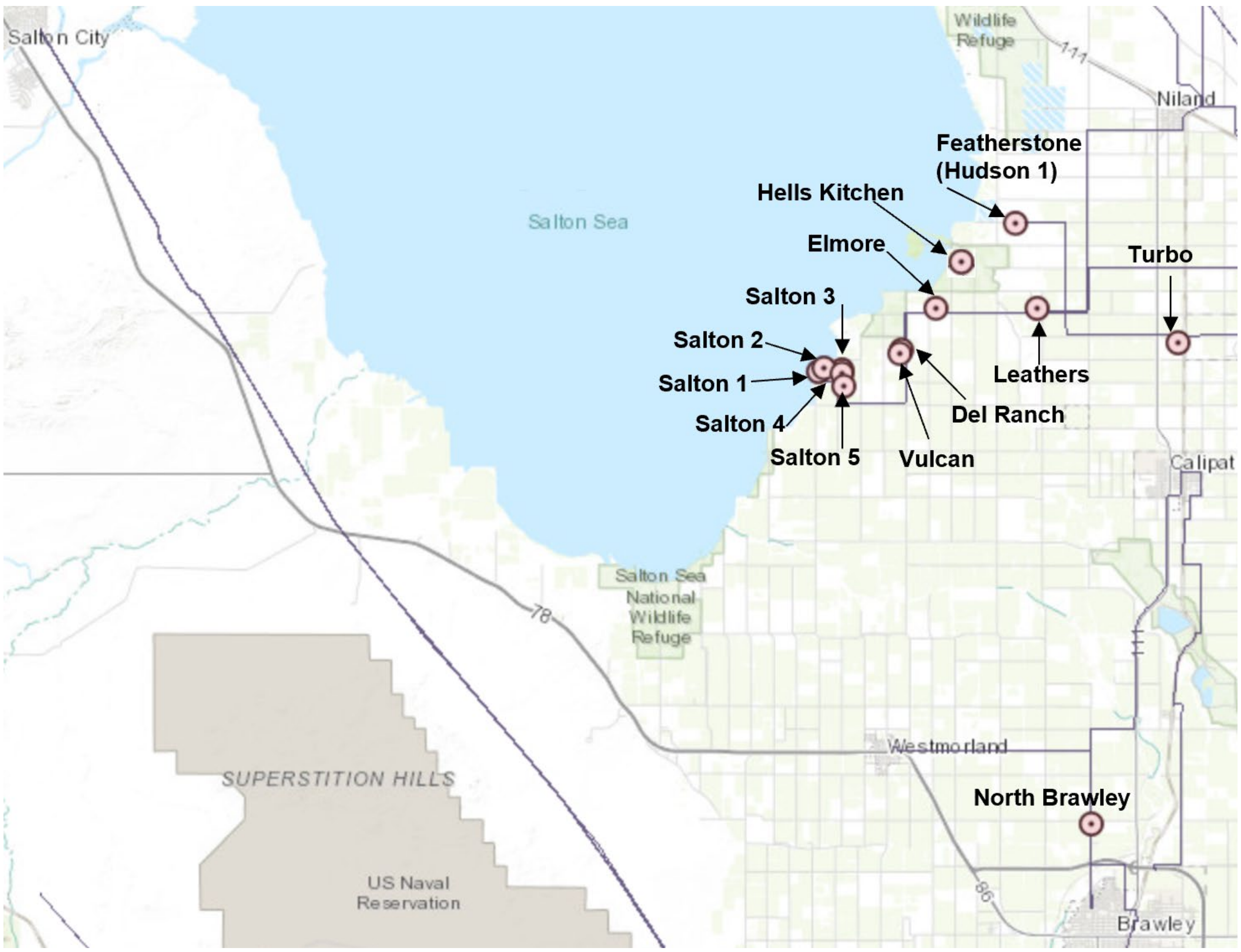


Figure 4-3. Map of the geothermal plants in the Salton Sea area.

The only project that has begun commercial operation since 2000 is the EnergySource-commissioned J.L. Featherstone Project (formally known as Hudson Ranch I), which began operation in 2012. This project signed a 30-year power purchase agreement with the Salt River Project in Arizona (Cision PR Newswire 2021). The opening of J.L. Featherstone added ~400,000–450,000 MWh of annual geothermal output, but the total Salton Sea output has only increased by about half of that due to reduced output at the other geothermal plants (Figure 4-4).

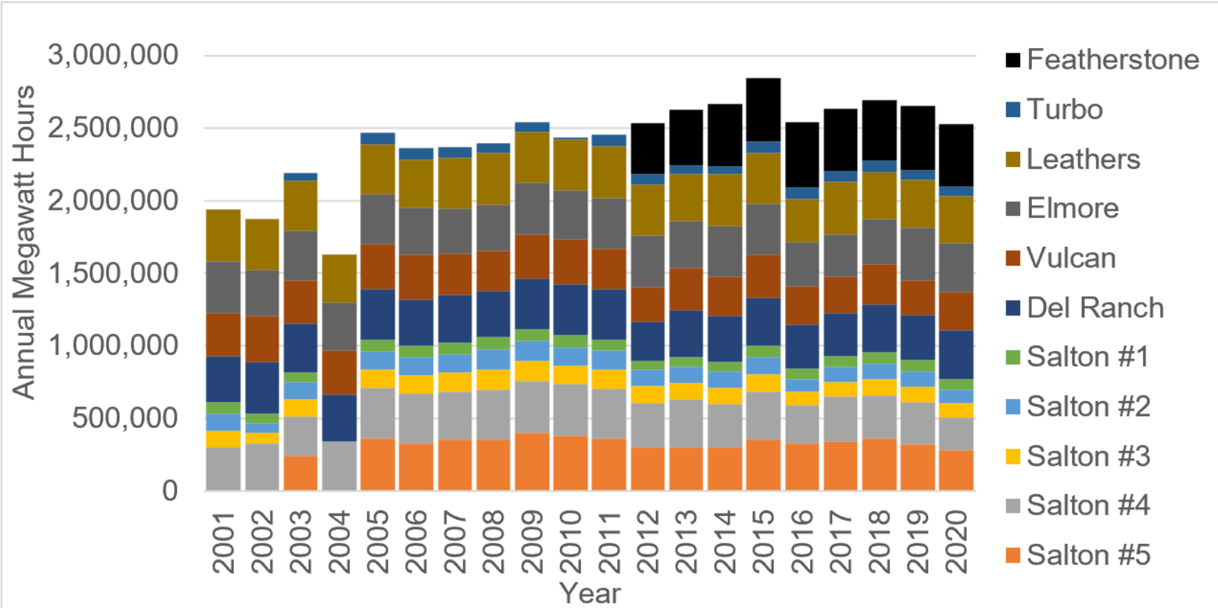


Figure 4-4. Total annual generation of projects at the Salton Sea.

The Hudson Ranch II project was initiated in 2010 but was not constructed. The proposed project would have included a 49.9 MW geothermal flash plant and wellfield on private lands in the Salton Sea KGRA and would have included a co-located lithium carbonate production plant adjacent to the geothermal plant. An environmental impact report (EIR) was developed for the project in 2012, but EnergySource canceled the project in 2014 due to unsatisfactory results associated with production wells for the project (Richter 2014).

4.1.2 Current and Future Projects

Controlled Thermal Resources (CTR) is currently in the process of developing the Hell's Kitchen project, an integrated lithium extraction and geothermal power facility at the Salton Sea KGRA. The CTR lease site is located along the southeast shore of the historical seabed and includes dry areas where the sea has receded.

The Hell's Kitchen project is being developed in phases. Phase 1 of the project involves development of a 49.9 MW plant. IID owns the land and mineral rights leased by CTR, and the two entities have entered into a power purchase agreement (PPA) for 25 years at a maximum hourly generation of 40 MWh.

CTR may ramp up to 260 MW of total output with multiple units in the future, but would need to negotiate and secure a PPA for this higher output. According to conversations with CTR, they consider 130 MW to be peak efficiency for geothermal power generation plants and CTR believes this could help geothermal become price competitive. Prospective power customers have signaled interest for up to a 500 MW PPA with CTR if they can continue to reduce their prices.

CTR plans on implementing a process to remove lithium directly from the brine and allows the brine to be reinjected back underground to repeat the process (CTR 2020b). This method of lithium extraction contrasts with and is intended to be more environmentally friendly than traditional lithium extraction techniques that include strip mining or water evaporation pits (see Section 1.1 for more information). CTR plans on starting with a 17,350-ton (annual output) lithium plant and adding similar size plants in the future. These lithium plants would be powered by a geothermal plant and would use the same brine in a looping process (i.e., power, lithium, reinjection). The removal of the lithium would have the symbiotic benefit of cleaning the brine for the geothermal process, which would need to be done with or without adding a lithium plant to the existing geothermal plant.

To date, CTR has received state and federal permits to conduct seismic surveys, research activities, and delineate drilling. Additional permits, including federal permits from the U.S. Army Corps of Engineers (Corps), and state permits, would be required to construct and operate the projects (CTR 2020b).

4.1.3 Untapped Potential

Current geothermal projects at the Salton Sea total 403 MW, and the Hell's Kitchen project, when fully developed, is anticipated to add up to another 140 MW. However, even with the potential addition of the Hell's Kitchen project, the KGRA is not fully developed—it has up to 2,950 MW of potential geothermal energy, of which approximately 700 MW is currently covered by the Salton Sea (Kaspereit 2016). As the sea continues to recede, these areas of potential may begin to be developed.

New wells drilled in the KGRA continue to increase in productivity, rising from 10–15 MW per well in the 1980s to as much as 30 MW per well as of 2015 (see Figure 4-5). As the KGRA becomes more well-defined and delineated, and technologies associated with drilling are optimized, further increases in productivity are likely. Well productivity is likely to increase if developers can access superhot geothermal energy (see Section 7.7).

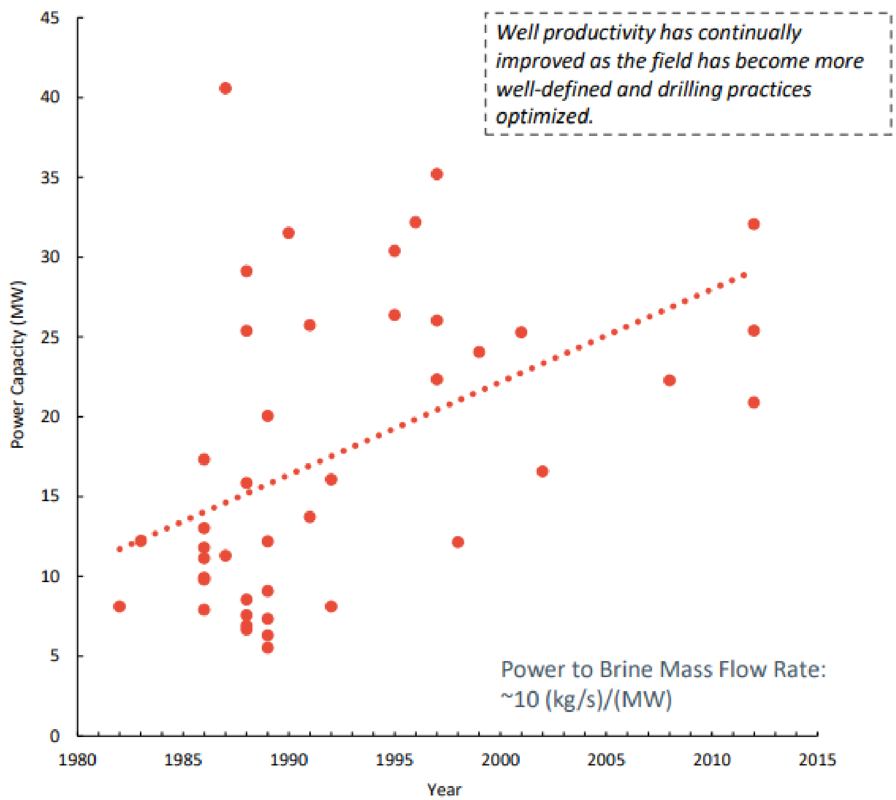


Figure 4-5. Salton Sea geothermal field average power capacity by year by well (CTR 2020a).

4.2 Solar Energy

Due to the arid and sunny climate, high temperatures, and low rainfall in Imperial County, both photovoltaic (PV) and concentrating solar power (CSP) are suitable for development there. While NREL estimated in 2015 that 1,851 acres of Imperial County geothermal KGRAs were within 1 mile of a 138 kV to 230 kV substation, they estimated that over 13,000 acres of potential solar potential (areas with less than 5% slope) were within 1 mile of transmission access (NREL 2015). In 2015, 19 solar power generation facilities had been either developed or approved in Imperial County, mostly in the southern portion of the county. By 2021, 26 projects had been either constructed or approved (ICPDSD 2021) in the southern portion of the county, and 16 projects had either been constructed or approved (ICPDSD 2022) in the northern portion of the county—many of which surround the City of Calipatria near the Salton Sea, close to some of the existing geothermal projects in the area.

4.3 Wind Energy

Wind potential in Imperial County is generally limited to higher elevation lands owned by the BLM. The BLM's 2016 Desert Renewable Energy Conservation Plan identified 110,000 acres of Development Focus Areas for renewable energy within Imperial County, but only 35,000 acres of these lands included wind, along with solar and geothermal (BLM 2016). Potential for wind development is only high in upland areas to the east and south of the Salton Sea (ICPDSD 2015), as shown in Figure 4-6. A large wind energy facility has been constructed in southwest Imperial County on both sides of Interstate 8 (ICPDSD 2015).

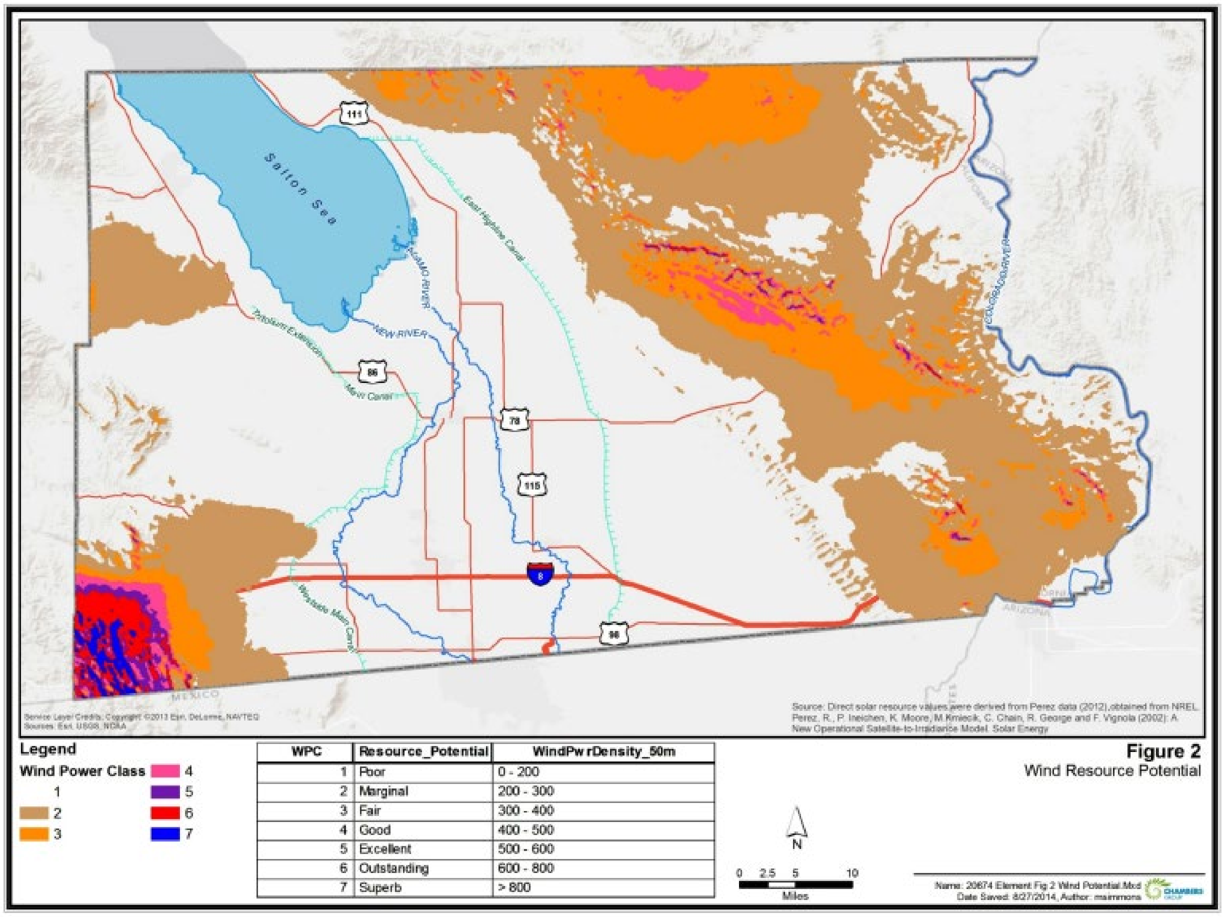


Figure 4-6. Potential wind power resource areas in Imperial County (ICPDSD 2015).

4.4 Battery Energy Storage Systems

As discussed in Section 5.0, solar and wind are not baseload energies; electricity is not produced when the sun is not shining or when there is no wind. To better compete with baseload energy sources such as geothermal and natural gas, battery energy storage systems (BESSs) for solar and wind energies are being developed. In a BESS, a battery charges or collects energy, and can then discharge that energy at a later time to provide electricity. While BESSs provide storage, they still have limitations in terms of scale, peaking, and a finite number of daily uses (Bade and Maloney 2017). IID has expressed interest in implementing BESSs at the Salton Sea to provide backup for existing and new solar generation facilities, although to date, no BESS is in place.

5.0 Geothermal Compared to Other Energy Sources

This section compares various attributes of geothermal energy resources to competing energy resources, with a particular focus on the Salton Sea. A discussion of these attributes helps to clarify the LCOE of geothermal resources and competitors like solar and wind, and also helps to understand the reasons for various PPAs and their associated prices.

When comparing geothermal to other renewable energies such as solar and wind, and non-renewables such as combined-cycle natural gas, the startup costs and wholesale price of generation from geothermal is relatively high. At the Salton Sea, the primary competitor to geothermal is solar PV, with some potential for wind development; therefore, these are the primary resources that are compared in this report. Natural gas and nuclear energy could also be competitors in California, but neither meet the CA RPS and both are politically controversial, so they are not discussed in detail.

Broadly, the advantages and disadvantages of individual energies considered in this analysis are summarized in Table 5-1. Many of these attributes are discussed in more detail below.

Table 5-1. Advantages and disadvantages of solar PV, wind, and geothermal energies (adapted from Li 2013).

Technology	Advantages	Disadvantages
Solar PV	Easy to assess resource	Low efficiency
	Easy to modularize	Low capacity factor
	Easy to install	Not weather proof
	Low social impact	High land use
	Easy to scale up	
	Short construction period	
Wind	Low cost	Low capacity factor
	Easy to assess resource	Not weather proof
	Easy to modularize	High land use
	Easy to install	
	Low-medium social impact	
	Easy to scale up	
	Short construction period	
Geothermal	Medium-high efficiency	High initial investment
	High capacity factor	Long payback time
	Low to medium cost	Long construction time

5.1 Positive Attributes of Geothermal Energy

5.1.1 Land Use/Resource Conflicts

Geothermal energy has a relatively small footprint compared to competing energies (Kagel et al. 2007). National Geographic found land use requirements associated with various types of energy sources (National Geographic 2022) presented in Table 5-2.

Table 5-2. Power-plant land use requirements per gigawatt-hour.

Type of Power Plant	Land Use per GWh (mi^2)
Geothermal	404
Wind	1,335
Solar PV	3,237
Coal	3,642

At the Salton Sea, studies have determined that a geothermal plant can produce about 1.2 MW/acre of land while a solar complex can produce about 0.19 MW/per acre, making geothermal more than six times as land-efficient as local solar facilities (Audubon California 2016).

While not a direct correlation, a smaller plant footprint generally leads to reduced resource conflicts associated with land disturbance, noise, and visual and aesthetic impacts.

5.1.2 Capacity Factor

The capacity factor, which can be used to determine the reliability of an energy project, is defined as the ratio of electrical energy output over a given period of time to the maximum possible electrical output that could have been generated over that period (NRC 2021). Energy output can decrease based upon a number of factors, including reliability, maintenance, weather conditions, and availability of the resource.

One major advantage of geothermal is that it has a high capacity factor that is not affected by weather. Both solar and wind are dependent on weather conditions; generation is affected when the sun is not shining or when the wind stops. Geothermal power, with its reliance on geothermal formations underground, is stable and can provide baseload power (Li et al. 2015).

A high capacity factor means that geothermal power plants can operate with a steady output throughout the day, which results in a plant that can generate about 2–4 times as much electricity as a wind or solar energy plant of the same installed capacity (DOE 2019).

Table 5-3. Capacity factor of various power-plant types (Li et al. 2015).

Type of Power Plant	Capacity Factor (%)
Geothermal	90
Wind	20-30
Solar PV	4-22
Coal	32-45

5.1.3 Grid Reliability and Flexibility

Because geothermal is a baseload energy source with a high capacity factor, it can be a critical part of a mix of energy sources that ensure grid stability and security, thereby reducing volatility (Matek and Gawell 2015). A 2014 study of different power mixes for California RPSs found that intermittent renewable energy sources like solar and wind would introduce challenges in terms of overgeneration during daylight hours and would need to be curtailed (Energy and Environmental Economics 2014). In 2014, because of reliance on intermittent solar and wind generation, the California Independent System Operator, which manages the flow of electricity in California, had to curtail generation multiple times to balance supply and demand on the system. The report found that "intermittent sources alone cannot cost-effectively generate electricity for a balanced grid," and that adding baseload renewables like geothermal to RPS scenarios is essential to reducing the overall costs of the grid to the minimum amount possible. As coal and natural gas plants that currently provide much of the baseload power are retired, geothermal power that can directly replace the reliability of these sources may be more valuable (Matek and Gawell 2015).

A PNNL web article provides a simple overview and case studies of why baseload power sources with deferable load capabilities ("power peaking") are important for preventing blackouts (PNNL 2022), and the same concepts apply to geothermal energy sources. In summary, if power demands exceed power supply, then the frequency of the grid can drop below 60 Hz and that can trigger rolling or even total blackouts. The benefit of baseload power resources such as geothermal is invaluable for providing grid reliability and a steady supply of power when the sun is not shining, and the wind is not blowing.

A separate unpublished PNNL report (Dhruv Bhatnagar, personal communication) uses case studies to demonstrate that geothermal plants could become profitable if they took better advantage of the ancillary benefits they can provide to the grid. Flexible PPA portfolios encompassing multiple power sources can be designed to provide higher revenue streams for geothermal power when it helps cover the gaps when output from other renewables falls. The PNNL model estimates that an active and flexible power market, taking ability of geothermal to ramp up or down power for grid frequency regulation, can result in prices to the geothermal plant owner that would exceed the LCOE – which would make some plants profitable and help geothermal become competitive.

5.1.4 Economic Benefits

The Geothermal Energy Association (GEA, now Geothermal Rising), an industry trade group, found that geothermal power plants employ about 1.17 persons per megawatt at operating plants (GEA 2015), and 3.1 persons per megawatt during construction. For a 49.9 MW plant, this would mean that about 58 employees would be required during operation and 155 employees during construction. Berkshire Hathaway estimated that a 350 MW geothermal plant would require approximately 235 employees during construction, and approximately 20–30 employees during operation. The differences in these estimates may reflect economies of scale; larger plants are likely to be able to benefit from a smaller workforce for certain tasks.

The GEA estimated that the persons per megawatt employed is 19 times the employment for wind or solar PV and 5 times the employment of CSP. Figure 5-1 includes a comparison of long-term jobs per 1,000 homes powered, by energy-generation technology.

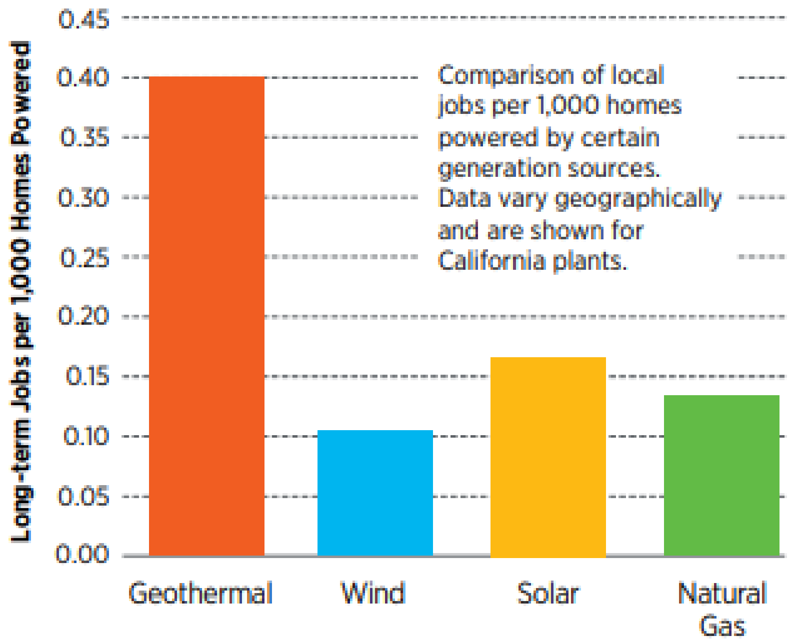


Figure 5-1. Comparison of long-term jobs per 1,000 homes powered, by energy-generation technology (DOE 2019). (Geothermal can provide more than double the long-term jobs per powered household compared to other electricity-generation technologies considered. The data shown are for California power plants.)

While this larger workforce during both construction and operation can be seen as a barrier to entry in terms of increased exploration/startup and operational costs (see Section 5.2.3), the workforce does provide economic benefits to the host community.

Research and stakeholder interviews reflected a desire to provide stable, well-paying jobs in economically depressed Imperial County. Geothermal energy development presents an opportunity to provide such an economic benefit, on top of the federal, state, and local royalties and property taxes paid (DOE 2019).

5.1.5 Emissions

Geothermal emissions of carbon dioxide (CO_2) and other pollutants are significantly less than those of fossil fuels, and comparable to renewable energies such as solar and wind (Figure 5-2, Table 5-4). Because balancing power is not needed for a geothermal plant, as is required for energy sources of lower-capacity factors, air quality impacts are generally minimal (Energy Warden 2021).

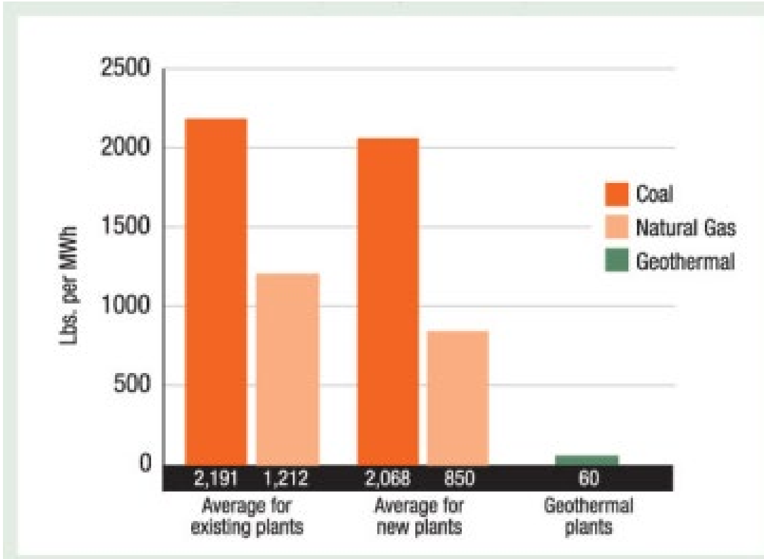


Figure 5-2. Carbon dioxide emissions from U.S. power plants (lb./MWh; DOE 2004).

Table 5-4. CO_2 emissions by power plant (Li et al. 2015).

Type of Power Plant	CO_2 Emissions (km/TWh)
Geothermal	170
Wind	25
Solar PV	90
Coal	1,004
Natural Gas	543

In the United States, geothermal electricity generation annually offsets the equivalent of 22 million metric tons of CO_2, 200,000 tons of nitrogen oxides, and 110,000 tons of particulate matter from conventional coal-fired plants (Green and Nix 2006).

5.2 Negative Attributes of Geothermal

5.2.1 Water Use

Geothermal power involves a relatively large consumption of water because of the need for cooling. As shown in Figure 5-3, this water use is generally more than solar PV and wind, but less than solar CSP and nuclear (Clark et al. 2011). However, the water consumption by geothermal power could be reduced remarkably by using new cooling technologies. Also, water consumption can be controlled by the total reinjection of polluted and foul-smelling wastewater, non-evaporative cooling, general pressure management, and closed-loop recirculating cycles (Li et al. 2015). Groundwater is not expected to be a constraint at the Salton Sea because IID has secured adequate water rights to expand future geothermal development.

Power Plant	Fuel Production	Plant Construction	Plant Operations	Total Life Cycle[b]
Coal	0.26	-	0.004–1.2	0.26–1.46
Coal with carbon capture	0.01–0.17	0.13–0.25	0.5–1.2	0.57–1.53
Nuclear	0.14	-	0.14–0.85	0.28–0.99
Natural gas conventional	0.29	-	0.09–0.69	0.38–0.98
Natural gas combined cycle	0.22	-	0.02–0.5	0.24–0.72
Hydroelectric (dam)	-	-	4.5	4.5
Concentrated solar power	-	0.02–0.08	0.77–0.92	0.87–1.12
Solar photovoltaic	-	0.06–0.15	0.006–0.02	0.07–0.19
Wind (onshore)[c]	-	0.02	3.62E-08	0.01
Geothermal EGS	-	0.01	0.29–0.72	0.3–0.73
Geothermal binary[d]	-	0.001	0.08–0.27	0.08–0.271
Geothermal flash[d]	-	0.001	0.005–0.01	0.01
Biomass	-	-	0.3–0.61	0.3–0.61

[a] Sources: Adee and Moore (2010), Maulbetsch and DiFilippo (2006), Frick et al. (2010), Gleick (1994), Goldstein and Smith (2002), Harto et al. (2010), NETL (2005), NETL (2008), Vestas Wind Systems A/S (2006).

[b] Reported when provided, otherwise summed from values in table.

[c] Assumes recovery of water in the end-of-life management stage.

[d] Assumes water consumed as makeup for operational loss is a small percentage of total operational geofluid loss.

Figure 5-3. Aggregated Water Consumption for Electric Power Generation at Indicated Life Cycle Stages in Gallons Per kWh of Lifetime Energy Output (from Clark et al. 2011).

5.2.2 Seismic Impacts

Geothermal energy presents a perceived risk of induced seismicity, due to the movement of fluids into or out of the geothermal well. This risk is particularly apparent with EGS reservoir creation and stimulation, which involves the injection of fluids and the fracture and stress of underground rock.

In California, the risk and threat of large earthquakes is of great significance to residents, stakeholders, and developers. A 2021 Caltech study found that while geothermal energy production triggers small earthquakes when pumping water into the reservoir, this actually reduces the risk of a large earthquake by relieving underground stress (Dajose 2021). DOE issued a 2012 *Protocol for Addressing Induced Seismicity Associated with Enhanced Geothermal Systems* to address public concern about induced seismicity, and to provide guidance to developers, regulators, and the public on useful steps to evaluate and manage seismic effects associated with EGS projects (DOE 2012).

5.2.3 Exploration/Startup/Construction Costs

5.2.3.1 Geothermal

Startup costs for geothermal projects are significantly higher than those for solar and wind, presenting a major barrier to their development (e.g., $400M for the J.L. Featherstone that is the newest plant at the Salton Sea). Because the geothermal resource is a subsurface resource, test and production wells must be drilled, increasing project time and risk.

Geothermal wells must be drilled deep into the earth's crust to access high-temperature resources. In many cases, this also involves drilling into hard rock, which can be a slow and expensive process (Richter 2019). "Geothermal prices are heavily increased by the long project development times, high costs and risk of exploratory drilling. And drilling can account for up to 50% of the total project cost" (Li et al. 2015).

Exploration, production, and injection well drilling are major cost components of any geothermal project (Petty et al. 1992; Pierce and Livesay 1994, 1993a, 1993b). Even for high-grade resources, they can account for 30% of the total capital investment (MIT 2006).

As stated in the GeoVision report, "Geothermal projects are often characterized by high upfront costs and long development timelines that lead to protracted investment payback periods relative to many other utility-scale power generation projects" (DOE 2019). The GeoVision report quantified capital costs of about $3,000–6,000 per kilowatt-electric (kWe) for geothermal developments, compared to $1,700–2,100 kWe for solar PV. Figure 5-4 provides information on various geothermal installed costs by project, technology, and capacity between 2007-2021.

Unlike with wind and solar, geothermal installed costs appear to have increased from 2010 to 2020 (see Table 5-5). Geothermal installed costs are site-sensitive and are dependent on the location, depth, and thermal properties of the reservoir, along with drilling costs for production and injection wells and field infrastructure. The rising costs between 2010 and 2020 may be a result of increased costs associated with civil engineering, along with increases in drilling costs associated with low priced oil and gas (IRENA 2021).

Source: IRENA Renewable Cost Database.

Figure 5-4. Geothermal power total installed costs by project, technology, and capacity, 2007–2021 (IRENA 2021).

5.2.3.2 Solar PV

The total installed costs of solar are significantly less expensive than those of geothermal. While certain costs associated with geothermal have decreased based upon new technologies and increased efficiencies, costs such as labor, engineering, and drilling costs have increased. The global capacity-weighted average installed cost of solar PV projects commissioned in 2020 was about $0.88M/MW, a decrease from about $4.7M/MW in 2010, and $1.8M/MW in 2015 (Table 5-5) (IRENA 2021).

5.2.3.3 Wind

Wind also has a lower total installed cost than geothermal. This cost has also been decreasing due to wind turbine prices and balance-of-plant cost reductions. The global weighted average for onshore wind projects dropped to $1.4M in 2020, declining from $1.9M in 2010 (Table 5-5) (IRENA 2021).

Table 5-5. Total global capacity-weighted average installed cost of renewable energy projects (2020 USD/MWh) (IRENA 2021).

Year	Solar PV	Wind	Geothermal
2010	$4.73M	$1.97M	$2.62M
2020	$0.88M	$1.36M	$4.47M

5.2.4 Development Timelines

The geothermal industry faces risks related to long development timelines (typically 7–10 years) that delay payback and increase project financing costs (DOE 2019).

5.2.5 Operations and Maintenance Requirements

Renewable energy sources do not use fuel like coal, oil, gas, and nuclear power plants, and therefore do not require the continual purchase and supply of fuel to run the plant, generally resulting in lower operations and maintenance costs.

The Salton Sea contains a relatively “briny” resource, containing numerous metals and other minerals that must be periodically removed to keep the geothermal plant online. This creates a greater expense to the operator to keep the plant online than is necessary for solar and wind. As discussed later in this report, the emerging lithium market may provide a revenue source that can effectively subsidize the brine maintenance requirements. Furthermore, well productivity decreases over time due to decreasing reservoir pressure around the geothermal well, requiring potential redrilling and reinjection of wells to maintain productivity (IRENA 2021).

While not specific to the Salton Sea, operations and maintenance cost requirements for geothermal, solar PV, and wind are included in Table 5-6.

Table 5-6. Operations and maintenance requirements for various energy sources ($/kW/yr) (IRENA 2021).

Year	Solar PV	Wind	Geothermal
2019	$10-18	$33-56	$115

5.3 Comparing the Costs of Different Energy Sources

It is important to compare the prices of different types of power sources (e.g., solar and wind) before reviewing the results of the sensitivity analyses for geothermal power in Section 6.3. That is because market constraints (e.g., competition with lower priced solar) are commonly identified as a main barrier for geothermal energy development. As described in the sections below, most data sources estimate that geothermal energy is more costly to generate than are solar and wind. It is therefore important to first quantify how large of a price gap geothermal power may have relative to other power sources like solar, which helps creates a target for MAGE (described in detail in Section 6.0 of this report), which examines how parameter adjustments affect geothermal price.

5.3.1 Levelized Cost of Electricity

Comparing geothermal to different energy sources requires the development of metrics that include similar inputs and outputs, which allow for the direct comparison of the costs of electricity generation projects with unequal economic lives. The primary two metrics that are most applicable to energy development and that are discussed further in this report are the LCOE and the price of PPAs. These metrics encompass the attributes discussed above, and potentially others, to generate a levelized cost per megawatt-hour that can be compared across generation types. The LCOE is a computed estimate requiring various input assumptions, including capital costs, risks and returns, capacity factor, efficiencies, and fuel costs. The subsidized LCOE differs from the unsubsidized LCOE because the latter also includes consideration of tax rates and subsidization. While the LCOE could provide a robust method of comparing prices across various energy types, there are not many publicly available LCOE data and the LCOE estimates can vary widely across data sources. The reason for the differences in LCOE estimates is difficult to evaluate because many reports do not list all their input parameters (e.g., discount rates, taxes, capital costs) or describe which types of plants are referenced (e.g., new vs older models), what region they are from (which highly affects resource productivity), etc.

Lazard computed an unsubsidized LCOE of between $56–93/MWh for geothermal, compared to $26–50/MWh for onshore wind and $28-–41/MWh for utility-scale solar PV (Figure 5-5) (Lazard 2021). IRENA's 2020 report computed an LCOE of $71/MWh for geothermal, compared to $57/MWh for solar PV and $39/MWh for onshore wind (Table 5-7) (IRENA 2021). For geothermal, the IRENA report computed a 71% increase in total installed costs and a 45% increase in the LCOE, compared to substantial decreases in total installed costs and LCOE for solar PV and wind.

The U.S. Energy Information Administration (EIA), on the other hand, derived a subsidized LCOE (after including tax credits) of $34/MWh for geothermal, compared to $37/MWh for wind and $30/MWh for solar PV (Table 5-8) (EIA 2021b). Unfortunately, there is minimal documentation about how the above LCOEs were calculated and why the values (particularly associated with the EIA estimates) are so variable and inconsistent. Differences may exist in terms of how the LCOE itself is defined, what types of projects, both in terms of technology and location are being considered, and whether existing plants are encompassed within the output values or whether these simply consider the anticipated LCOE associated with new construction.

Globally, the LCOE for geothermal projects has varied significantly for installed projects. This range has generally depended on the location of the geothermal facility, with a higher LCOE for greenfield developments in remote areas, and lower LCOE for development of existing fields (IRENA 2020). Because of various factors discussed below, it is expected that the LCOE at the Salton Sea would fall toward the lower end of the range.

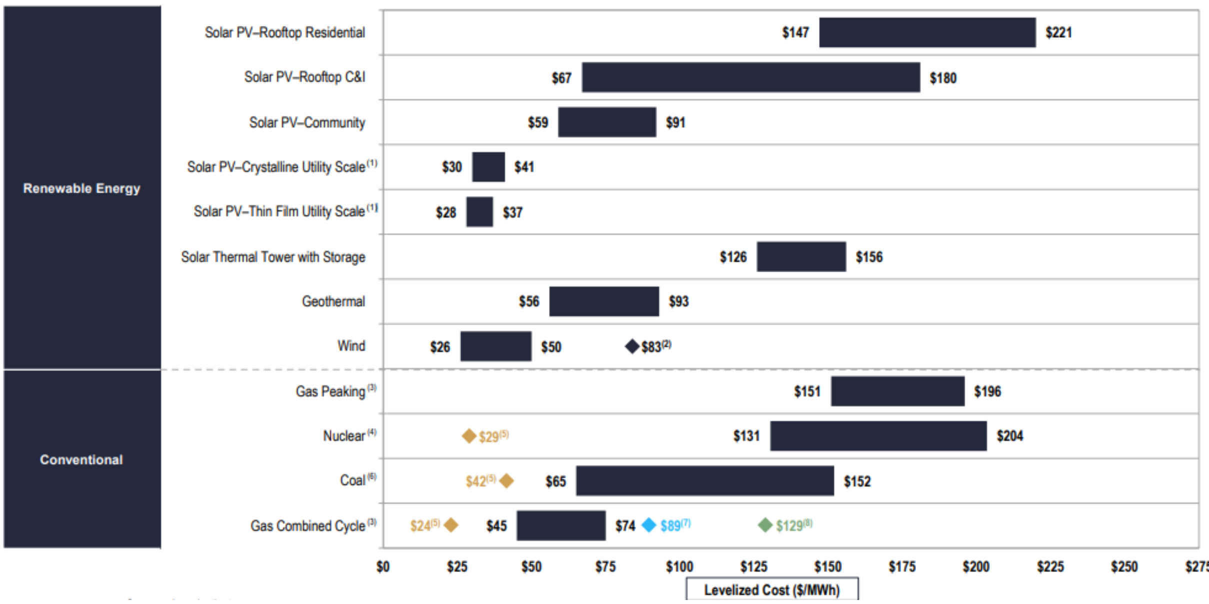


Figure 5-5. Levelized cost of energy comparison – unsubsidized analysis showing that renewable energy generation sources are cost-competitive with conventional generation technologies under certain circumstances (Lazard 2021).

Table 5-7. Estimated unweighted LCOE for new resources entering service in 2026 (IRENA 2021).

	Total installed costs (2020 USD/kW)			Capacity factor (%)			Levelised cost of electricity (2020 USD/kWh)		
	2010	2020	Percent change	2010	2020	Percent change	2010	2020	Percent change
Bioenergy	2 619	2 543	-3%	72	70	-2%	0.076	0.076	0%
Geothermal	2 620	4 468	71%	87	83	-5%	0.049	0.071	45%
Hydropower	1 269	1 870	47%	44	46	4%	0.038	0.044	18%
Solar PV	4 731	883	-81%	14	16	17%	0.381	0.057	-85%
CSP	9 095	4 581	-50%	30	42	40%	0.340	0.108	-68%
Onshore wind	1 971	1 355	-31%	27	36	31%	0.089	0.039	-56%
Offshore wind	4 706	3 185	-32%	38	40	6%	0.162	0.084	-48%

Table 5-8. Estimated unweighted LCOE (EIA 2021b).

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[1]	Levelized variable cost	Levelized transmis-sion cost	Total system LCOE or LCOS	Levelized tax credit[2]	Total LCOE or LCOS including tax credit
Dispatchable technologies								
Ultra-supercritical coal	85%	$43.80	$5.48	$22.48	$1.03	$72.78	NA	$72.78
Combined cycle	87%	$7.78	$1.61	$26.68	$1.04	$37.11	NA	$37.11
Combustion turbine	10%	$45.41	$8.03	$44.13	$9.05	$106.62	NA	$106.62
Advanced nuclear	90%	$50.51	$15.51	$9.87	$0.99	$76.88	-$6.29	$70.59
Geothermal	90%	$19.03	$14.92	$1.17	$1.28	$36.40	-$1.90	$34.49
Biomass	83%	$34.96	$17.38	$35.78	$1.09	$89.21	NA	$89.21
Battery storage	10%	$57.98	$28.48	$23.85	$9.53	$119.84	NA	$119.84
Non-dispatchable technologies								
Wind, onshore	41%	$27.01	$7.47	$0.00	$2.44	$36.93	NA	$36.93
Wind, offshore	44%	$89.20	$28.96	$0.00	$2.35	$120.52	NA	$120.52
Solar, standalone[3]	29%	$23.52	$6.07	$0.00	$3.19	$32.78	-$2.35	$30.43
Solar, hybrid[3, 4]	28%	$31.13	$13.25	$0.00	$3.29	$47.67	-$3.11	$44.56
Hydroelectric[4]	55%	$38.62	$11.23	$3.58	$1.84	$55.26	NA	$55.26

5.3.2 Power Purchase Agreements

PPAs provide another way to compare the relative costs of different types of energy sources. Unlike the LCOE, a PPA is an actual price agreed upon in a contract by an energy producer and a buyer. PPAs are set based on numerous factors but are mainly based on the plant owners trying to reach a price that, at minimum, covers their LCOE costs and power buyers (e.g., utilities) wanting lower prices to ensure profitability and low customer rates.

One of the main advantages of using PPAs for price comparisons is the large amounts of publicly available PPA data by type of power plant, location, and contract terms (e.g., price, years, power output). For instance, the Lawrence Berkeley National Laboratory maintains a PPA data set that covers about 80 GW of renewable energy projects throughout the country and contains itemized details for about 857 different PPAs that have been signed since 2001 (Bolinger 2020). This PPA data set also covers ~75% of operating geothermal capacity and ~50% of wind and solar capacity. Results from this data set are provided below.

Geothermal PPAs used to be comparable to solar and wind throughout the entire United States before 2010 (Figure 5-6); however, recent geothermal PPAs ($50–$100/MWh) are now approximately two to three times the amounts of recent wind ($15–$50/MWh) and solar ($25–$35/MWh) PPAs. The PPAs for wind and solar have experienced steady declines during the past decade due to technological advancements that make them exponentially more efficient. In contrast, geothermal PPAs had experienced slighter linear declines due to more constant technologies, but industry has new high hopes that new geothermal technologies (e.g., EGSs) could reduce their LCOEs (and PPAs) by half (see Section 7.8)

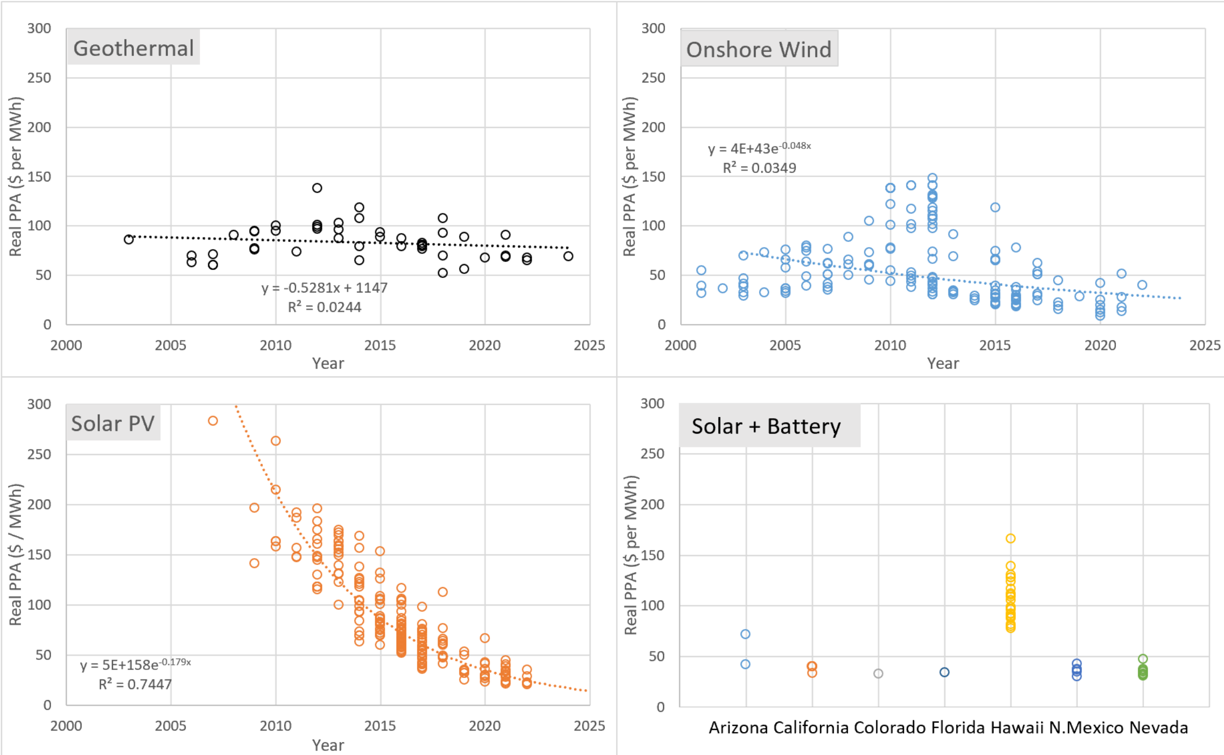


Figure 5-6. Real PPAs for renewable energy sources by year (entire United States) or by state (for recent 2015–2024 solar + battery PPAs).

At the Salton Sea, even with a well-mapped and available geothermal resource, PPAs for geothermal energy generally remain more expensive than for other renewables. Notable PPAs for new geothermal plants at the Salton Sea include the J.L. Featherstone (formerly Hudson Ranch I) and Hell's Kitchen facilities. The owners of J.L. Featherstone signed a PPA with the Salt River Project in Arizona for up to 55 MW/hr at $85.29/MWh from 2016–2019 and $90/MWh for 2021 and beyond (LADWP 2015). The owners of Hell's Kitchen recently signed a PPA with IID for 25 years at $69/MWh (CTR 2020c).

The PPAs for Hell's Kitchen and Hudson II at the Salton Sea are consistent with other geothermal PPAs throughout the Southwestern United States where solar has become prevalent (Table 5-9). Similar to the national PPA trends (Figure 5-6), the average geothermal PPA ($71/MWh) is about 2.2x higher than the average solar PPA ($32/MWh) and 3.1x higher than the average wind PPA ($23/MWh).

Table 5-9. PPAs for renewable energy throughout the Southwestern United States from 2020–2024.

PPAs in Southwestern[(a)] States from 2020–2024 ($/MWh)				
	Geothermal	Solar PV	Onshore Wind	Solar PV + Battery
Count (of PPA contracts)	8	29	13	7
Mean (PPA $)	71	32	23	37

PPAs in Southwestern[a] States from 2020–2024 ($/MWh)				
	Geothermal	Solar PV	Onshore Wind	Solar PV + Battery
25th quartile (PPA $)	66	25	14	33
75th quartile (PPA $)	69	36	34	40
PPA = Power Purchase Agreement; PV = photovoltaic. (a) California, Colorado, Arizona, Utah, New Mexico, Texas, Oklahoma				

One of the main downsides to the PPA price comparisons shown above (Table 5-9; Figure 5-6) is that they do not necessarily quantify the ancillary benefits that a power source can provide for grid reliability and flexibility. For example, geothermal energy can provide reliable baseload power 24 hours per day whereas solar and wind are intermittent. The value of baseload power sources (e.g., geothermal, gas, nuclear) cannot be understated because power shortages can cause blackouts for large portions of the grid.

Solar plus battery storage is an emerging renewable baseload power source that is in competition with geothermal. PPAs for recent (2020–2024) solar plus battery projects in the Southwestern United State now typically range from $35–$50/MWh compared to the typical range of $60–$90/MWh for geothermal (Table 5-9; Figure 5-6). These systems are described in more detail in Section 4.4).

5.3.3 Ancillary Benefits

While the LCOE is an attractive metric for comparing power generation technologies, it should be noted that LCOE is regarded as poorly suited to valuing energy systems of the 21st century, with an inability to account for services (and benefits) provided by a given energy asset beyond electricity production (IEAGHG 2020).

LCOEs and PPAs are helpful for comparing prices and market constraints for different types of power, but they do not necessarily consider ancillary benefits to grid stability, reliability, and reduced carbon that geothermal provides. Additional ancillary benefits include “flexibility, reserve capacities, insulation from fluctuating fuel prices, and plant life, which may exceed typical planning periods of thirty years” (ClearPath 2020). These ancillary benefits are often not reflected in PPAs, which is a main reason why renewable energy sources such as geothermal may be provided with tax incentives and other governmental subsidies to help with costs.

Several studies attempt to quantify the ancillary benefits that geothermal provides for providing low carbon and reliable baseload power, which are discussed below. One caveat is that the estimated ancillary benefits that geothermal provides over solar (intermittent power) are based on studies that used data from 2010–2015, which was when solar was ~2–3x more expensive than it is in 2022 (Figure 5-6). The new battery energy storage systems (Section 5.3.4) are starting to have the same ancillary benefits and a potentially lower cost (Figure 5-6).

A 2016 study by the Center for Energy Efficiency & Renewable Technologies considered the effects of replacing 3,800 MW of solar generation with 1,250 MW of new geothermal generation at the Salton Sea. The results indicated that, because of geothermal’s higher capacity factor and increased flexibility relative to solar energy, CO_2 emissions in California would be reduced by 4.2 million metric tons per year in California and 2.4 metric tons per year in the rest of the

West, along with saving California "$662 million per year in energy and ancillary service costs, $44 million per year in system resource adequacy costs, and $29 million per year in flexible resource adequacy costs" (Caldwell and Anthony 2016). The report found that each megawatt-hour of additional geothermal production would lower California energy costs by $75 over a base scenario.

Even under a scenario where solar battery backup is implemented, geothermal would still be over $20/MWh more valuable than solar (Caldwell and Anthony 2016). Factors considered when quantifying this cost savings include:

- Reducing curtailment means delivering more zero variable cost renewable energy to serve electric load and using less fossil energy that requires purchasing natural gas for fuel,
- Reducing carbon emissions, which is the result of burning less natural gas and using the gas fleet more efficiently, means purchasing fewer cap and trade allowances,
- Reducing starts and stops on the gas fleet mean less operating and maintenance expenses and higher fuel efficiency, and
- Producing more renewable energy "on-peak" when prices are higher and reducing the hours with negative pricing due to overgeneration lowers system costs.

A 2017 study by Orenstein and Thomsen quantified geothermal as $32/MWh more valuable than generation from solar PV, when combining the energy and capacity basis; when adding the ancillary services and operational flexibility, this increased to more than $40/MWh (DOE 2019).

5.3.4 Battery Energy Storage Systems

BESSs are intended to mitigate some of the grid flexibility and reliability issues associated with solar and wind energy and to make these energies more directly competitive with baseload energy sources like geothermal. However, BESSs are a relatively new technology, and uncertainty remains about whether a BESS can provide lower price renewable baseload power than geothermal, and whether a BESS can be viewed as a direct competitor of geothermal (Chowdhury 2020). It is also unclear whether, at a large scale, a BESS can supply variable load during peak times as effectively as can geothermal, because a BESS's capacity factor is dependent on the number of cycles per day and the length of such cycles (NREL 2021b).

Recent LCOE data do suggest geothermal energy has a price advantage relative to BESSs, but it is unknown how these LCOE estimates were derived, and this is counter to the PPA and anecdotal evidence that suggests that a BESS may result in a lower price. Lazard (2021) estimates the geothermal LCOE to be $56–93/MWh compared to $120–$156/MWh for solar BESSs (Figure 5-5). The EIA estimates the LCOE for a BESS to be $120/MWh, compared to $35/MWh for geothermal.

In contrast, PPAs for geothermal in the Southwestern United States range from $60–$70/MWh compared to $33–40/MWh for solar BESSs. The price for solar BESSs is about $5–10/MWh more than solar systems without batteries (Table 5-9). These PPA data and findings are consistent with anecdotal evidence from the power industry. Interviews with IID indicated that a BESS for solar (in the $40/MWh range) would likely cost around $10/MWh more than solar without a BESS (in the mid- to high-$30/MWh range). IID also expects new BESSs may become the future of renewable baseload power unless actions are taken soon to assist geothermal. Similarly, a common theme at the 2021 Geothermal Rising Conference was that geothermal energy-generation was more expensive than solar or BESSs. However, there was optimism about the costs of geothermal decreasing due to new technologies such as EGSs and the existence of lithium at the Salton Sea.

While not specific to Imperial County or the Salton Sea, Pacific Gas and Electric Company (PG&E) in California is proposing to add nine solar BESS projects that would add 1,600 MW of power to the grid. These new projects would increase PG&E's total battery energy storage to 3,330 MW by 2024 and help counter the closing of their 2,200 MW Diablo Canyon nuclear power plant (Solar Builder 2022). These projects, subject to approval by the California Public Utilities Commission (CPUC), are projected to power about 2.5 million households in California. PG&E's solar BESS projects could therefore power 22% of California's 11.5 million total households (California Census Data 2007).

5.4 Geothermal Comparison Conclusion

In conclusion, one of the main barriers for geothermal energy is not being cost competitive with other forms of renewable energy such as wind and solar based on PPA data and industry insights from our interview process. Although geothermal may be a relatively expensive renewable energy source, wind and solar are intermittent and do not provide reliable 24/7 baseload power as does geothermal. Geothermal also can ramp-up output ("power peak") to help provide grid stability, prevent blackouts, and could help geothermal plants become profitable by increasing output when prices and demand are high. A well-balanced energy portfolio can include low-cost intermittent power sources like solar, but must contain reliable baseload power sources like geothermal; however, geothermal will have to compete with solar BESS systems that may provide a form of baseload power at a lower cost, while meeting California's RPS standards.

6.0 Model for Analysis of Geothermal Economics (MAGE)

Based upon its research and understanding of geothermal development, PNNL has developed MAGE to analyze the relative sensitivity of both technical and nontechnical variables affecting the LCOE of geothermal generation and the likelihood of future PPAs.

MAGE estimates the financial viability of a potential geothermal power plant. The model estimates various outputs, described below, that help determine the viability of a project. MAGE takes inputs that are standard for economic analyses—capital costs, operating and maintenance costs, sale price—and appropriately discounts these values over time. MAGE also includes relevant taxes and tax depreciation allowances. Features added to the standard techno-economic model include permitting costs, permitting and exploration time, changes in the discount rate, potential subsidies, and other potential tax breaks.

All MAGE inputs, outputs, and discount rates should be considered “real” prices, meaning that they are adjusted for future inflation. This does assume that future operating costs, revenues received, and all increase at the rate of inflation. This choice was made because using nominal prices in a TEA model causes the inflation rate to influence model outputs such as LCOE and DNPV.

MAGE differs from GTO’s Geothermal Electricity Technology Evaluation Model (GETEM), which is used to model the physical features of the geothermal well such as depth or temperature and converting those to costs and electricity output (DOE 2016b). These types of changes can be entered as changes in capital costs, prices, etc., but the magnitude of the changes in cost are not estimated within the model. GETEM focuses on financial and economic parameters and outputs, and greater flexibility in examining timeline reduction. MAGE is more appropriate when costs and output estimates have been obtained from feasibility studies or engineering assessments.

Other differences include MAGE’s ability to output DNPV and BCR, use of power purchase price as an input (allowing for the analysis of potential prices that would be received from a PPA), and inclusion of a lithium extraction addition to the power plant. MAGE is also written with a user-friendly interface that is able to run in a web browser.

One of the main benefits of MAGE is that it allows users to evaluate how effective certain actions may be (e.g., reducing permitting costs) for reducing the price of geothermal electricity relative to other competition renewables. Although the model was designed with the Salton Sea in mind, it can be customized to explore geothermal solutions and benefits throughout the country.

6.1 MAGE Data Sources and Inputs

MAGE attempts to derive input values associated with conditions and trends present in the Salton Sea area. These values were obtained from stakeholder interviews, published papers, journal articles, government and industry reports, and other previous studies that have estimated costs for geothermal plants. Preference is given to more recent values because recent technological progress has shown the potential for reducing drilling, exploration, and startup costs. Using older cost estimates could bias the results with higher LCOEs and lower profitability.

A critical issue with choosing input values is that most of these parameters have a range of input choices, some of which have large variations. The criteria that we used for choosing which value to use as the baseline included:

- known values specific to the Salton Sea;
- recent estimates reflecting current technology; and
- values specific to geothermal for parameters such as the discount rate and power price.

After identifying the baseline, sensitivity analyses can be used to determine the effect of changing a single parameter. Sensitivity analysis has two benefits. It shows which parameters have the largest impact on the output parameters, and it allows an interested party to see how the output values would change if their situation would dictate a different input value.

6.2 MAGE Outputs

MAGE calculates five different output metrics to assess the economics of a geothermal power plant and various changes in regulatory costs and conditions. These metrics are the

- discounted net present value (DNPV)
- benefit-to-cost ratio (BCR)
- discounted payback period
- undiscounted payback period
- levelized cost of electricity (LCOE).

6.2.1 Discounted Net Present Value

The first of these metrics is the DNPV. For this calculation the costs and revenues are determined for each year of the project, appropriately discounted, and then summed for the full-time horizon of the project. The following formula is used to calculate this metric:

$$\text{DNPV} = \sum_{n=0}^{T} \frac{R_n - C_n}{(1+r)^n} \tag{1}$$

where R_n represents the revenue in year *n*, and C_n represents the costs in year *n,* and *r* is the discount rate. A DNPV greater than zero indicates that the project will provide a return to potential investors greater than the discount rate, making it profitable over the course of its lifetime (see Section 6.3 for an overview of how discount rates affect the DNPV).

6.2.2 Benefit-to-Cost Ratio

The project will be profitable if the BCR is greater than one. The BCR is calculated using the following formula:

$$BCR = \frac{\sum_{n=0}^{T} \frac{R_n}{(1+r)^n}}{\sum_{n=0}^{T} \frac{C_n}{(1+r)^n}} \tag{2}$$

A BCR greater than one is equivalent to a DNPV greater than zero. The advantage of the DNPV is that it is expressed in units of currency, so it can quickly inform what the extra profit or loss will be after accounting for the discount rate (see Section 6.3). The BCR is sometimes preferred because it is measured on a relative scale that is near one, while the DNPV for projects on the scale of power plants is often in millions of dollars and can be more difficult to quickly gauge. Hence, the BCR is more useful for comparing projects of different scales with a similar metric. For both measures, higher values indicate higher profitability and a higher likelihood that a project would be adopted.

6.2.3 Discounted Payback Period

The third metric calculated is the discounted payback period. This is calculated by finding the value of *n* such that

$$\sum_{n=0}^{T} \frac{R_n - C_n}{(1+r)^n} \geq 0$$

where *n* is the number of years since the project began exploration and has paid those costs. This value represents the time required for a project to achieve a DNPV of zero. This is the point at which a project would be considered to have achieved the desired rate of return as indicated by the discount rate. If this time is less than the lifetime of the project, it is likely to be attractive to potential investors.

6.2.4 Undiscounted Payback Period

The fourth metric calculated is the simple payback period. It is calculated by finding the value of *n* such that:

$$\sum_{n=0}^{T} (R_n - C_n) \geq 0 \qquad (3)$$

This value represents the time that the project will take to recoup the initial investment costs, informing potential investors of the time scale required for their investment to become profitable. This measure does not use discounting and estimates the value of a project by informing an investor how long it would take for their initial investment to pay itself off.

6.2.5 Levelized Cost of Electricity

The final output value is the LCOE. The LCOE determines the discounted present value of the costs divided by the discounted present value of the energy produced, which is calculated using the following formula:

$$LCOE = \frac{\sum_{n=0}^{T} \frac{C_n}{(1+r)^n}}{\sum_{n=0}^{T} \frac{E_n}{(1+r)^n}} \qquad (4)$$

where C_n is the cost in year *n*, E_n is the electricity produced in year *n*, and *r* is the discount rate. The costs include capital costs, operating and maintenance costs, and permitting costs. For this report, the LCOE includes all relevant taxes as costs and subsidies as negative costs. LCOE is useful for comparing the cost of geothermal electricity generation to other sources of electricity generation. LCOE is equivalent to the minimum average selling price of the power for the plant to be profitable over its lifetime. This feature is useful for comparing LCOE to PPA prices and other potential agreements.

6.3 Discount Rates

High discount rates have been described as one of the main barriers to geothermal energy development. Discount rates, for these purposes, are equivalent to opportunity cost that an investor has when lending money. The discount rate of a project is the expected return on a financial asset of similar risk (Ross 2019). For a geothermal project to attract investors, it must provide a return at or greater than other similar assets. A DNPV greater than zero indicates that the project is providing this required return. Mathematically, using a lower discount rate will increase the DNPV, BCR, and LCOE of a project. In practice, a lower discount is used to represent a project with lower risk.

To illustrate the role the discount rate plays in calculating the DNPV, a basic example is presented that requires a $1 million initial investment, with an annual payout of $150,000 for 10 years (see Table 6-1). The example shows the difference in annual discounted payout and DNPV for a 7% and 10% discount rate while holding all other parameters constant. The example represents an attractive investment at a 7% discount rate because the DNPV is greater than zero. However, at a 10% discount rate the DNPV is less than zero and would likely be an unattractive investment. In summary, if the project's risk was comparable to other assets with a 7% return, investors could be found, and funding would be available, but if the risk was comparable to other projects returning 10%, it would be unlikely to attract the necessary funding.

Table 6-1. Example of changing discount rates on the DNPV.

Year	Discounted Payout (7%)	Discounted Payout (10%)
1	140,187	136,364
2	131,016	123,967
3	122,445	112,697
4	114,434	102,452
5	106,948	93,138
6	99,951	84,671
7	93,412	76,974
8	87,301	69,976
9	81,590	63,615
10	76,252	57,831
Total Discounted Payout	1,053,537	921,685
Initial Investment	1,000,000	1,000,000
DNPV	53,537	-78,315
Initial Investment	**1,000,000**	
Annual Net Revenue	**150,000**	
Time	**10 Years**	

6.4 Baseline Parameters

Geothermal plant, financial, regulatory, and lithium parameters compose the MAGE baseline parameters.

MAGE divides the geothermal process into three stages: exploration and permitting, construction, and operation. Exploration and permitting are the first steps in the process and may occur concurrently. Steps associated with exploration may include acquisition of the land and/or obtaining a lease, water sampling, exploration surveys, and drilling of exploratory and test wells. Permitting encompasses compliance with federal, state, and/or local environmental compliance requirements, along with acquisition of any land use, zoning, and/or construction permits. Construction involves the building of the plant, wells, and ancillary facilities. Steps may include drilling production wells, construction of the geothermal plant and support structures, and construction of offsite transmission lines necessary to transport the power to load centers.

6.4.1 Geothermal Plant Parameters

We chose to model a 49 MW nameplate capacity plant. This is the largest plant that does not require CEC permitting and oversight, is a common size of plants at the Salton Sea (Table 4-1), and several of stakeholder interviews indicated this as a target size required to avoid any multijurisdictional issues. We chose a plant with an uptime of 330 days per year (90% capacity factor) to reflect the necessary reality of planned maintenance and upkeep and some unplanned maintenance issues (Huang et al. 2021).

A variety of sources have surveyed the costs of geothermal plants, including Lazard (2021) and Clauser and Ewert (2018). These both have a large variety in the capital cost per kilowatt-hour, making it difficult to choose the best value. The large variety is largely attributed to different conditions (depth, temperature etc.) and to local capital and labor costs. Specific to the Salton Sea, CTR has done some initial studies of conditions associated with the Hell's Kitchen project. They estimate construction costs to be $3,500/kW for an initial 49 MW plant, and they claim that capital cost could be reduced to as low as $2,500/kW at a plant size of around 125 MW from multiple wells sharing the same control center and aboveground power generation equipment. We use $3,500/kW as the baseline value to best represent current conditions at the Salton Sea.

6.4.2 Financial Parameters

We use 2021 values for federal corporate tax and California State sales tax and property tax, and the 5-year modified accelerated cost recovery system schedule for depreciating capital, which is used for geothermal projects (IRS 2021). Choosing the correct discount rate is difficult because of the wide variety of sources. Our baseline value is 7.1%, a rate obtained from previous geothermal projects (Wall et al. 2017). This value is also close to the 7% recommended for the "base-case analysis" in Office of Management and Budget Circular A-94 (OMB 1992) that approximates the marginal pretax rate of return on private investments in recent years. The potential downsides of this source are that it may not reflect current market conditions, and it has a small sample size compared to other sources such as Damodaran (2022). The default model uses a single discount rate for the entire project. One of the scenarios considered splits the discount rate into a higher rate for the exploration phase that represents the higher risk associated with that portion of a project.

6.4.3 Regulatory Parameters

The baseline regulatory parameters were obtained from a variety of different sources. The direct permitting costs were obtained from interviews with the local jurisdictions. Tax credits, tax rates, and subsidies were obtained from the relevant Internal Revenue Service codes and laws. The exploration costs were obtained from a more general source, and do not include a Salton Sea-specific value.

6.4.4 Lithium Parameters

We also include some analysis with the addition of a lithium extraction plant to the geothermal plant (see Table 6-2 for the lithium plant assumptions). The costs listed assume that the geothermal plant is already constructed and operational; that is, that the capital cost to explore, drill, pump etc., are accounted for in the geothermal costs. These costs would underestimate the costs of a standalone lithium mine but represent the current situation at the Salton Sea where lithium extraction is being considered only in tandem with geothermal generation.

There is limited cost information about lithium brine extraction. To date, no brine extraction plant has sustained commercial operation and success at the Salton Sea or at any other location in the United States.

Table 6-2. MAGE baseline parameters.

Parameter	Value	Source
Geothermal Plant		
CAPX geothermal	$3,500/kW (171.5M for a 49 MW plant)	Stakeholder interviews
OPEX geothermal	$3.25M/yr	The National Renewable Energy Laboratory's Geothermal Electricity Technology Evaluation Model
Permit + habitat mitigation costs	$1,000,000	Stakeholder interviews
Plant lifetime	30 years	Assumption
Plant size	49 MW	Assumption
Capacity factor	90% (330 days per year, 24 hours per day)	Huang et al. (2021)
Annual production decline	1%	Sanyal et al. (2000)
Financial		
Discount rate	7.1% WACC for exploration, construction, and operation.	Augustine et al. (2019), Wall et al. (2017)
Power Price ($/MWh)	80	Assumed PPA for Salton Sea geothermal plants
Federal tax rate	21%	Fed tax rate
State tax rate	8.84%	CA tax rate
Regulatory		
Construction time	4 years	Young et al. (2019)
Exploration time	4 years	Young et al. (2019)
Exploration cost	$10M	Young et al. (2019).
Investment tax credit	10%	Clocktower tax credits (2022)
Property taxes	3.5M	2% of capital costs (Huang et al. (2021))
Lithium		
CAPX lithium	$35M	Huang et al. (2021)
OPEX lithium	$40M/yr	Huang et al. (2021)
Lithium harvest	8,350 tons per year	Huang et al. (2021)
Lithium price	$13,000 per ton of lithium carbonate	USGS (2020) 2019 price.
CA = California; CAPx = capital costs; OPEX = operations costs; USGS = U.S. Geological Survey; WACC = weighted average cost of capital.		

6.5 Baseline Outputs

Based upon MAGE results using the inputs described in Table 6-2, the DNPV using baseline inputs is $3.4M and the BCR is 1.02. Because the DNPV is larger than zero and the BCR is greater than one, a baseline Salton Sea geothermal project with these input values would be considered profitable (see Figure 6-1). However, a slight change in input parameters such as construction cost overruns could render the project unprofitable.

The figures described in this report, including Figure 6-1, demonstrate the overall timeline of a project. Exploration costs are paid fully in Year 1. Years 2–3 do not have any associated costs or benefits. Permitting and mitigation costs are paid in Year 4. Construction costs are paid fully in Year 5, and while construction is ongoing in Years 5–8 there are no additional costs or revenue. Operation begins in Year 9 and lasts until the project is completed in Year 38. During operation, revenue is accrued from electricity sales, and operating and maintenance costs are paid.

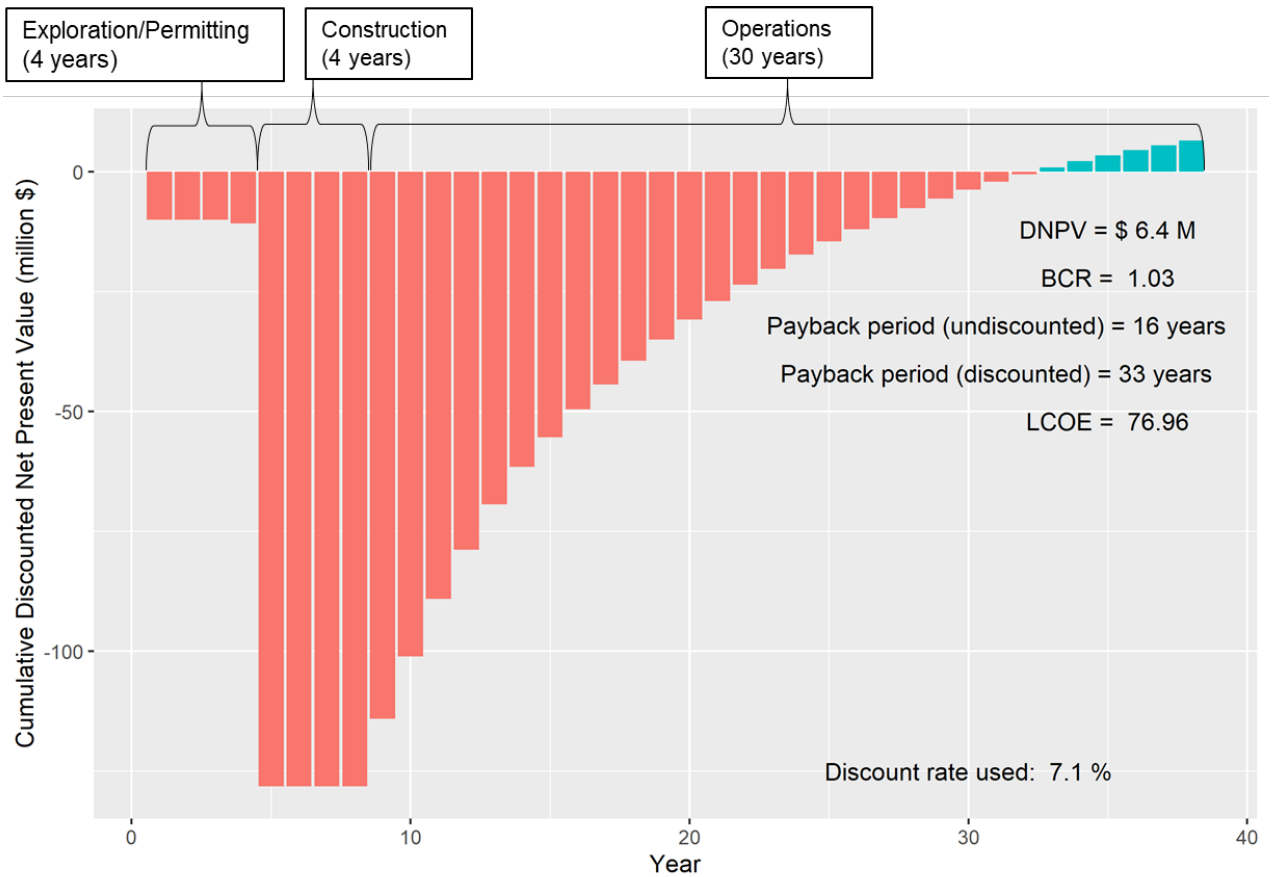


Figure 6-1. Baseline MAGE outputs.

The LCOE of $77/MWh is within the estimates presented by Lazard (2021) for geothermal projects but is toward the lower end. This means that for a project to be profitable it would need to secure a PPA with a price greater than $77, and this may prove difficult when competing against other potential projects at the Salton Sea such as solar PV and/or an associated BESS.

Section 7 provides MAGE results for alternative cases, where baseline parameters from Table 6.2 are adjusted to represent variations which might be viable, or which may provide a sense of which parameters are most sensitive to alternative operating assumptions.

7.0 Challenges and Opportunities at the Salton Sea

As previously discussed, geothermal development involves a longer, more complex, and more expensive exploration, development, and permitting process than do solar or wind development. This factor leads to an LCOE that is higher than competing renewable energy sources. While geothermal has the benefits of being a baseload renewable power resource, and thus warrants a slightly higher LCOE than non-baseloads such as solar and wind, the relative lack of geothermal development at the Salton Sea illustrates that the gap has not been closed. The sections below explore both technical and nontechnical opportunities and scenarios for geothermal power generation to effectively reduce its LCOE at the Salton Sea and be a competitive renewable energy source.

Certain potential challenges relevant to other geographic areas are not relevant to the Salton Sea. For example, social acceptance for geothermal development appears to be high in Imperial County. Many existing geothermal projects have been operating for decades, providing employment and tax revenue to the county without significant resource impacts or demands.

7.1 Exploration and Construction

As discussed in Section 5.2.3 of this report, costs associated with exploration and development of the geothermal resource are higher than those for solar and wind development. Geothermal requirements for subsurface well drilling results in longer, less certain, and more expensive exploratory processes than do those for other renewable energies, which are constructed on the land surface where resource potential surveys have been completed. At the Salton Sea, the numerous wells drilled for various projects mean that the resource is well-mapped and understood compared to other areas, thereby reducing risk to developers. Despite this reality, the Hudson Ranch II project was canceled in part because of unsatisfactory results associated with production wells for the project (Richter 2014).

While the risks associated with geothermal exploration are mitigated by the well-understood resource at the Salton Sea, in general, geothermal is at an exploration disadvantage compared to other energy resources. Thus, streamlining the exploratory and permitting process is vital to reduce investor risk and potentially lower the discount rate.

While the global installed costs of geothermal projects are relatively high, these costs are decreasing due to improved drilling technologies. Furthermore, at the Salton Sea, where the geothermal resource is relatively well known and understood, the costs may be less than the global average. Ongoing efforts to collect new geophysical data at the Salton Sea can “identify potential geothermal resources as well as monitor earthquake and flood hazards, groundwater, mineral deposits, and conservation areas,” as well as lithium deposits (DOE 2021). These efforts can meaningfully reduce the cost of exploration as well as the risk associated with an unsuccessful exploration effort.

The Hudson Ranch I project cost about $400M to complete (PMC 2011). For the 49.9 MW project this equates to about $8,000/kW. While the Hudson Ranch II project was not completed, well drilling had a sunk cost of about $20M.

CTR indicated that Phase I of the Hell’s Kitchen project, 49.9 MW, is expected to cost around $3,500/kW ($175M). CTR has indicated that larger projects, such as the fully implemented 125 MW project, could reduce this cost further, potentially to as low as $2,500/kW.

7.1.1 Discount Rates – MAGE Results

Figure 7-1 shows the results of MAGE when the discount rate used is reduced by one percentage point to 6.1%. As discussed above, larger discount rates are associated with industries and projects that have higher risk, so lowering the discount rate represents a project with a lower risk. In practice, the discount rate could be reduced by having a well-known and well-characterized resource, lower likelihood of drilling failure, greater certainty in construction costs, or regulatory approval. Changes in the discount rate increase the DNPV and BCR and reduce the LCOE. As modeled at the Salton Sea, each one percent point reduction in the discount rate reduces the LCOE by around 5%, but this varies across the range of possible discount rates.

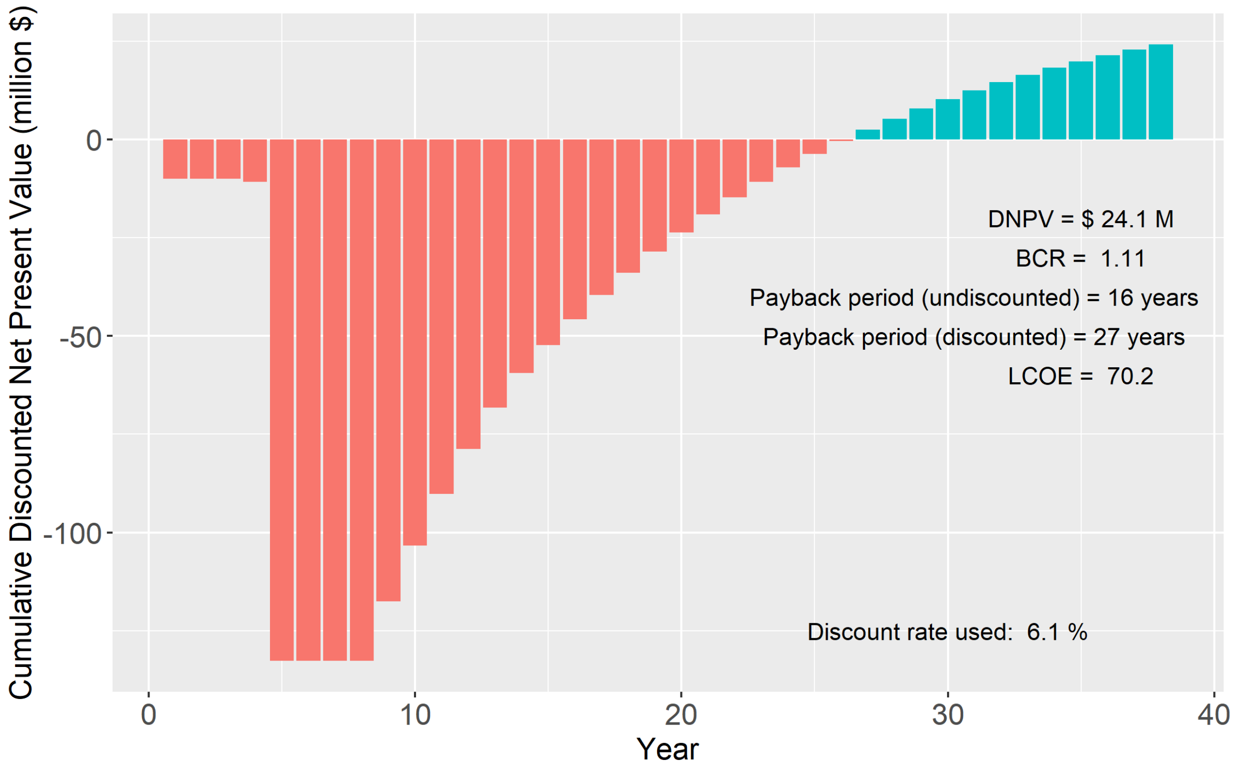


Figure 7-1. Discount rate reduced by 1 percentage point.

Figure 7-2 shows the results of MAGE using a 3% discount rate. This discount rate represents the discount rate that a project would likely face if most or all the risk were guaranteed by a third party. This would be representative of a project that was able to secure a federal loan guarantee and is the discount rate recommended by OMB for publicly funded projects (OMB 1992).

Figure 7-2 demonstrates that a reduced 3% discount rate could provide considerable benefits for the geothermal industry. For instance, a 3% discount rate is expected to reduce the discounted payback period by 14 years (i.e., 19 instead of 33 with the base model) and reduce the LCOE by $24/MWh (i.e., 53/MWh instead of 77/MWh with the base model). An LCOE of $53/MWh with a reduced 3% discount rate would help geothermal become very price competitive with other renewables, such as wind and solar, when also considering the important ancillary benefits geothermal provides for reliable baseload power and grid stability.

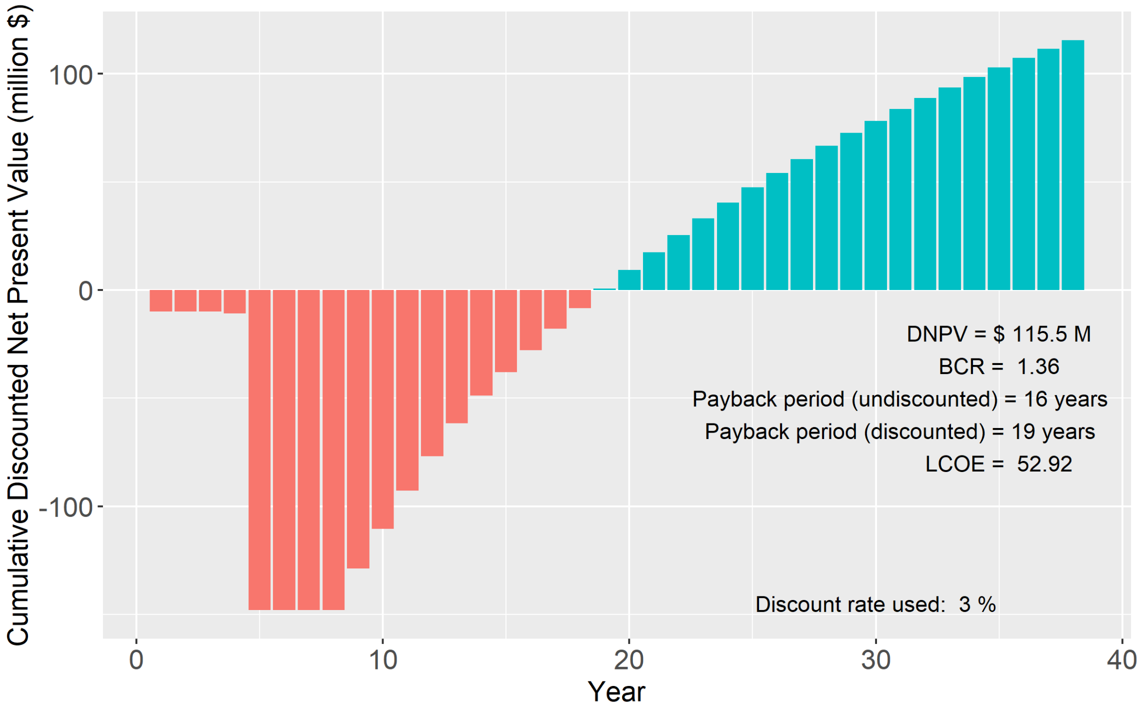


Figure 7-2. 3% Discount Rate

In contrast, Figure 7-3 shows the results of MAGE if equity-based financing for the exploration phase of the project must be used with higher discount rates due to failure risks. The rates used for this scenario are 13% for the exploration phase and 10.9% for the remainder of the construction and operational period, which were obtained from estimates based upon previous geothermal projects (Wall et al. 2017). Equity financing typically requires higher rates of return because it is used for projects that have inherently higher risks. Higher discount rates lead to higher LCOEs, and this is shown in the increase in LCOE from $77/MWh to $109/MWh. Equity based financing for the exploration phase also places a higher emphasis on the costs and timelines during this phase.

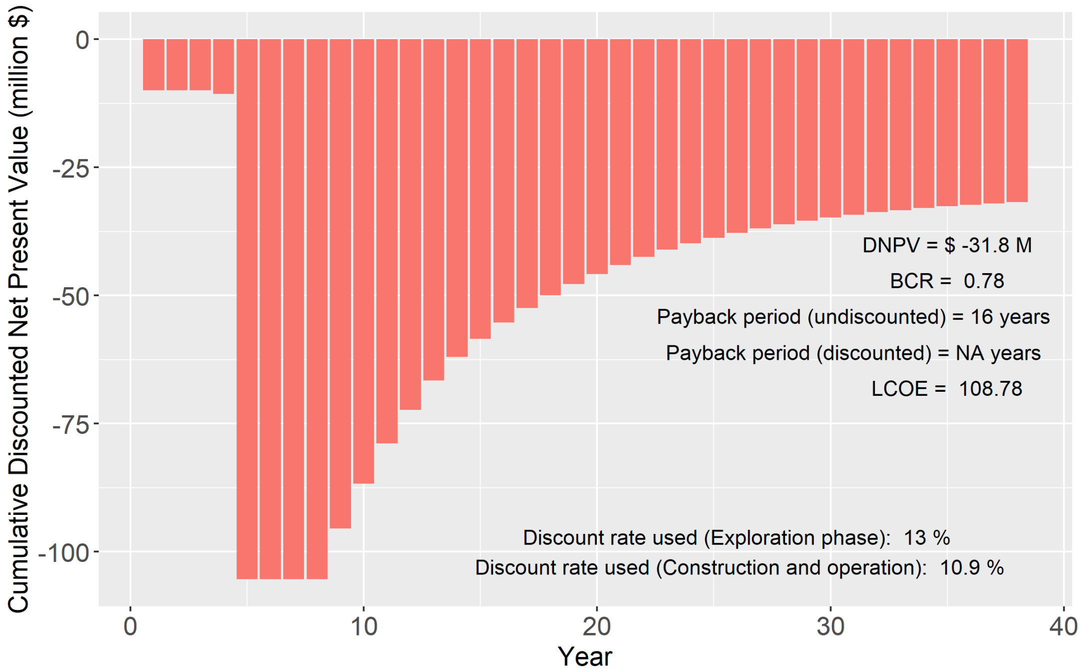


Figure 7-3. Equity-based financing – Internal funding.

Figure 7-4 shows the results of MAGE using discount rates for external funding (Wall et al. 2017). Here, the rate for exploration is 35% and is 16.6% for the remainder of the construction and operational period. These high discount rates significantly reduce the potential profitability, and yield an LCOE of $188/MWh, which would require much higher PPA prices to achieve the desired rate of return.

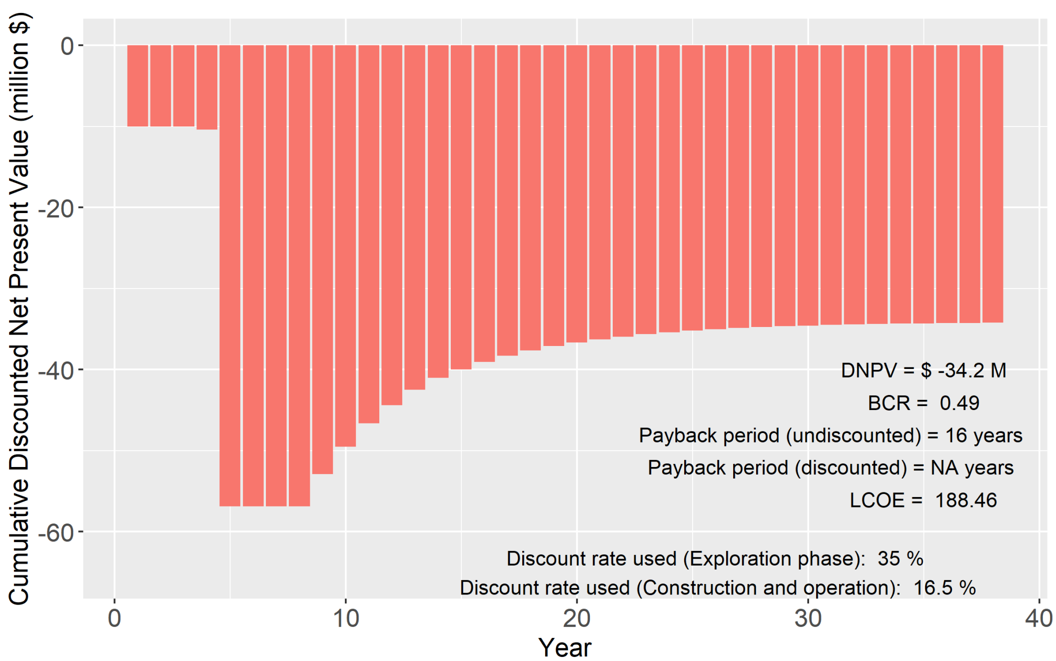


Figure 7-4. Equity-based financing – external funding.

7.1.2 Exploration Costs – MAGE Results

Figure 7-5 shows the results from MAGE when the exploration costs are doubled to $20 million. These higher costs represent a project where initial drilling is not successful, and more wells or more depth than initially anticipated is required. The results show that LCOE increases to $82, a 5% increase and that BCR and DNPV are lower with the higher exploration costs.

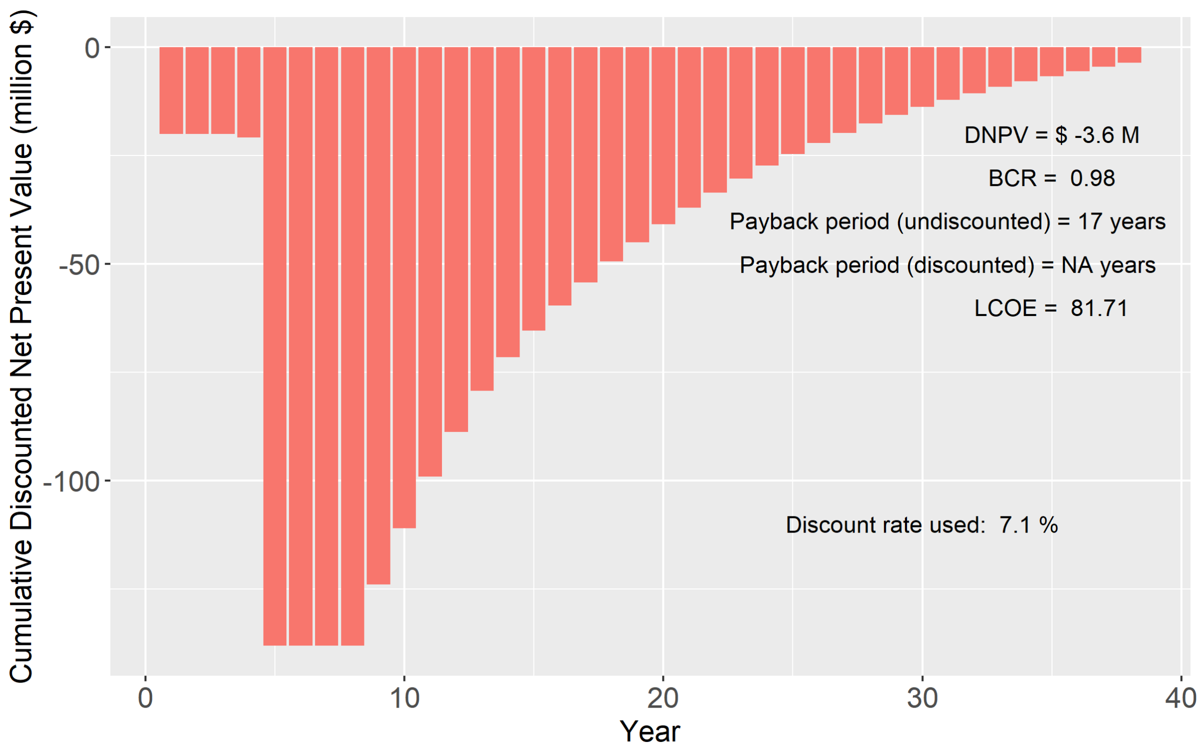


Figure 7-5. Power plant with $20M exploration cost.

7.1.3 Capital Construction Costs – MAGE Results

Figure 7-6 shows the results of MAGE when the capital construction costs are lower than the baseline. For the lower capital costs, we used $2,500/kW ($122.5M for a 49 MW plant). This value represents the costs expressed by CTR associated with the Hell's Kitchen project for a "best case" scenario of multiple wells using the same control structure and benefiting from economies of scale. It also represents the low end of costs listed in other sources. This lower capital cost improves the DNPV, BCR, and payback period, and lowers the LCOE to $59. This 33% reduction in capital cost results in a 26% reduction in LCOE.

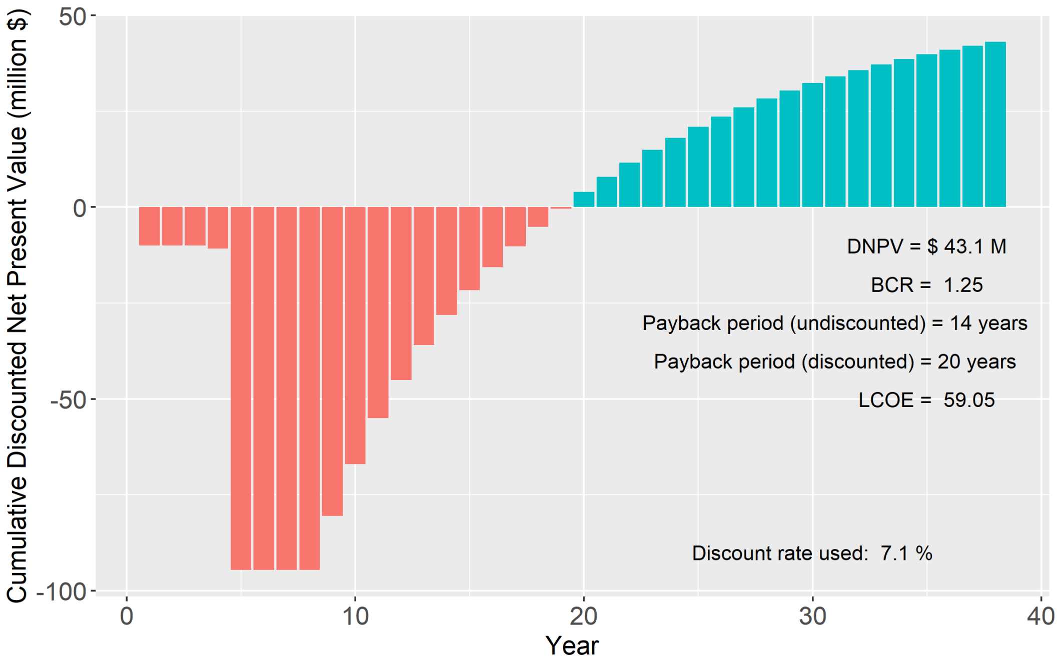


Figure 7-6. Power plant with $125M capital cost.

Figure 7-7 shows the results of MAGE when the capital costs are reduced by 20% to $2,800/kW (137M for a 49MW plant). This value is included for comparison with increasing the capital investment tax credit from 10% to 30%. The model outputs for these two scenarios are similar with both showing around a 17% reduction in LCOE.

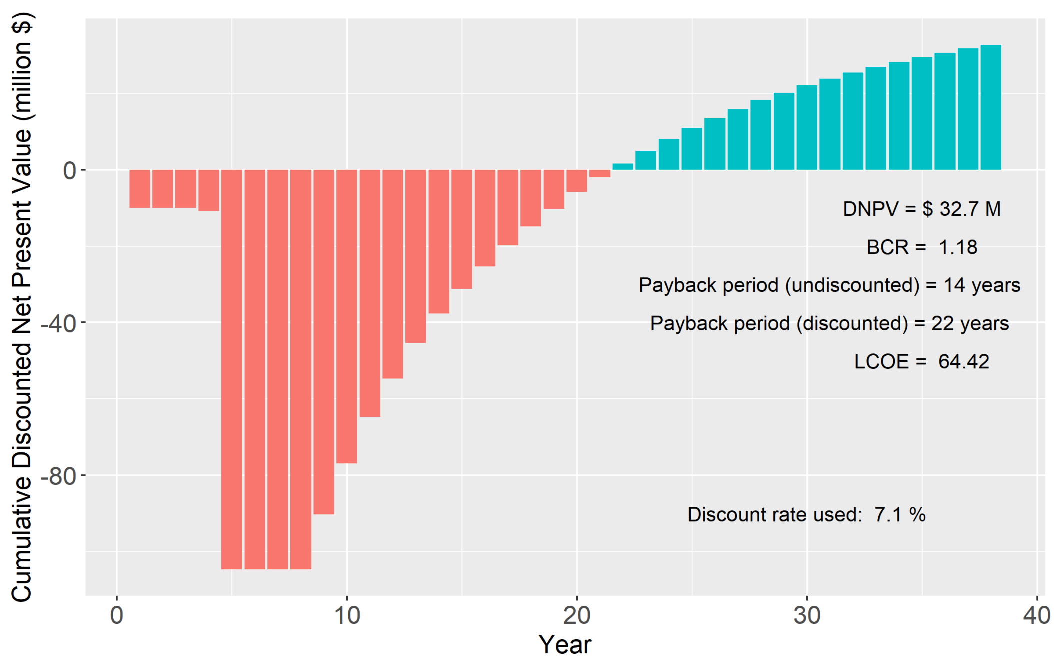


Figure 7-7. Power plant with $137M capital cost.

Figure 7-8 shows the results of MAGE when the capital costs are increased to $400M. This is the amount required to construct the J.L Featherstone (formerly Hudson Ranch I) project.

These construction costs represent an upper bookend to evaluate what happens if costs run high. The results show that the plant would be considerably unprofitable, with a DNPV of -$176M and a BCR of 0.55. The LCOE for this project would be $160/MWh, a price that is unlikely to be agreed upon in a PPA.

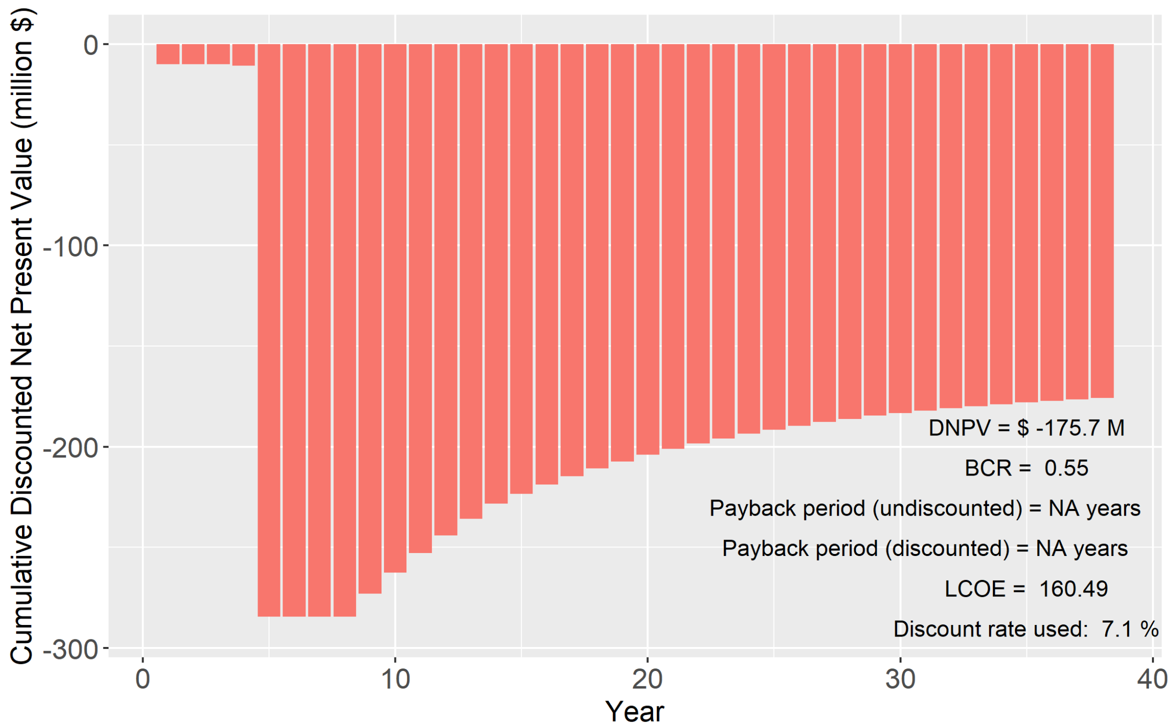


Figure 7-8. Power plant with $400M capital cost.

7.2 Permitting

Environmental permitting and regulatory compliance in the Salton Sea requires compliance with the California Environmental Quality Act (CEQA), which was signed into law in 1970, shortly after the federal *National Environmental Policy Act* (NEPA) was enacted. CEQA and NEPA are similar in their intents, review processes, and analytical requirements. CEQA compliance requires a similar level and depth of analysis in EIRs as does NEPA in environmental impact statements (EISs), which are required for projects that have the potential to have significant impacts. However, there are differences between the two laws. Unlike the NEPA process, the CEQA process requires that agencies apply mitigation measures “proposed to minimize significant effects on the environment” (AEP 2021) and identify the “environmentally superior alternative” among all of those considered (AEP 2021). While determinations of “significance” differ between NEPA and CEQA, in general, a single document can be developed to meet both NEPA and CEQA requirements without substantial modifications from a document developed to meet only one of the laws. Often, when projects need to comply with both NEPA and CEQA, a single joint review process is the appropriate pathway (OPR 2014), leading to a combined EIS/EIR.

7.2.1 State Permitting

Because projects in the Salton Sea KGRA are generally on private lands, NEPA does not apply to these projects. However, CEQA compliance is necessary for all projects in California that require a state/local approval. The California Geologic Energy Management Division (CalGEM) is responsible for regulating the drilling, operation, and maintenance of exploration and production wells used for the extraction of geothermal resources (CDOC 2019). The California Energy Commission (CEC) is responsible for permitting and oversight of the siting of thermal energy-generation facilities in the state, including geothermal facilities, that are 50 MW or larger. CalGEM may also delegate its environmental review authority to Imperial County for exploratory projects. For projects less than 50 MW, CEC has delegated permitting authority to Imperial County's Planning and Development Services Department (ICPDSD 2015). Imperial County has expressed interest in acquiring authority for projects larger than 50 MW; related discussions with CEC are ongoing.

Geothermal development in Imperial County is generally conducted in two steps. Step 1 involves CalGEM or Imperial County granting a conditional use permit for the drilling of the exploratory wells. Step 2 involves issuance of permits for the development of the project itself, issued by either CEC or Imperial County. CEQA compliance is required for both the exploration and development phases of the project.

The lead agency must prepare an initial study to determine whether the project may have a significant adverse effect on the environment; if so, an EIR is required. If no adverse effects are associated with the project, a Negative Declaration can be issued. A Mitigated Negative Declaration (MND) can be issued (OPR 2004), if there are potentially significant effects on the environment, but

> (1) revisions in the project plans or proposals made by, or agreed to by, the applicant before the proposed negative declaration and initial study are released for public review would avoid the effects or mitigate the effects to a point where clearly no significant effect on the environment would occur, and (2) there is no substantial evidence in light of the whole record before the public agency that the project, as revised, may have a significant effect on the environment..

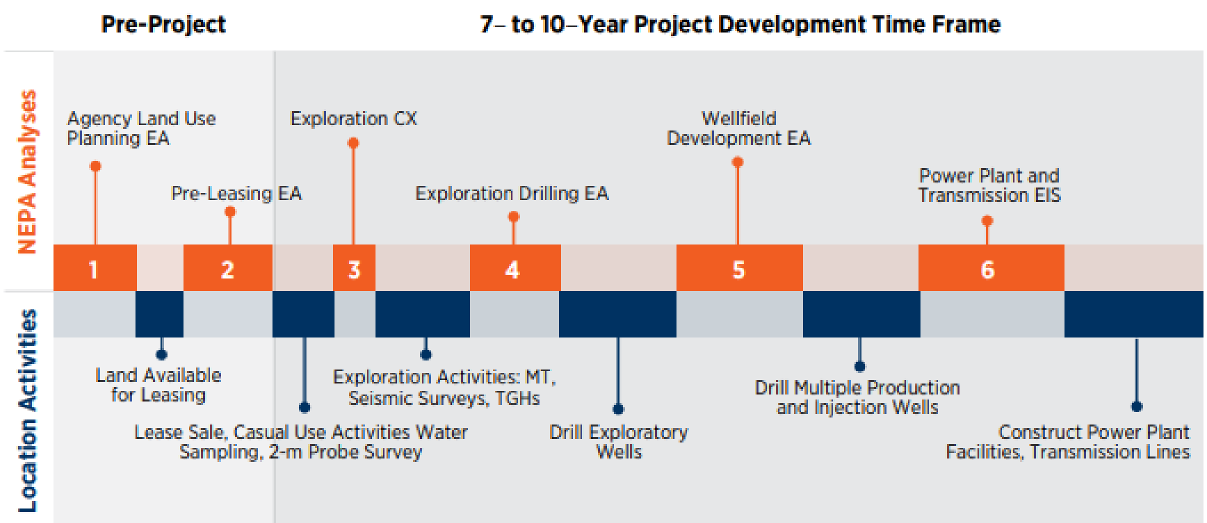
Imperial County has identified a Geothermal Overlay Zone, which integrates Imperial County regulations with those of other regulatory agencies. Because environmental impacts in this area associated with geothermal development are fairly well understood, past projects were generally permitted under an MND. For example, the Hudson Ranch I project was originally permitted under an MND in 2007. However, when the Hudson Ranch II project was proposed in 2012, Imperial County determined that preparation of an EIR was necessary, due to the potentially significant environmental effects associated with implementation of the proposed project. While an EIR can cost between $250–400K to complete, the relative cost is a small impact in the expensive project development process. The larger issue with the EIR is the time associated with developing the EIR and the potential impacts related to delaying the project. For example, in addition to requiring a lengthier EIR, the Hudson Ranch II project was delayed because labor unions objected to the EIR to push for unionization for workers associated with construction and operation of the proposed facility.

The emergence of lithium as a resource may complicate future geothermal development. Responsibility for permitting both the exploratory process and the production of lithium is the responsibility of CalGEM. It is unclear whether CalGEM would delegate lithium permitting responsibility to Imperial County, and if so, under what circumstances.

7.2.2 Federal Permitting

The Biden Administration has expressed a national goal of producing no less than 25 GW from solar, wind, and geothermal on Federal Lands by 2025 (*Consolidated Appropriations Act* 2021). Since 1978, the BLM has approved slightly more than 8 GW of total renewable generating capacity. To meet the 25 GW goal, streamlined federal permitting processes are necessary. Based upon this new legislation, the BLM created a new office responsible for permitting coordination. Other ideas that have not yet been implemented include using revenues from projects to reduce a permitting backlog for renewable energy projects and to hire staff to conduct more efficient processing of permitting applications (Hale and Christian 2021). The MAGE results described in Section 7.2.3 consider the relative effectiveness of more efficient permitting.

As discussed in the GeoVision report, the need for multiple federal approvals for projects proposed on federal lands under NEPA can lead to a lengthy and complex development schedule (DOE 2019). At the Salton Sea, almost all the lands with geothermal potential fall on private lands and do not have a federal nexus; thus, NEPA compliance is not required as indicated in Figure 7-9.



EA = environmental assessment; EIS = environmental impact statement; CX = categorical exclusion; MT = magnetotelluric; TGH = temperature-gradient hole.

Figure 7-9. Geothermal project development time frame (DOE 2019).

While NEPA compliance has not been historically required for geothermal exploration or development at the Salton Sea, the Corps has expressed an interest in asserting jurisdiction over portions of the area. Section 404 of the *Clean Water Act* (CWA) “establishes a program to regulate the discharge of dredged or fill material into waters of the United States, including wetlands (EPA 2021a). No discharge of dredged or fill material may be permitted if practicable alternatives exist that are less damaging, or the nation’s waters would be significantly degraded.

This requires that permittees avoid impacts on wetlands, streams, and other aquatic resources, minimize impacts to the extent possible, and compensate for all remaining unavoidable impacts. General permits may be issued for discharges that have only minimal adverse effects, while individual permits are required for potentially significant effects. Nationwide permits are a type of general permit developed and issued by the Corps authorizing certain types of activities across the country.

For purposes of Section 404 of the CWA, the Corps has determined that the Salton Sea and tributaries flowing into the sea qualify as “waters of the United States,” and as having “a significant federal interstate commerce nexus that do not rely on migratory bird use as the sole basis” (Corps 2001). Qualifications of the Salton Sea having a nexus to federal interstate commerce included:

- use of the Salton Sea by interstate or foreign travelers for recreational or other purposes;
- commercial fisheries from which fish or shellfish are or could be taken and sold in interstate or foreign commerce;
- isolated waters that are used or could be used for industrial purposes by industries in interstate commerce; and
- waters that affect the degradation and destruction of foreign commerce.

As a result, the Corps determined that “all tributaries that flow into the Salton Sea are deemed jurisdictional” (Corps 2001) under the CWA (33 CFR 328.3(a)(5)). Proposed future geothermal development would occur on exposed playa that was previously under the sea, which has raised the question of whether the Corps has jurisdiction over the playa under the CWA. As the Salton Sea has receded, the direct connection between various irrigation canals and tributaries that previously drained to the sea have been lost. The irrigation canals and tributaries, instead of flowing directly into the sea, are flowing out onto the playa and creating wetlands, some of which are ephemeral and some of which may be permanent. The proposed geothermal projects, although constructed on the playa, could potentially affect these water features and/or *Endangered Species Act* (ESA)-listed species living at or using these features.

The Corps conducts aquatic resources surveys to determine whether it has jurisdiction; these surveys and determinations occur on a case-by-case basis. The Corps office overseeing CWA Section 404 permitting in Imperial County is the Los Angeles District, Regulatory Division, San Diego and Imperial Counties Section. According to this office, some of the drainage from the irrigation canals and tributaries would falls within Corps jurisdiction, particularly where the drainage is creating new wetlands. Specific Corps involvement for geothermal projects at the Salton Sea would involve the issuance of permits for impacts on these wetlands. To date, no nationwide permit exists for geothermal exploration and operation; as a result, for activities affecting drainages where the Corps has asserted jurisdiction, either a general or individual permit is required, depending on the nature of the proposed activity. To determine whether a general or an individual permit is required, and whether different phases of an activity require separate permits, the Corps must determine whether the phases of the project are independent or whether they rely upon each other. At the Salton Sea, the Corps has determined that geothermal exploration does not necessarily lead to development of a project; therefore, separate permits would be required for the various phases of the project.

Further complicating the issue is that some of these new wetlands are becoming habitat for threatened and/or endangered species listed under Section 7 of the ESA, raising the potential for necessary involvement and consultation with the FWS.

The lack of certainty and determination with both ESA Section 7 and CWA Section 404 permitting has caused confusion and delay for geothermal developers interested in developing the playa, and for projects such as the Hell's Kitchen project currently going through the permitting process. In October 2021, IID sent a letter to President Joe Biden requesting support "to ensure that the federal permitting process does not delay the beginning of construction of [the Hell's Kitchen] facility." For the Hell's Kitchen project and for potential future developments, including lithium co-development projects, certainty in terms of the requirements of the federal permitting process are necessary to avoid cost overruns and time delays. Increased certainty would also be consistent with Biden Administration goals of increased renewable energy development.

7.2.3 Permitting – MAGE Results

Figure 7-10 shows the results of MAGE when reducing the permitting and mitigation costs to zero. This is an extreme scenario that represents the upper bound of savings derived from reducing permitting and mitigation costs. This scenario reduces the LCOE by about 0.5%, and the DNPV and BCR show similarly small changes. This indicates that reducing permitting and mitigation costs has a minimal impact on the profitability of a project.

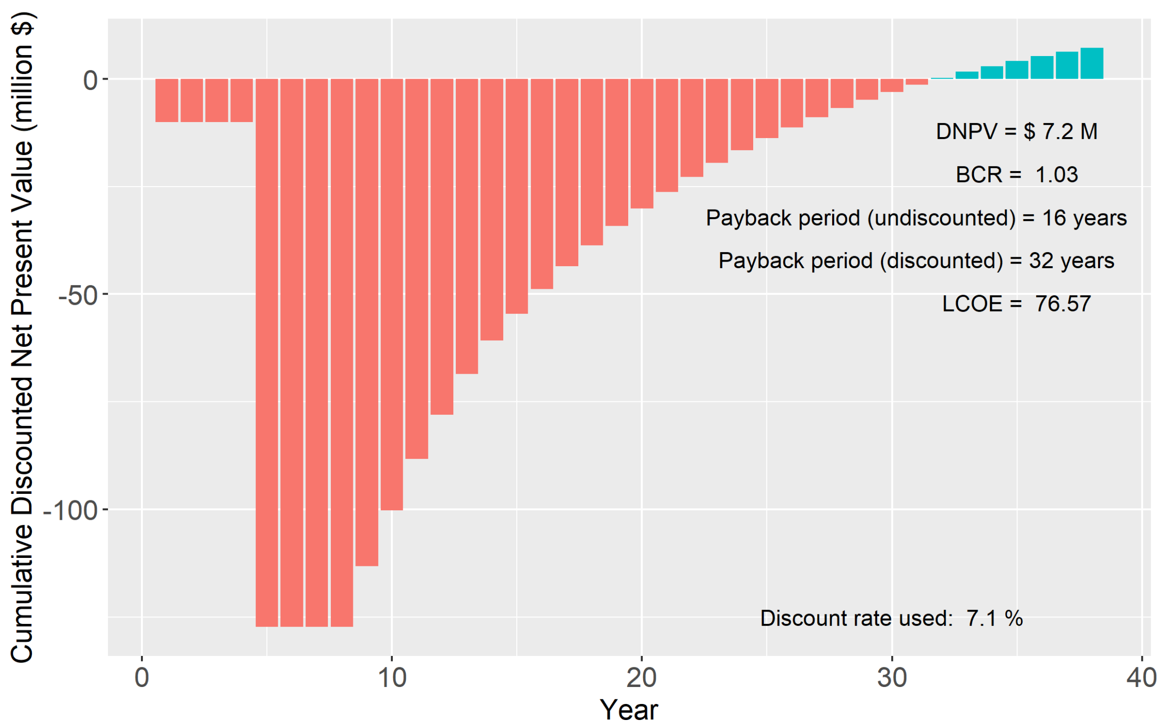


Figure 7-10. Power plant with zero permitting and mitigation costs.

Figure 7-11 and Figure 7-12 shows MAGE results when the exploration phase is reduced by 1 and 2 years, respectively. The discount rate plays a critical role in changes in the DNPV, BCR, and LCOE derived from reducing timelines. Reducing the permitting, exploration, or construction timelines allows revenue production to begin sooNner, reducing the compound effect of the discount rate on those revenues.

Under the 1-year reduction scenario, the shortened permitting and exploration timeline reduces the LCOE around 0.5%, with small increases in the DNPV and BCR. Because this reduces the timeline by 1 year, the undiscounted payback period is reduced by 1 year, and is the only parameter that shows a significant benefit. This section uses a weighted average cost of capital for the discount rate that is the same over the lifetime of the project. Section 7.8 considers how the benefits of reducing the permitting time by 1 year change when equity funding is used for the exploration cost.

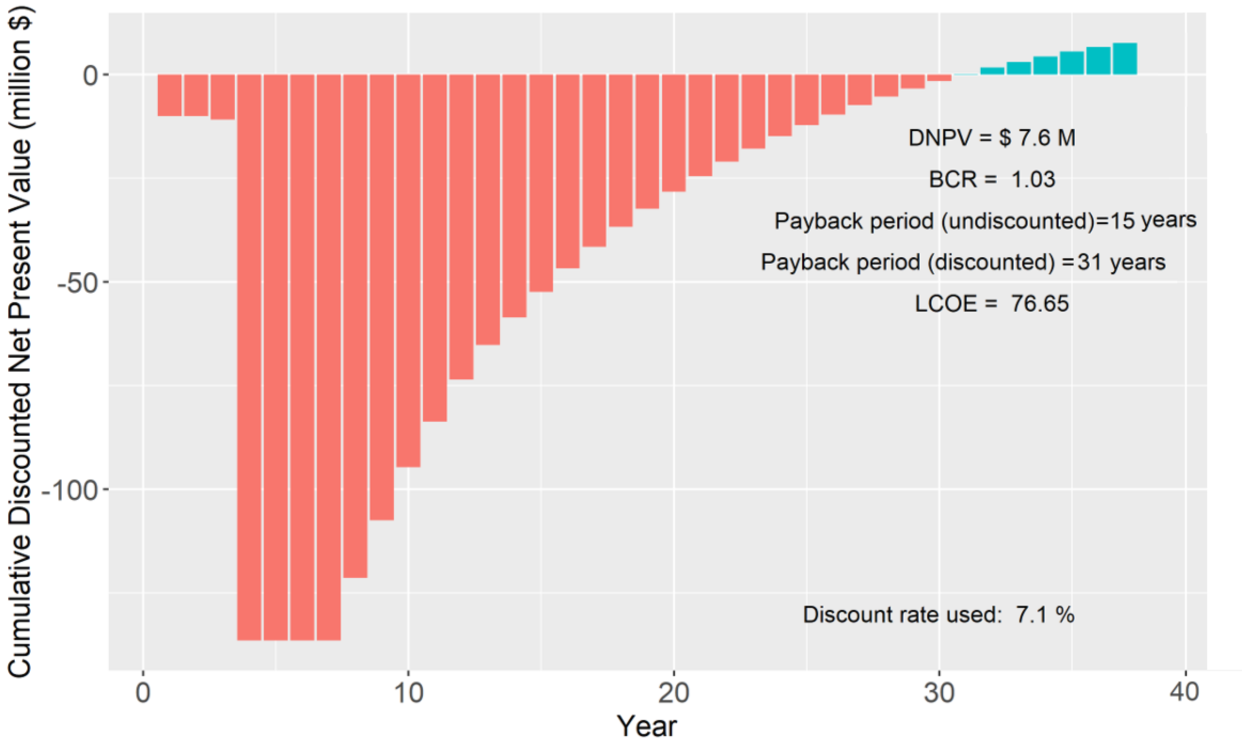


Figure 7-11. Power plant with 1-year reduced permitting time.

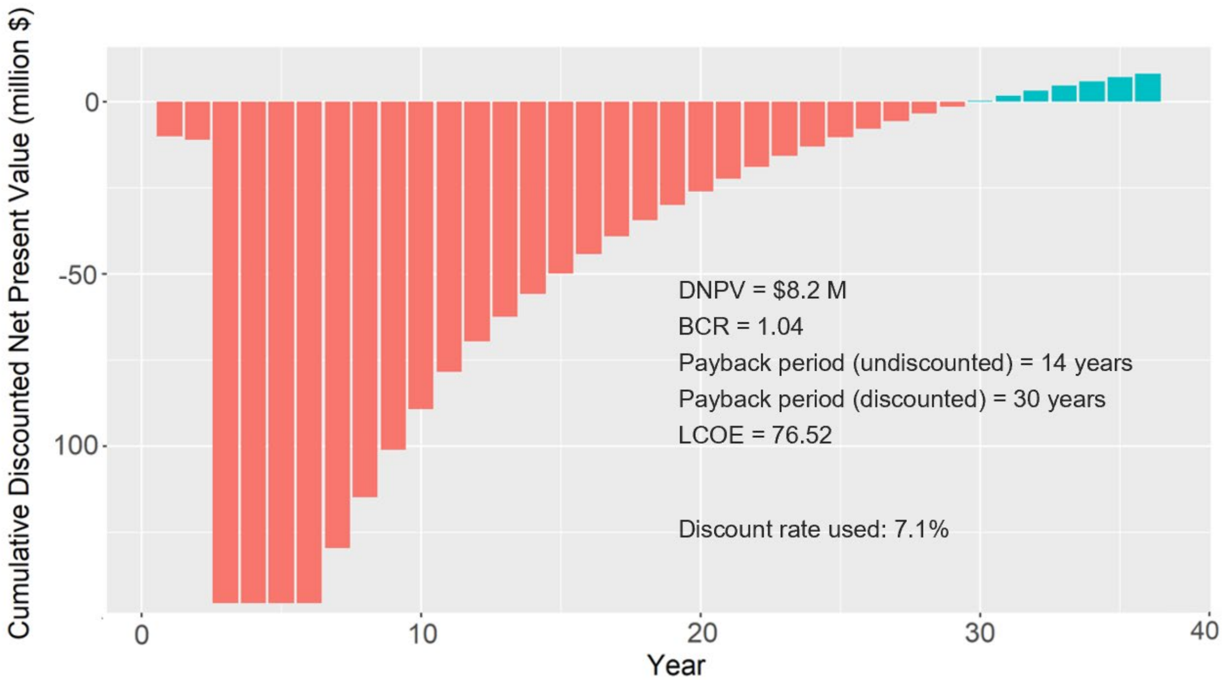


Figure 7-12. Power plant with 2-year reduced permitting time.

Figure 7-13 shows MAGE results of a 10-year project timeline, with 6 years for exploration and permitting and 4 years of construction. This corresponds to the mostly lengthy timeline outlined in Young et al. (2019). The LCOE with this timeline is $78, a small increase from the baseline timeline of 8 years.

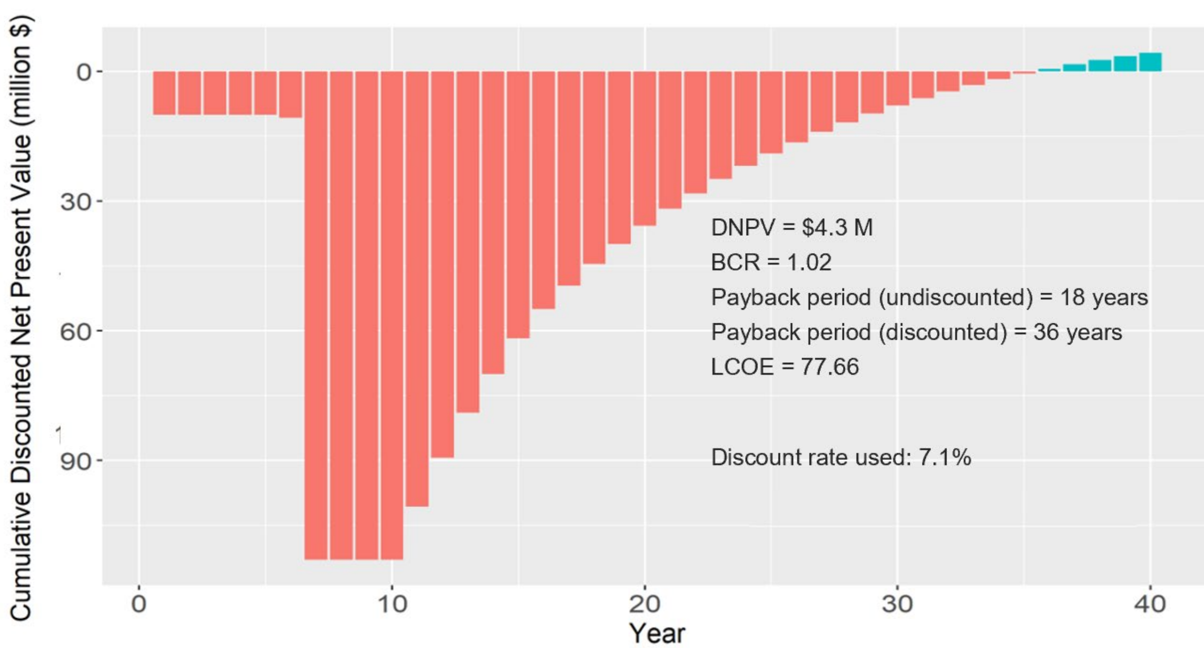


Figure 7-13. Power plant with 6-year exploration and permitting timelines

Figure 7-14 shows MAGE results derived from reducing construction time by 1 year. The LCOE from this reduction in construction time is $73, a 5% reduction from the $77 of the base model. This time reduction could be achieved by improving the engineering and construction process but could also be aided by streamlining the approval process for mitigation that has been completed, and preventing regulatory issues that would slow operation commencement.

Comparing the benefits of reducing exploration and permitting time or only construction time shows that reducing the construction time has a greater impact. This is due to the construction costs being approximately fifteen times greater. A project with expected greater exploration costs should expect to see greater impacts derived from reducing exploration times. These savings would be additive if both exploration and construction times could be reduced, or if either could be reduced by multiple years.

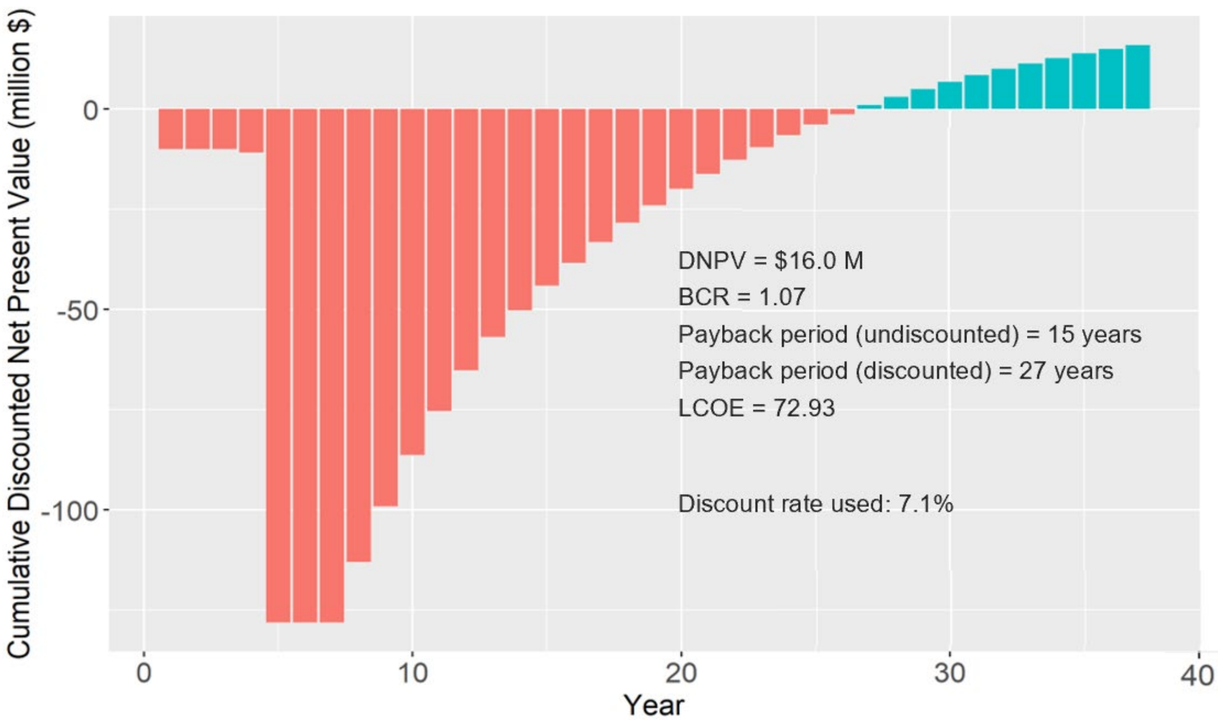


Figure 7-14. Power plant with a 1-year reduced construction time.

Figure 7-15 shows MAGE results when the exploration phase is reduced by 3 years and the construction phase is reduced by 1 year. The reduction of the exploration phase has a smaller impact than does the reduction of the construction phase.

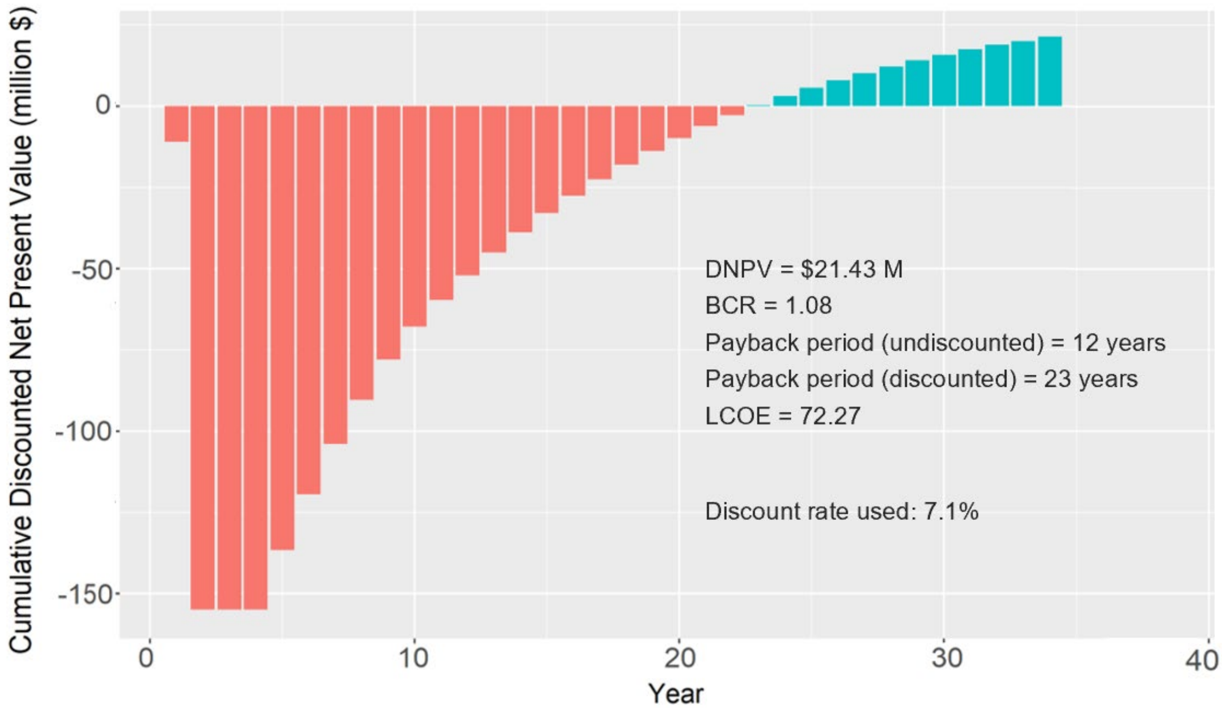


Figure 7-15. Power plant with 3-year reduced permitting time and 1-year reduced construction time.

One aspect of exploration and permitting that is not covered in this section is the risk of failure in exploration. Such failure may occur due to unsatisfactory drilling results or an inability to obtain necessary permits. In those situations, the costs incurred are typically sunk, and cannot be recouped and do not provide a return to investors. A potential benefit of streamlining the permitting process could be to reduce the risk of failure, which would yield a reduction in the discount rate. The benefits of reducing the discount rate are discussed in Section 7.1.1.

7.2.4 Permitting Issues and Recommendations

Overall, the state and local permitting process for geothermal projects at the Salton Sea is well understood. Historically, applicants appeared to prefer the Imperial County CEQA review and permitting process, because many projects, such as the Hudson Ranch I (Power Technology 2013) and Hudson Ranch II (OPR 2022) projects, were sized at 49.9 MW, or just below the 50 MW threshold at which point CEC would be the responsible agency. However, many interviewees mentioned that this no longer appears to be a substantial barrier, and that the CEC process has become better understood and streamlined over time and does not necessarily take longer to complete than the Imperial County process.

Stakeholders and developers have expressed a desire to both speed up and reduce costs associated with the permitting process. While NEPA compliance is generally not required for geothermal projects at the Salton Sea, the federal permitting process under the CWA and ESA is opaque and has created confusion. While reduction of costs is a worthy goal, shortening the timeframe from initiating exploration to bringing a project online has a much larger impact on the profitability of the project.

Below are four concepts which, if implemented, could result in a shorter and less expensive geothermal permitting process.

1. An areawide determination about CWA Section 404 jurisdiction by the USACE would provide certainty to developers and the public.

   Nationwide Permits are issued by the USACE to "help protect the aquatic environment and the public interest by providing incentives to reduce impacts on jurisdictional waters and wetlands while effectively authorizing activities that have no more than minimal individual and cumulative adverse environmental effects." Nationwide Permit 51 authorizes

   > [d]ischarges of dredged or fill material into non-tidal waters of the United States for the construction, expansion, or modification of land-based renewable energy production facilities, including attendant features. Such facilities include infrastructure to collect solar (concentrating solar power and photovoltaic), wind, biomass, or geothermal energy.

   Furthermore, "[t]he discharge must not cause the loss of greater than 1/2-acre of non-tidal waters of the United States" (Corps 2021).

   For geothermal development at the Salton Sea, the determination about whether the irrigation ditches, drainages, and associated wetlands on the playa constitute waters of the United States remains unclear, and thus whether Nationwide Permit 51 applies. USACE determination about CWA Section 404 jurisdiction thus remains a primary barrier and source of frustration to the development community. Identification of locations of suitable geothermal development and certainty about the mitigation that should be applied for the Salton Sea playa would provide a substantial incentive for future development.

2. Development of a programmatic EIS/EIR for the Salton Sea that analyzes the environmental impacts of geothermal development, from exploration to production, encompassing both geothermal and lithium.

   The 2015 Renewable Energy and Transmission Element from the County of Imperial General Plan is a good starting place for such a review, describing the history of renewable energy generation in the county, describing existing conditions and resource concerns, and including a series of specific goals that "support development of renewable energy resources that will contribute to the restoration efforts of the Salton Sea" (ICPDSD 2015). A comprehensive CEQA/NEPA document could provide greater certainty for geothermal development permitting and approval. The resource issues and environmental impacts of geothermal development at the Salton Sea are well known and well understood. However, the environmental impacts and considerations for a co-located lithium plant have not been analyzed on a comprehensive scale. Sponsoring such a programmatic review could be a form of a subsidy undertaken by either the federal government, the state of California or Imperial County, or could be issued by a geothermal developer interested in subsequent future developments in the area.

3. Issuance of a geothermal/lithium MOU between CEC and CalGEM.

   Regardless of whether a comprehensive EIS/EIR is developed for geothermal development at the Salton Sea, it would be beneficial for CEC and CalGEM to issue an agreement, likely in the form of an MOU, making the roles and responsibilities for a co-located geothermal and lithium extraction plant clear. This would provide greater certainty to developers in obtaining approval through the CEQA process, particularly because of the limited history of such co-located development. Alternately, CalGEM could potentially delegate authority for permitting lithium production to Imperial County for projects below a certain size threshold, as has already been done for conventional geothermal development.

4. Development and funding of a state permitting coordination office.

   While geothermal development at the Salton Sea does not require preparation of a federal NEPA document, the concepts included in the *Federal Consolidated Appropriations Act* of 2021 could be extrapolated to streamline local and state permitting. Dedicated geothermal staff either funded by the state, the development community, or through a general fund can conduct more efficient reviews and coordinate necessary approvals more effectively than staff that currently handle geothermal permitting as an extension of other work.

7.3 Government Intervention

Federal, state, and local governments have all expressed interest in increased renewable energy development at the Salton Sea, including a desire for increased geothermal exploration and production. In some cases, these expressions have led toward financial incentives specific to geothermal. New or increased subsidization or incentivization would render new geothermal development more economically competitive.

Exploration and development incentives provide assurance and reduce risk to geothermal developers, while production tax credits, property tax waivers, and other incentivization of producing and transmitting the geothermal energy can help to reduce the effective LCOE and lower the prices associated with PPAs to be more on par with other energy resources. However, the structure and duration of federal incentives compared to long geothermal development timelines make it difficult for developers to rely on such incentives (Young et al. 2019). For example, the Production Tax Credit has rarely been guaranteed to be in effect for longer than 5 years, and geothermal exploration and development timelines are typically longer than this (DOE 2019).

As an example of how government intervention can lead to development, PURPA (discussed in Section 2.3) required that utilities purchase power at the avoided cost of power, which led to the purchase of geothermal energy at above market rates. The Energy Tax Act of 1978 incentivized geothermal development in the 1980s through various tax incentives, including investment tax and income tax credits. The Economic Recovery Act of 1981 allows for depreciation of geothermal equipment. All of these helped to lead to a boom in geothermal development, including at the Salton Sea, in the 1980s (Owens 2002).

New geothermal development at the Salton Sea could promote various other federal, state, and local goals, including Salton Sea habitat restoration, meeting CA RPS standards, meeting federal renewable energy goals, improving US air quality and reducing CO_2 emissions, and promoting high-paying jobs and economic benefits in Imperial County.

Furthermore, as discussed in Section 5.3.3, geothermal energy contains benefits to the power grid that are not necessarily reflected in the LCOE or PPAs associated with a specific project. To the extent that government incentives exist, they are generally not specific to incentivizing geothermal development, and in some cases, greater incentives exist for solar and wind than for geothermal development.

If the ancillary benefits of geothermal power generation can be better understood and quantified, applicable federal and state governments would have a better reason to incentivize geothermal development and reduce the up-front risk to investors and developers. The sections below include specific examples of relevant geothermal-promoting government intervention, while also identifying needs and opportunities for future incentivization.

Table 7-1. Types of subsidies and potential effects on geothermal development.

Subsidy Type	Description	Incentive Type	Likely to Affect Geothermal at Salton Sea	Likely to Affect Lithium Add-on
Investment tax credit	Cost of capital can be claimed on federal or state corporate taxes	Investment	Yes	Yes
Property Tax waiver/credit	Reduction in annual state and county property taxes	Investment	Yes	Yes
Corporate Tax waiver/credit	Reduction in the rate paid for state or federal corporate tax	Both	Yes	Yes
Production tax Credit	Tax credit given per unit of production that can be claimed on corporate tax	Production	Yes	Yes
Accelerated Depreciation	Allow for increased deduction in early years of the project	Investment	Yes	Yes
Longer loss carry forward	Allow businesses to carry forward losses to offset revenue in future years	Investment	No	No
Royalties reduction or modification	Royalties are typically paid to BLM for extraction on public land	Production	No	Yes
Import/Export subsidy or relief	Lithium or other minerals extracted from the brine could be traded on global markets and subject to tariffs, quotas or other trade restrictions	Production	No	Yes
Loan guarantees	If a geothermal developer defaults on their loan, the federal government may pay off the loan. This reduces the investment risk and can lower the discount rate.	Investment	Yes	Yes

7.3.1 Federal

There are numerous benefits to geothermal energy that could warrant federal support, including providing reliable renewable baseload energy while also providing an environmentally sustainable means for extracting lithium and other rare earth minerals. Developing a domestic supply of lithium could have large economic and national security benefits, as most lithium is currently imported and demand for lithium has continued to increase (see Section 7.6).

The Biden Administration has expressed a national goal of producing no less than 25 GW from solar, wind, and geothermal on Federal Lands by 2025 (*Consolidated Appropriations Act* 2021) and has acknowledged that geothermal is an important part of this portfolio. Congress' 2021 *Consolidated Appropriations Act* provided funds for multiple geothermal development and research opportunities, including the following:

- programs of research, development, demonstration, and commercial application for geothermal energy production;

- prioritizing technologies to increase the use and lower the cost of geothermal energy in the United States, including drilling technologies and well construction;
- initiatives to demonstrate the coproduction of critical minerals from geothermal resources;
- research and development to increase the energy efficiency, lower the cost, increase the use, and improve and demonstrate the effectiveness of geothermal heat pumps and the direct use of geothermal energy; and
- programs to develop a geothermal energy workforce.

The Biden Administration has taken a particular interest in advancing environmental justice and addressing climate change as a part of the work of the federal government. Executive Order (EO) 14008, "Tackling the Climate Crisis and Home and Abroad," notes that the United States "face[s] a climate crisis that threatens our people and communities, public health and economy." EO 14008 implemented a "Government-wide approach that reduces climate pollution in every sector of the economy; increases resilience to the impacts of climate change; protects public health; conserves our lands, waters, and biodiversity; delivers environmental justice; and spurs well-paying union jobs and economic growth, especially through innovation, commercialization, and deployment of clean energy technologies and infrastructure." EO 14008 requires development of a plan to create a carbon-free electricity sector no later than 2035, eliminated fossil fuel subsidies, and required federal agencies to identify opportunities for federal funding to spur innovation, commercialization, and deployment of clean energy technologies such as geothermal.

Furthermore, EO 14008 requires that agencies "make achieving environmental justice part of their missions by developing programs, policies, and activities to address the disproportionately high and adverse human health, environmental, climate-related and other cumulative impacts on disadvantaged communities, as well as the accompanying economic challenges of such impacts." A goal of the administration is to "spur economic opportunity for disadvantaged communities." See Section 7.4.1 for a description of how geothermal development can meet these goals.

However, a lack of geothermal-specific federal incentives has led to geothermal power generation remaining relatively more expensive than solar and wind power generation (ClearPath 2020). Broadly, three main forms of federal government funding applicable to renewable energy development include direct expenditures, tax expenditures, and research and development funding (Lofthouse et al. 2021). Government loan guarantees can also help to reduce investor risk (see Section 7.1.1).

7.3.1.1 Direct Expenditures

As of 2013, it was estimated that the federal government provided the geothermal industry with $312 million in direct expenditures (Lofthouse et al. 2021).

7.3.1.2 Production Tax Credit

The production tax credit (PTC) is a federal subsidy in the form of a tax credit. The PTC has historically been made available for renewable energies, ranging from 2.3 cents per kWh in 2014 (Lofthouse et al. 2021) to 2.5 cents per kWh in 2021 (EPA 2021b). The PTC expired for all renewable energy technologies commencing construction after December 31, 2021 (EPA 2021b).

7.3.1.3 Investment Tax Credit

Congress recently extended the investment tax credit (ITC) for renewable energy projects (Table 7-2). The ITC provides a dollar-for-dollar reduction in the income taxes that both residential and commercial entities must pay associated with the installation, development, and financing of a renewable energy project (SEIA 2022). The *Taxpayer Certainty and Disaster Tax Relief Act* of 2020 extended the phase out of the ITC for certain technologies. The ITC currently provides higher credits for solar and wind energy than it does for geothermal energy; while these incentives are scheduled to phase out and normalize at 10% for solar, wind, and geothermal energy by 2026, the phase out has historically been extended.

Table 7-2. Federal investment tax credit (NCCETC 2021).

Technology	12/31/20	12/31/21	12/31/22	12/31/23	12/31/24	12/31/25	Future Years
PV, Solar Water Heating, Solar Space Heating/Cooling, Solar Process Heat	26%	26%	26%	22%	22%	22%	10%
Hybrid Solar Lighting, Fuel Cells, Small Wind, Waste Energy Recovery	26%	26%	26%	22%	N/A	N/A	N/A
Geothermal Heat Pumps, Microtubines, Combine Heat and Power Systems	10%	10%	10%	10%	N/A	N/A	N/A
Geothermal Electric	10%	10%	10%	10%	10%	10%	10%
Large Wind	18%	18%	N/A	N/A	N/A	N/A	N/A

For purposes of illustrating the sensitivity of the geothermal LCOE to federal government subsidies of various types, the sections below analyze the impacts of a 30% and 26% ITC for geothermal development, in comparison to the existing and scheduled 10% ITC.

Figure 7-16 and Figure 7-17 show MAGE results with a 26% and 30% capital subsidy respectively. Higher subsidies improve profitability and reduce the LCOE, with the 30% subsidy showing a larger impact than the 26% subsidy The projected benefits of increasing the ITC from 10% (status quo) to 30% are: (1) reducing the discounted payback period by 11 years (22 years instead of 33 years); (2) reducing the LCOE by $13/MWh ($64/MWh instead of $77/MWh), and helping geothermal become more competitive with solar and wind PPAs ($25-$36 is the 25-75th percentile range).

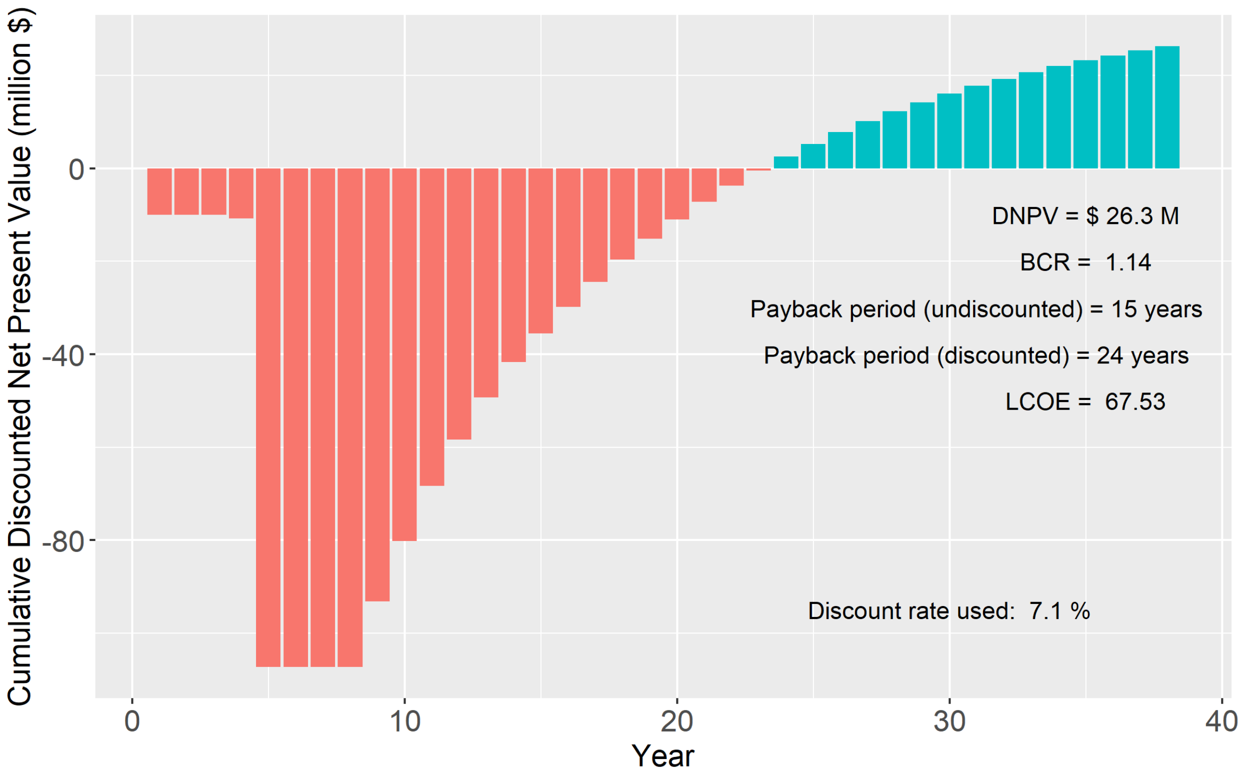


Figure 7-16. 26% capital subsidy MAGE results.

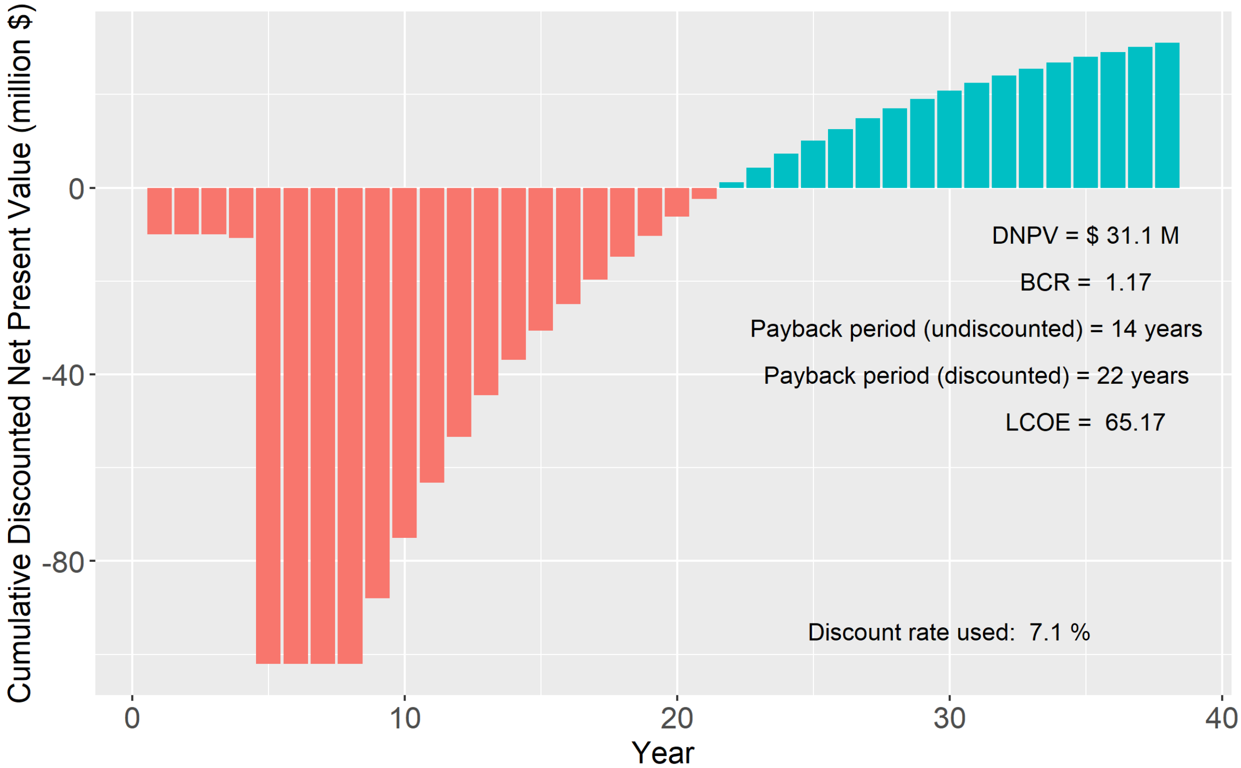


Figure 7-17. 30% capital subsidy MAGE results.

7.3.1.4 Loan Guarantees

Loan guarantees help reduce the risk associated with geothermal exploration and development. In turn, this can help reduce the discount rate associated with project financing (see the results of a changing discount rate in Section 7.1.1). A loan guarantee lowers the risk of a project by assuming the debt if the borrower defaults. This can reduce the required premiums on debt financing for the project and lowers the required rate of return for equity financing. Such federal and state incentives can provide a substantial incentive to investors concerned about loss of investment associated with unsuitable or unsatisfactory exploratory drilling. A potential downside with a federal loan guarantee would be that the government would have to cover the costs of failed geothermal projects.

In 2013, the federal government provided the geothermal industry with $13M in loan guarantees. Future loan guarantees would need to be larger in scale to effectively fund geothermal plants that may cost several hundred million dollars to construct.

Federal loan guarantees could be the most effective form of government intervention for geothermal energy based on the model results in this report. These federal loan guarantees could reduce the discount rate from 7.1% (base model) to 3% (with a loan guarantee) by reducing financial risks to investors. The projected benefits of reducing the discount rate from 7.1% to 3% include: (1) reducing the discounted payback period by 14 years (19 years instead of 33 years); (2) reducing the LCOE by $24/MWh ($53/MWh instead of $77/MWh with the base model), and help geothermal become more competitive with the PPAs for solar and wind ($25-$36 is the 25-75th percentile range).

7.3.2 State

While California's RPS has been important in promoting the development of renewable energy throughout the state, it has the downside of treating renewable energy as a fungible commodity. Not all renewable energy sources are the same; as discussed in Section 5.0 of this report, the geothermal resource provides benefits beyond those of solar and wind resources. These benefits include:

- Geothermal is a baseload power source that is not dependent on weather conditions.
- Geothermal has a relatively small footprint compared to solar and wind.
- Locations for potential future geothermal development at the Salton Sea would be on lands that have no other utility.
- Geothermal has limited concerns relative to sensitive species or habitats.

In 2002, California established the RPS (California S.B. 1078) as a primary driver for increasing clean electricity generation. The original approved Senate Bill (S.B.) 1078 created the RPS with an initial target of 20% renewable energy by 2017, citing goals of "stable electricity prices, protect public health, improve environmental quality, stimulate sustainable economic development, create new employment opportunities, and reduce reliance on imported fuels." The RPS program included "eligible renewable energy resource[s]," including certain geothermal facilities.

In 2018, California enacted SB 100 (California S.B. 100), requiring that zero-carbon energy sources, including geothermal, supply 100% of electric retail sales to customers by 2045, and updating the state's RPS to ensure that by 2030, at least 60% of California's energy would be renewable. S.B. 100 required that the CEC, CPUC, and California Air Resources Board develop a joint agency report assessing the goal of achieving 100% clean electricity in the state. The report, published in March 2021, concluded that

> Geothermal costs are heterogeneous and can vary widely depending on project location. Coproduction of lithium from geothermal brine may also provide additional revenue streams, effectively lowering the cost of geothermal power, and will be evaluated by the Blue-Ribbon Commission on Lithium Extraction in California (CEC 2021a).

The Blue Ribbon Commission, named the Lithium Valley Commission, is directed to review, investigate, and analyze opportunities and benefits for lithium recovery and use in California, and provide a final report due to the State Legislature by October 1, 2022 (CEC 2021c). This includes the potential analysis of incentives regarding lithium extraction and use.

In July 2021, the Governor of California signed a proclamation (CED 2021) of a state of emergency finding of extreme peril due to the combined effects of drought, wildfire, and extreme heat on the state's energy system, and due to energy shortages throughout California caused by these climate events. As such, the Governor ordered that all state energy agencies work on accelerating plans for the construction, procurement, and rapid deployment of new clean energy and storage projects to mitigate the risk of capacity shortages and increase the availability of carbon-free energy at all times of day. The proclamation also suspended certain statutes and regulations regarding post-certification petitions for changes in power-plant project design, operation, and performance, including geothermal generation.

Furthermore, as discussed in Section 3.3 of this report, the existence of the SSRP and the need for habitat restoration provide additional rationale for state financial support and subsidization of geothermal projects. Such subsidies could benefit the geothermal industry and well as the habitat restoration needs of the Salton Sea.

In summary, because geothermal energy falls within California's RPS, because of its role in providing clean energy to mitigate energy shortages, and because of the opportunities of co-located lithium extraction and use, the geothermal resource is well suited for increased development in California, and particularly in the Salton Sea, where both the geothermal resource and lithium are ample. However, because of the high LCOE compared to competing RPS technologies such as wind and solar, and nonrenewables such as combined-cycle gas, there has been limited development of the resource. Appropriate financial and permitting incentives developed by the state, through the Lithium Valley Commission or otherwise, may incentivize future development and help to meet the 100% renewable energy goal of S.B. 100.

7.3.2.1 Property Tax Waiver – MAGE Results

This section presents the results of MAGE for a project that receives an exemption on state property tax (Figure 7-18). These types of exemptions can be a way for the state to incentivize this type of project, which can help California achieve its RPS with baseload power or for the county to promote local economic development. California property taxes are required once production commences and are not required during exploration or construction (State of California Board of Equalization 1995). The model assumes that property taxes are 2% of the capital costs and are paid during years of production only.

The MAGE result for a waiver of property taxes over the full lifetime of the project is shown in Figure 7-18. Property tax waiver MAGE results. A property tax waiver over the full lifetime reduces the LCOE by around $10/MWh compared to the baseline model—a 13% reduction. A property tax exemption for the first ten years of production or operation has been used in the past to incentivize development (Kenyon et al., 2012), and this would reduce LCOE by 8%. The full lifetime exemption is comparable to the reduction achieved by increasing the capital subsidy from 10% to 30%, as discussed in Section 7.3.1.3. These savings are not exclusive, and if a project could secure both a 30% capital subsidy and a property waiver it could reduce the LCOE to around $58/MWh.

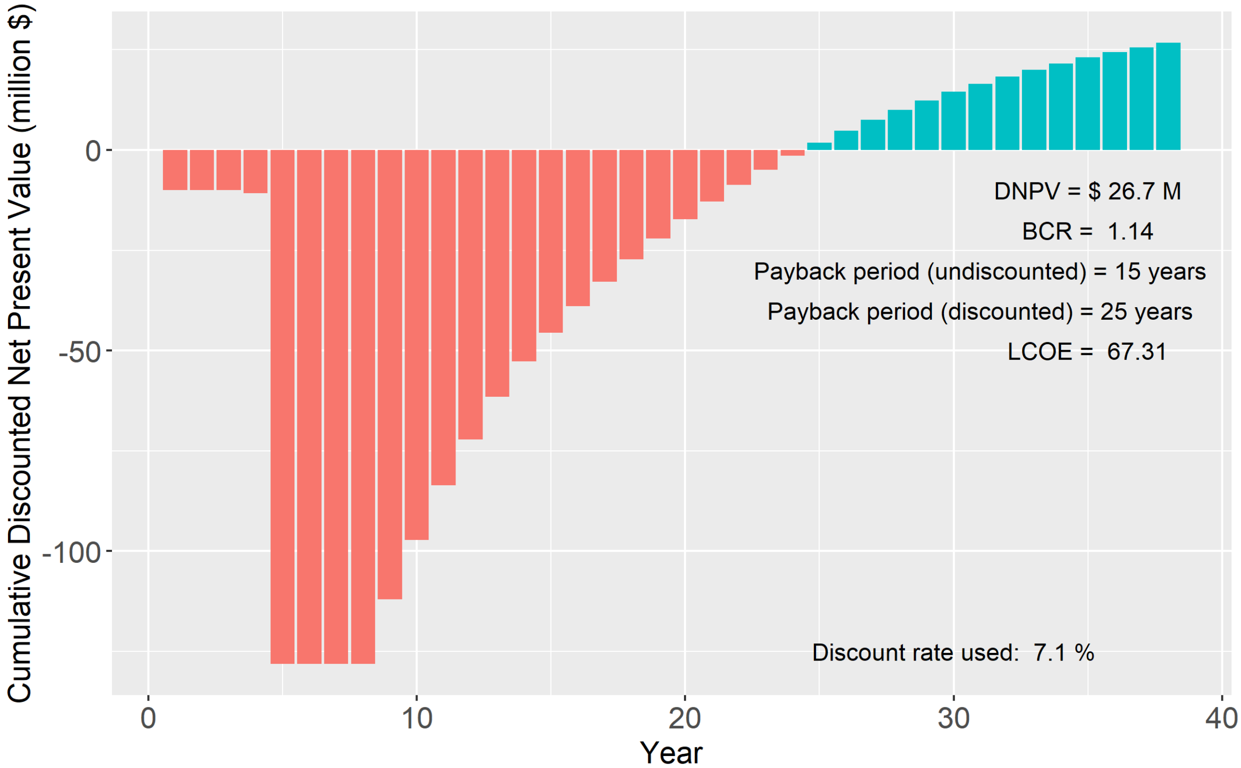


Figure 7-18. Property tax waiver MAGE results.

7.4 Resource Conflicts

At the Salton Sea, the land most suitable for geothermal development is the playa recently exposed by the receding sea, which generally does not have infrastructural or resource conflicts. This land is also generally owned by IID, which is supportive of new geothermal development. The sections below describe some of the resource-related impacts that have the potential to limit future geothermal development in the area.

7.4.1 Environmental Justice and Climate Change

As noted in Section 3.2, Imperial County is one of the poorest and most disadvantaged counties in California, with the majority of census tracts in the county, including the playa, meeting at least one the criteria laid out in the CEQ Climate and Economic Justice Screening Tool. In light of the Biden Administration's focus on developing clean energy and securing environmental justice and economic opportunities (see Section 7.3.1), geothermal development presents an opportunity to meet multiple administration goals, including carbon-free energy independence and development of jobs and tax revenues that can help to mitigate for the historic health, environmental, climate, and economic impacts to the local community.

As such, instead of being a potential limiting factor at the Salton Sea, geothermal development instead presents opportunities at the Salton Sea to mitigate historic environmental justice and climate change concerns and meet multiple federal agency mandates.

7.4.2 Sensitive Species

The existence of sensitive species and the potential impact of development upon such species is a major factor when siting project locations. If state or federal threatened, endangered, or candidate species exist at or near the project site, consultation under Section 7 of the ESA or the *California Endangered Species Act* (CESA) may be required. If impacts on such species are likely because of the project, the project may need to be moved, may need to avoid certain habitat, may require timing limitations on construction or operational activities, and/or may require habitat and/or compensatory mitigation.

Compared to other locations, areas proposed for geothermal development at the Salton Sea have relatively low potential for conflict with sensitive species and have generally not required extensive ESA or CESA reviews. At the Salton Sea, habitat exists for three special status species (Table 7-3).

Table 7-3. Special status species at the Salton Sea (FWS 2011).

Species	Status
Yuma clapper rail	Federally Endangered
Desert pupfish	Federally Endangered and State Listed
Burrowing owl	California Species of Special Concern

However, it is unlikely that any of the activities associated with constructing and operating a geothermal plant at the Salton Sea, particularly on the playa, would have the potential to affect any of these species. The 2013 Salton Sea Species Conservation Habitat Plan found that "[habitat restoration] activities would not affect burrowing owls because none is expected to be present in the recently exposed playa/seabed due to lack of suitable habitat" (Corps 2013). As such, it is likely that there would be no effect associated with geothermal development on the playa.

Similarly, the Yuma clapper rail is a bird whose habitat includes freshwater marshes (Corps 2013). Therefore, construction and operational activities associated with geothermal development on the Salton Sea playa would be unlikely to have any effect on this species.

Desert pupfish habitat includes shoreline pools and shallow waters; it is possible that construction and operational activities could affect this species, but the larger impact on the desert pupfish is ironically the evaporation of the Salton Sea that is leading to the potential to develop the playa. Previous geothermal development projects have not required federal Section 7 ESA consultation.

As a result, while the presence of and potential impacts on threatened or endangered species can be a limiting factor in the timing and location of energy development in other areas, it is generally not a factor in slowing down geothermal development at the Salton Sea.

7.4.3 Habitat Mitigation

As the Salton Sea recedes and becomes more saline, fish species are expected to decline, as are the birds that prey on these fish. Furthermore,

> A key issue at the Salton Sea is exposure of previously submerged lakebed, known as playa, as the lake surface shrinks. This playa exposure is subject to wind erosion and can be a source of fine airborne dust smaller than 10 micrometers, known as particulate matter (PM) 10; as well as a source of PM 2.5. The dust is a significant health hazard and can contribute to respiratory illness in humans. It can also damage agricultural crops and wildlife, and harm the region's tourism industry (CNRA 2018).

Decades of research have been conducted at the Salton Sea to attempt to improve ecological conditions there, but for many reasons, including a lack of comprehensive funding to complete proposed restoration projects, conditions at the Salton Sea have continued to degrade over time. Various related programs have continued to be proposed at the local and state levels; these projects are in various forms of implementation. Funding to complete these projects continues to be an issue.

The Salton Sea Species Conservation Habitat (SCH) EIS/EIR was finalized in 2013, with the goal to "[d]evelop a range of aquatic habitats that will support fish and wildlife species dependent on the Salton Sea" (Corps 2013). The project involved constructing a series of interconnected shallow ponds in areas where the Salton Sea recedes that would be fed by rivers. These ponds would have various levels of salinity and various fish and invertebrate habitat to enhance the prey base for shorebirds and wading birds. However, due to a general lack of funding, full build-out of the project has not been completed to date.

In 2015, CA Governor Jerry Brown formed the Salton Sea Task Force, which was tasked with identifying goals to respond to air quality and ecological threats at the Salton Sea. These goals included the following:

- Develop and implement the Salton Sea Management Program (SSMP) through departments within the California Natural Resources and Environmental Protection agencies.
- Meet a short-term goal of 9,000 acres to 12,000 acres of dust suppression and habitat projects.
- Establish a medium-term goal of 18,000 acres to 25,000 acres of dust suppression and habitat projects.

Phase 1 of the SSMP identified various shovel-ready projects and estimates of cost including, the SCH, air quality and habitat projects, wetlands projects, and conveyances of river and Salton Sea water. These projects (excluding the SCH, which is funded by other sources) were projected to cost $383M, and only $80M of the funding was available.

Geothermal development would occur in generally the same locations as those proposed for the SCH program and SSMP (areas on the southern end of the Salton Sea where the sea has receded), and the disturbance of lands and impacts on sensitive species associated with this development may result in the need for mitigation.

Geothermal developers need to mitigate land use and ecological impacts, but there are limited lands on which to do so in the Salton Sea area. Additionally, limited parcels of private land are available, and opportunities for in-kind mitigation are lacking. According to CTR, a 1.5-acre parcel for mitigation purposes cost $218K, primarily because of the lack of suitable lands elsewhere.

To summarize, the need for ecological restoration at the Salton Sea is well known. Various projects have been proposed at the local and state levels to restore fish and bird habitat and suppress dust. Despite its relatively small footprint and benefits compared to other types of energy, geothermal exploration, construction, and development have various negative ecological impacts in terms of land disturbance, potential impacts on sensitive species, and water and air quality. Thus, mitigation is necessary, but opportunities for conducting mitigation are generally lacking in and around the Salton Sea.

There has been a historic lack of coordination between the various ecological restoration projects and the development occurring at the Salton Sea. Geothermal developers, IID as the primary landowner, and the SSMP and SCH projects would symbiotically benefit from increased coordination to identify opportunities for mitigation that provide additional funds for conducting habitat restoration and dust suppression at the Salton Sea, while also providing opportunities for compensatory mitigation that allows for increased geothermal development.

Furthermore, it is possible that the footprint of the geothermal development itself can incorporate beneficial practices and aspects that themselves improve habitat and suppress dust on the Salton Sea playa.

7.4.4 Water Availability

The existence of IID as both the landowner and a local utility that encourages geothermal development has beneficial impacts in terms of making sure that adequate water is set aside. The Salton Sea is an arid desert environment, and much of the freshwater available is allocated for irrigation and municipal purposes. While geothermal energy-generation uses more water than solar or wind, the amount of freshwater needed for cooling and other purposes is relatively low compared to coal, natural gas, or nuclear (see Section 5.2.1). IID has set aside water for energy development and has indicated that more could be set aside as necessary. Thus, at the Salton Sea, water availability does not appear to be a limiting factor in geothermal development.

In areas beyond the Salton Sea, where the landowner and utility may be different entities, coming to early agreement on acquiring adequate water rights is a crucial step in encouraging geothermal development.

7.4.5 Cultural Resources

Development of new renewable energy facilities at the Salton Sea would have the potential to disturb and/or destroy known or found historic or cultural resources. While the California Office of Historic Preservation has previously identified 10 archaeological sites and districts eligible for listing in the National Register of Historical Places, 14 California Historic Landmarks, and 4 cultural sites listed as points of historical interest, many areas remain unsurveyed (ICPDSD 2015). This includes areas that have been recently exposed by the evaporation of the Salton Sea, which also happen to be the areas with the highest potential for geothermal development. In compliance with Section 106 of the *National Historic Preservation Act* and California’s requirements, proposed geothermal development would need to consult with Native American tribes and minimize/mitigate any impacts. Such consultation would occur on a project-by-project basis and would occur without comprehensive knowledge of the existence or potential for cultural and historic resources in the area.

Cultural resources surveys are categorized into either Class I, Class II, or Class III surveys. As defined by the BLM (BLM 2021):

> Class I inventory is not merely a records search or prefield literature review, conducted prior to land disturbance actions. A Class I inventory is most useful for gaining a comprehensive view of all the known archaeological, historical, cultural, and [Traditional Cultural Properties] within a large area. By definition, it is a professionally prepared study that includes a compilation and analysis of all reasonably available cultural resource data and literature. Additionally, this study is a management-focused, interpretive, narrative overview and synthesis of the data.
>
> Class II inventory is a professionally conducted, statistically-based sample survey designed to aid in characterizing the probable density, diversity, and distribution of cultural properties within a large area. Intensive pedestrian inventory is conducted in limited and discontinuous portions of the [Area of Potential Effect]. Within individual sample units, survey aims, methods, and intensity are the same as those applied in a Class III inventory. A Class II inventory may include an approach that is based on a professional but judgmental strategy that needs to be specifically defined for a project. A Class II inventory may be conducted in several phases, using different sample designs to improve statistical reliability.
>
> Class III inventory is a professionally conducted, continuous, intensive pedestrian survey of an entire project area aimed at locating and recording all cultural properties. Intensive inventory describes the distribution of properties in an area; determines the number, location and condition of properties; determines the types of properties actually present within the area; permits classification of individual properties; and records the physical extent of specific properties.

In general, Class III surveys would be required for any given geothermal or other energy development project. While generally, the developer bears the cost of the Class III survey, a comprehensive Class III cultural resources survey covering the totality of the Salton Sea KGRA could identify and provide opportunities and mitigation. Such a survey would allow for resolution of potential issues without affecting the timeline or cost of a specific project. Such a survey would not only benefit private developers, but would also help to meet the renewable energy goals of IID, the state of California, Imperial County, and the federal government. Therefore, the costs of the survey could be shared among various entities or subsidized by the state of California or the federal government.

7.4.6 Land Access/Ownership

While the checkerboarded land ownership at the Salton Sea presents certain challenges, overall, compared to other areas, this is a relatively small challenging factor. Because most of the lands with geothermal potential are privately owned by IID and do not have a federal nexus, federal NEPA compliance is generally not necessary. Instead, CEQA compliance is generally sufficient, with potential federal participation associated with the Corps and the CWA Section 404 permitting process.

Because the lands with geothermal potential are generally located on the Salton Sea playa, limited conflicts exist with agricultural or other private land uses. As a result, general support exists for geothermal development as an economic driver for Imperial County.

7.5 Transmission Network and Capacity

One important consideration for geothermal development is that regardless of whether new geothermal development is economically feasible, a transmission infrastructure must be in place to carry potential new generation to populations centers. At the Salton Sea, transmission infrastructure and interconnections would need to be in place to carry renewable energy to load centers such as Los Angeles to the west and Nevada and Arizona and to the east.

A 2011 study conducted for IID indicated that new proposed generation projects would create transmission overloads and outages under various scenarios (IID 2011). The study determined that $279 million in system investments and upgrades would be necessary to interconnect a potential 1,223 MW of new generation within the IID system, including both geothermal and solar development.

In partial response to this need, IID initiated the construction of new transmission infrastructure. Phase 1 of the Midway-Bannister Transmission Project, completed in 2011, included construction of a 230 kV transmission line to deliver geothermal and solar energy from the Salton Sea to interconnection points with neighboring electrical grids (IID undated), while Phase 2, completed in 2013, involved construction of additional 230 kV transmission lines to interconnect to future geothermal development (TransmissionHub 2018). Much of the potential developable land within the KGRA is more than 1 mile away from a 138 kV to 230 kV substation, which would require construction of additional intertie infrastructure in addition to the geothermal plant itself (NREL 2015). Storms in August 2021 near the Salton Sea damaged up to 100 poles managed by IID, rendering existing geothermal plants in the area idle (Richter 2021). Redundancy in the system would allow for repair and/or maintenance of aspects of the transmission system, while not necessarily idling existing renewable energy facilities.

Although transmission progress has been made, both IID and power producers indicated (during 2021 interviews) that transmission congestion remains a constraint at the Salton Sea. Getting power to the independent system operator is possible, but it remains difficult to transport the power to load centers (e.g., cities) that need the power due to bottlenecks at the interconnects (Figure 7-19). Figure 7-20 shows the existing and proposed transmission system in Imperial County.

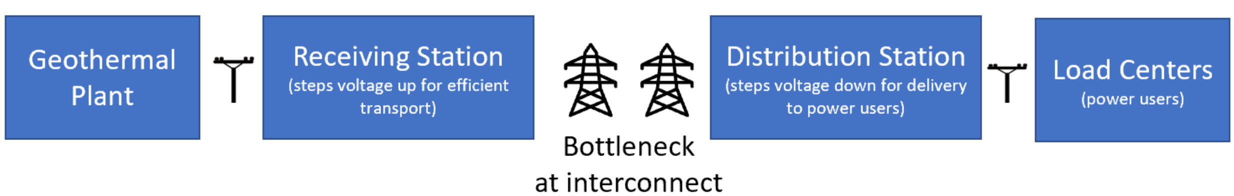


Figure 7-19. Power generation and distribution process that includes a potential bottleneck in the high-voltage interconnections.

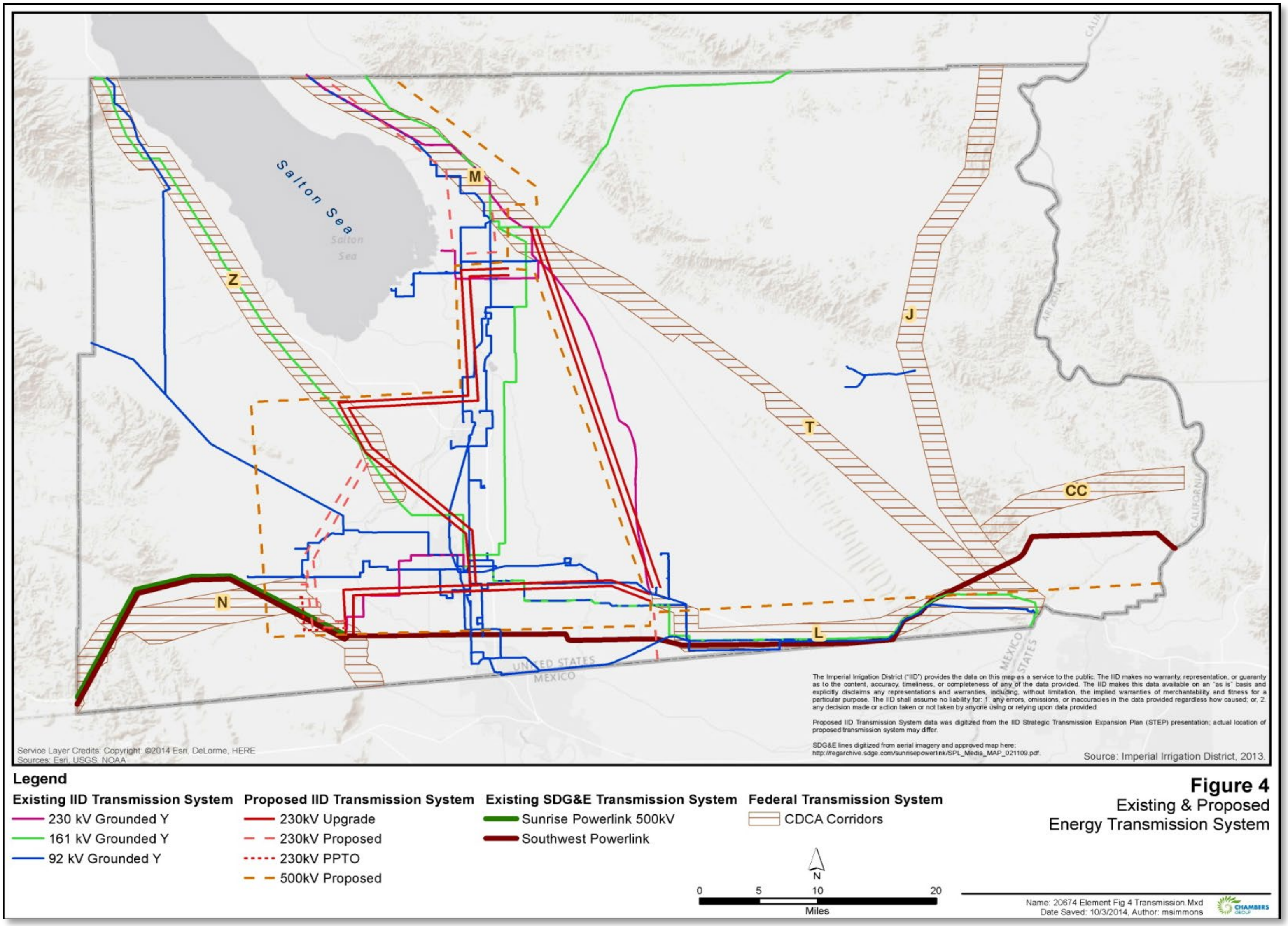


Figure 7-20. Existing and proposed energy transmission system – Imperial County, CA (ICPDSD 2015).

7.6 Lithium

Lithium is a soft alkali metal that has numerous industrial uses (Eason 2010). Most lithium is used for batteries, although ceramics and glass, lubrication, and polymer production are other uses. As battery-powered electrical devices such as vehicles, phones, and tools gain in popularity, global demand for lithium is increasing substantially.

Concurrently, identified lithium resources have increased substantially. It is estimated that 7.9 million tons of lithium exist in the United States, out of a total of 86 million tons worldwide. While the United States has high potential for lithium production, domestic production is limited, and most lithium is imported from Argentina, Chile, and China (USGS 2020). Other sources of lithium include Chile (the largest producer of lithium in the world), along with Bolivia and Australia. Because lithium is highly flammable (Eason 2010), most lithium is produced from brine pools such as those found at the Salton Sea. Geothermal brines at the Salton Sea contain high levels of dissolved metals and minerals, most notably including lithium, but also manganese, zinc, and others (Chao 2020).

The Salton Sea area is commonly referred to as “Lithium Valley” in national news stories because it could become a major domestic lithium source. The CEC estimates that the Salton Sea has the potential to supply 40% of global lithium demand (Chao 2020), produce more than 600,000 tons of lithium carbonate per year (CEC 2020), and produce $7.2 billion in revenue at a price of $12,000 per ton. The total potential value would be contingent on the lithium market prices, which are volatile. Lithium increased from $6,500 per ton in 2015 to $17,000 per ton in 2018, according to the USGS (2020). However, lithium then decreased to $8,000 per ton in 2020. In 2021, certain estimates of lithium were as high as $26,000 per ton. Lithium demand is based upon an increased need for lithium for electric vehicles and other uses, along with limited supplies (Erickson 2021). As such, interest in developing additional viable domestic supplies of lithium have increased.

Several lithium extraction technologies, including membranes, supercapacitors, and nanofiltration, have been demonstrated at pilot scales (Somrani et al. 2013; Kim et al. 2015; Li et al. 2019), but none has been successfully implemented on a commercial scale at a geothermal facility. To extract the lithium from the brine, production wells need to be drilled and operated. Thus, lithium extraction has a symbiotic relationship to geothermal development. Ambrose and Kendall (2019) find brine extraction to be of lower cost than pegmatite (surface) mining, before considering the cost reduction of co-siting with geothermal development. The brine extracted that is converted to heat to produce geothermal power needs to eventually be reinjected; adding a phase to the geothermal cycle that extracts lithium can be seen as an add-on to the existing geothermal project. The economies of scale of being able to share a project footprint and share in the costs of well exploration and drilling effectively reduce the costs and risk of both the geothermal generation and the lithium extraction, compared to proceeding with either type of project on its own. While developers have expressed the need for the geothermal and the lithium facilities to be profitable on their own, the existence of an add-on lithium facility can be seen to effectively decrease the risk, cost, and eventual LCOE of geothermal development at the Salton Sea.

As discussed previously, CTR is currently in the process of constructing the Hell’s Kitchen project, which includes a co-located lithium plant along with a geothermal facility. CEC is also funding various lithium extraction projects to increase the viability of a co-located geothermal/lithium plant (de Jong 2021). At the same time, research is ongoing to increase the extraction of lithium and other metals from the brine. PNNL is working on technological improvements to improve the extraction of lithium, to potentially achieve a 10–30% improvement in efficiency (Shane Addleman, personal communication).

While the co-located lithium plant has the potential for substantial profit, it has not been successfully implemented, either at the Salton Sea or elsewhere. Interviews with developers such as CTR have indicated that while lithium helps with synergies and economies of scale, it cannot be considered a potential way to subsidize the geothermal resource. That is, to achieve economic viability, both the lithium and the geothermal plants need to be profitable on their own.

Figure 7-21 shows MAGE results related to including a lithium plant as an addition, holding constant all other parameters. The lithium addition changes multiple features of MAGE's output. Foremost, the DNPV is approximately 10 times higher, indicating that lithium provides considerable revenue and profit potential. The lithium addition also increases the BCR to 1.52, but this increase is not as dramatic as the change in DNPV. The lithium plant adds a revenue stream that is greater than revenue derived from the power plant, but also substantially increases annual operation and maintenance costs. The risk associated with the lithium plant is not the initial exploration costs that have already been paid, or capital costs which are relatively low. One risk involves a substantial decrease in the global market price of lithium, which is volatile. However, even at a relatively low price, the addition of the lithium plant is likely to be profitable. Another risk involves the lithium extraction not being able to keep up with the 24-hour operation of the power plant.

The LCOE is not shown with the addition of the lithium plant because there would now be two revenue sources, and the formula does not fit within that framework. Levelized cost can only be computed for a single output and the cost of power and lithium cannot be summarized together by a single number.

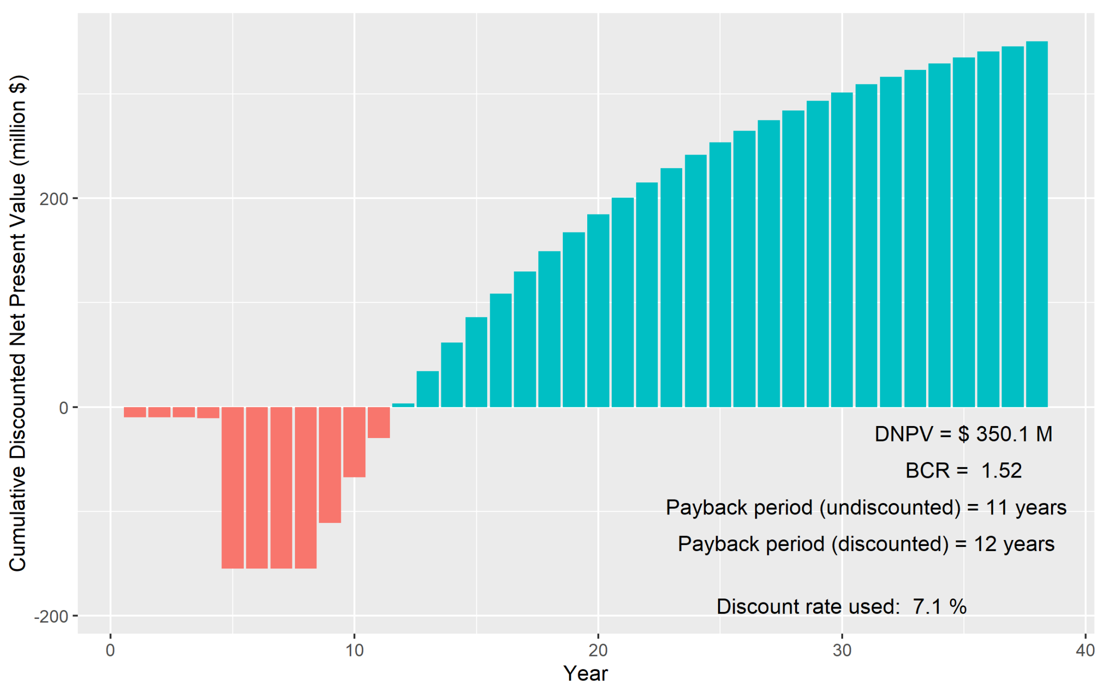


Figure 7-21. MAGE with a lithium plant addition.

One complicating factor in the co-development of lithium and geothermal energy is that these resources would require the participation and cooperation of different California State agencies. As mentioned previously, CEC is the lead regulatory agency for permitting geothermal projects over 50 MW in capacity and can delegate authority to Imperial County for projects less than 50 MW in capacity. However, CalGEM has regulatory authority for permitting mineral development, including lithium. Because neither standalone lithium nor co-located projects have not been permitted to this point, the delegation of authority and responsibility between the two agencies is not yet well understood. Developing a system and a framework for how to ensure an efficient permitting process that meets the needs of both agencies will be important as lithium technologies continue to improve and co-location opportunities become more prevalent and important.

7.7 Technical Barriers

While not the focus of this report, other technical barriers also lead to geothermal energy being a more expensive resource than solar and wind energy, even at the Salton Sea. Over time, technological changes are increasing the efficiency and productivity of both geothermal energy and other renewables. Technical improvements associated with geothermal development can help to reduce the cost gap between geothermal, solar, and wind power. For example, at the Salton Sea, exploration and startup costs are generally decreasing due to a well-understood resource, increased characterization of the reservoir due to data from new wells, and an understanding of the appropriate economies of scale for construction of a new geothermal plant. CTR's development of the Hell's Kitchen project has been determined to be in large part economically feasible because of the economies of scale associated with the size of the plant being considered. Furthermore, technological changes such as EGS, an ability to access hotter subsurface geothermal resources, and other increasing efficiencies can help to reduce costs and the LCOE.

Various models have been produced indicating that the power production per well increases exponentially as the production temperature increases. AltaRock presented Figure 7-22 at the 2021 Geothermal Rising Conference, which indicated that supercritical wells higher than 375°C could produce five times more power per well than 225°C wells.

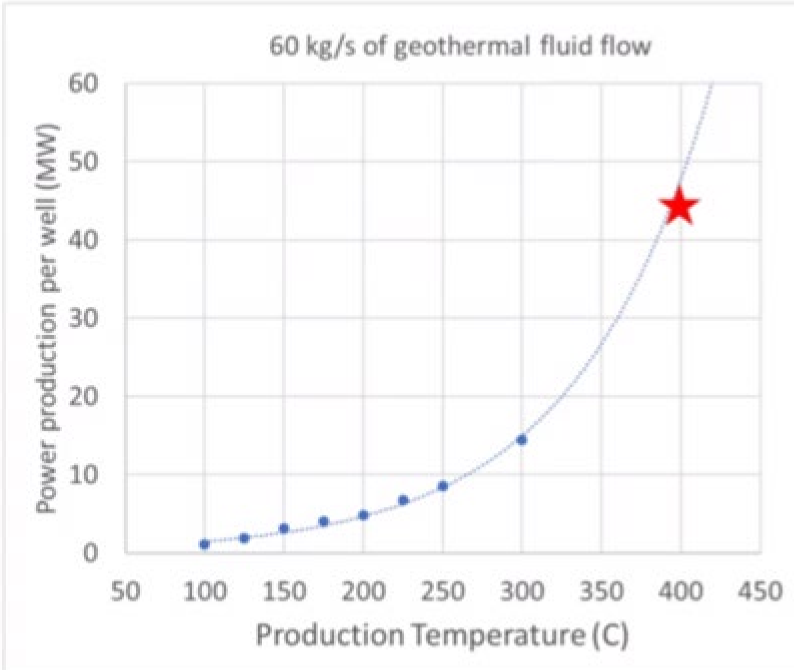


Figure 7-22. Geothermal power production compared to production temperature.

AltaRock, Baker Hughes, and the University of Oklahoma have been studying an EGS for accessing superhot water (>400°C) at the Newberry Crater in Oregon (Tsanova 2021). They anticipate formal demonstration of the well system by 2025 and commercial development by 2030. Their LCOE projections for superhot EGS would be $46 per MW/hr, which would be comparable to other power sources (Cladouhos et al. 2018). These projections are for a 106 MW plant, with $330 million in capital costs, ~200 million in interest payments (20-year loan at 5%), and $6.5 million in annual operations and maintenance costs.

Being able to access this supercritical water remains a challenge and would require substantially increased exploration and drilling costs. Depending on the characteristics of the reservoir, significant variations in heat may exist and it may be substantially more expensive to access the supercritical water depending on the drilling location. Supercritical water does appear to exist in certain locations at the Salton Sea. Figure 7-23 illustrates the potential costs of increased drilling and the opportunities of increased power production, analyzing various scenarios and their impacts on the LCOE.

Figure 7-21 shows the results of using AltaRock's inputs in MAGE. We used our baseline inputs for parameters not listed by Cladouhos et al. (2018) such as exploration costs and exploration and construction time. The model gives an LCOE of $63/MWh—substantially higher than their reported value of $46. Removing federal and state corporate taxes, state property taxes, and the capital subsidy from the model yields an LCOE of $46. If this project is compared to our baseline inputs using the same discount rate, AltaRock's scenario has an LCOE about 15% lower. While this is a substantive cost reduction, the gains may not be as large when considering extra costs.

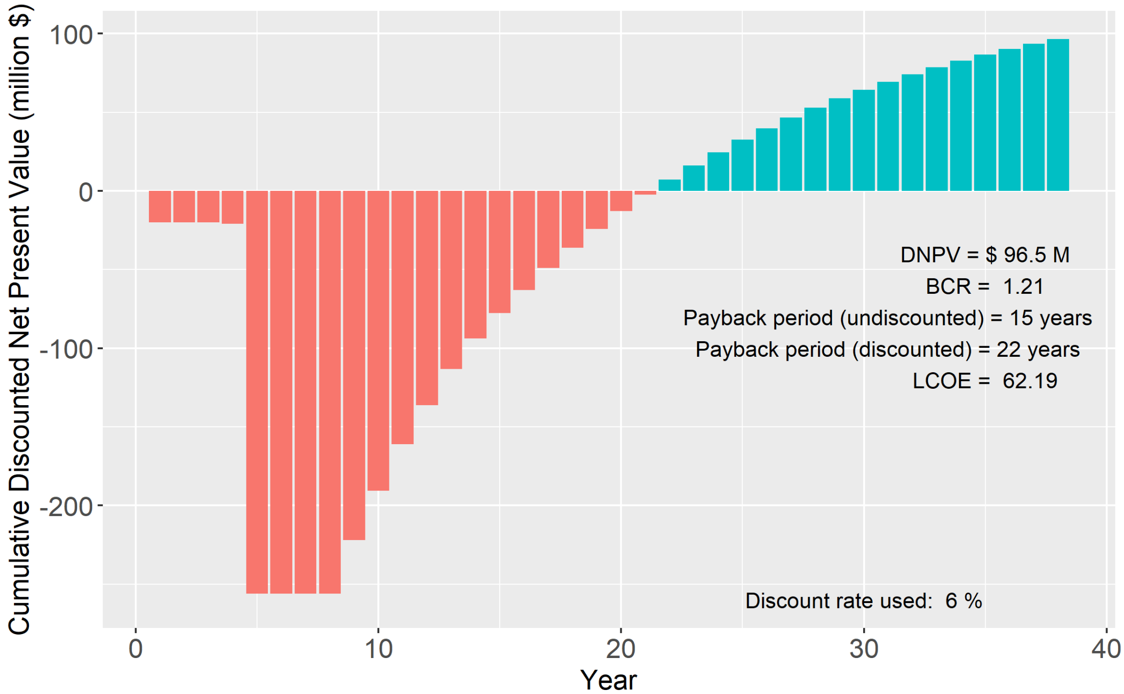


Figure 7-23. MAGE results for a potential EGS.

7.8 Multiple Parameters

The preceding sensitivity analyses evaluate how beneficial singular actions (e.g., reducing permitting costs) are at reducing LCOE and payoff years. This section addresses combinations of actions that can be taken (e.g., reduce permit costs and increase tax subsidies), which could provide even greater benefits. MAGE will be made available to the public so that they can evaluate their own combinations of potential solutions by adjusting toggles for the associated parameters.

The discount rate plays a critical role in determining the benefits derived from reducing timelines. When using a single Weighted Average Cost of Capital discount rate, the reduction in LCOE derived by reducing the exploratory phase by 1 year is less than 1%. Wall et al. (2017) and our stakeholder interviews said that the exploration phase is typically more difficult and expensive to finance because there is a higher risk of failure. This phase is often financed with equity or high-interest debt to reflect the higher risk that exploration costs are sunk even for a canceled project.

This section analyzes the change in LCOE derived from reducing the exploration phase from 4 years to 3 years for different discount rates. The output shown the LCOE for the standard 4-year exploration and permitting time, the streamlined 3-year time, and the LCOE savings achieved from this 1-year reduction. Table 7-4 shows the results indicated earlier that increasing the discount rate increases the LCOE and reducing the permitting and exploration time by 1 year reduces the LCOE. The table shows that the LCOE reduction increases as the required discount rate increases. At the high-end equity rates of 40% that would be associated with risky venture capital-funded projects, the savings are around $4 per MWh. While the LCOE reductions are larger at the higher rates, this table shows that the greatest cost reduction from streamlining the permitting process is likely to be derived by reducing the risk of the project, thereby reducing the required discount rate.

Table 7-4. Change in LCOE derived by reducing permitting time by 1 year for different exploration phase discount rates.

Exploration Phase Discount Rate	LCOE: 4-Year Exploration and Permitting ($/MW)	LCOE: 3-Year Exploration and Permitting ($/MW)	LCOE Reduction from Streamlined Permitting and Mitigation ($/MW)
7%	76.94	76.63	-0.31
10%	77.51	77.03	-0.48
13%	78.12	77.44	-0.68
16%	78.78	77.88	-0.90
20%	79.74	78.49	-1.25
23%	80.52	78.98	-1.54
26%	81.37	79.50	-1.87
30%	82.60	80.22	-2.38
33%	83.59	80.79	-2.80
36%	84.65	81.39	-3.26
40%	86.19	82.23	-3.96

8.0 Summary of Modeled MAGE Scenarios

Table 8-1 summarizes the findings of MAGE and the various scenarios presented in this report. The potential viability can be increased through a variety of inputs. Reducing capital costs and the discount rate shows the largest gains in LCOE and other outputs. Reducing permitting and mitigation costs, reducing the regulatory timeframe, and reducing the exploration costs do not have as large of an impact. Figure 8-1 shows the relative sensitivity of these inputs in changing the LCOE.

Table 8-1. MAGE outputs associated with various scenarios.

Scenario	DNPV (M$)	BCR	Payback period (Discounted)	Payback period (Undiscounted)	LCOE ($/MWh)
Baseline (4 years exploration and permitting; 4 years construction)	**6.4**	**1.03**	**33**	**16**	**76.96**
Zero Permit Costs	7.2	1.03	32	16	76.57
Exploration and permitting time reduced 1 year	7.6	1.03	31	15	76.65
Exploration and permitting time reduced 2 years	8.4	1.04	30	14	76.52
Exploration and permitting time 6 years	4.3	1.02	36	18	77.66
Construction time reduced 1 year	16.0	1.07	27	15	72.93
Exploration and permitting time reduced 3 years, construction time reduced 1 year	21.43	1.08	23	12	72.27
Exploration and permitting costs increased to $20M	-3.60	0.98	NA	17	81.71
Construction costs reduced 20%	32.7	1.18	22	14	64.42
Construction costs reduced 33%	43.1	1.25	20	14	59.05
Capital costs increased 110%	-175.7	0.55	NA	NA	160.49
30% Capital Subsidy	31.1	1.17	22	14	65.17
26% Capital Subsidy	26.3	1.14	24	15	67.53
Property Tax Waiver	26.7	1.14	25	15	67.31
Discount rate reduced by 1%	24.1	1.11	27	16	70.20
3% Discount Rate	115.5	1.36	19	16	52.92
Equity financing - internal funding	-31.8	0.78	NA	16	108.78
Equity financing - external funding	-34.2	0.49	NA	16	188.46
EGS inputs	96.5	1.21	22	15	62.19
Lithium plant	350.1	1.52	11	12	N/A

BCR = benefit-cost ratio; DNPV = discounted net present value; EGS = enhanced geothermal system; LCOE = levelized cost of electricity.

Government policy has little direct influence over the capital or operating costs of a project. These costs can only be reduced via subsidies or tax waivers. These types of subsidies result in a dollar-for-dollar gain for the project. Increasing the ITC for geothermal projects from 10% to 30% has almost identical gains as reducing the capital costs by 20%. State property tax subsidies and waivers have a similar effect on operating and maintenance costs. Government policy can reduce costs associated with permitting and mitigation, but these reductions provide relatively small benefits. Reducing the regulatory and approval timeline can result in some cost reductions. These reductions are greater for projects that require high discount rates for the early years of a project when there is greater uncertainty and risk.

Government policy can influence the discount rate by reducing the risk of a project. Streamlining the regulatory process and helping to ensure a successful exploration and construction process can help reduce the risk, and subsequently the required discount rate. Loan guarantees or loan subsidies can also directly reduce financing costs, thereby reducing the discount rate.

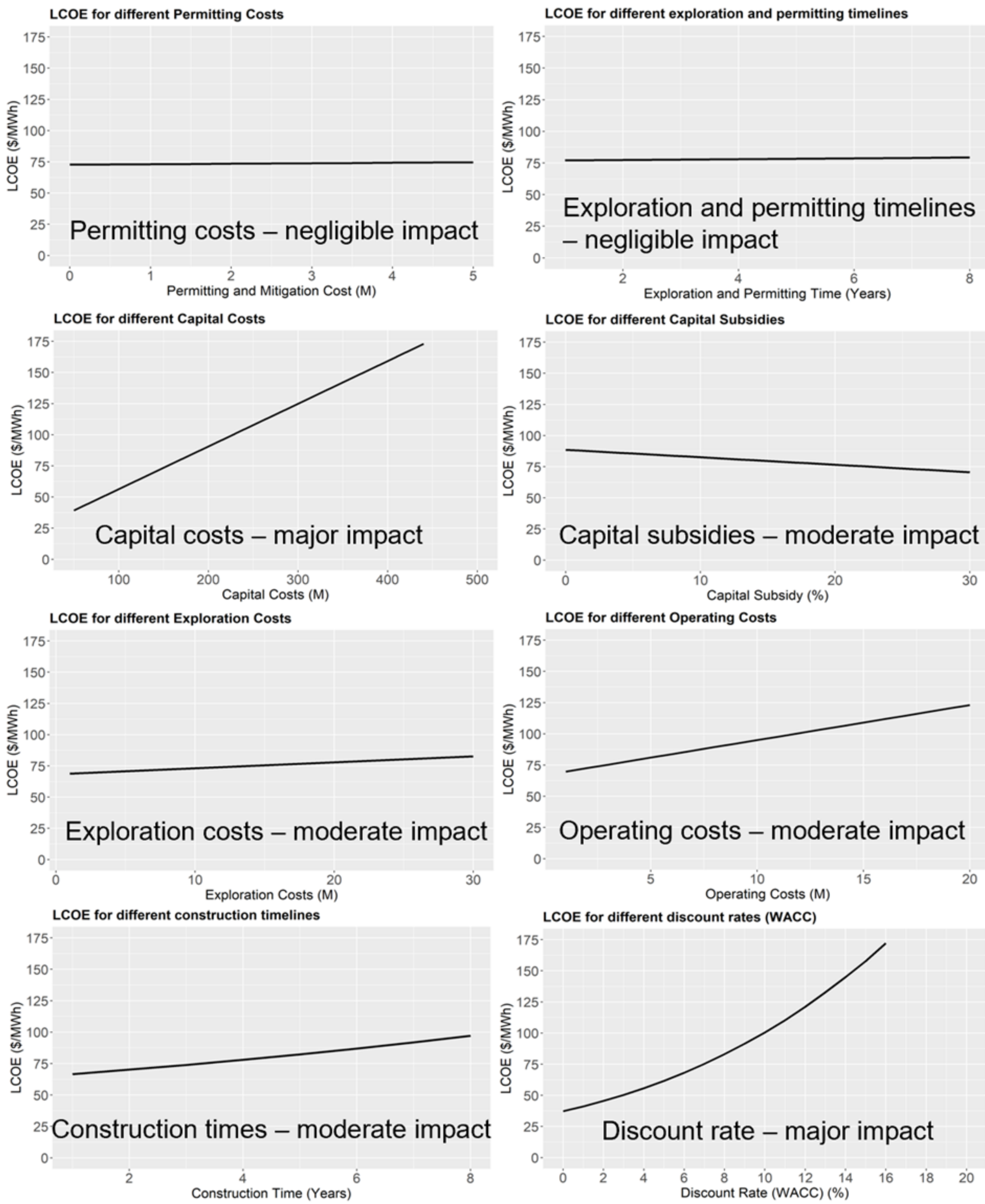


Figure 8-1. Sensitivity of various parameters in changing the geothermal LCOE.

9.0 Streamlining Geothermal Development Outside of the Salton Sea

The Salton Sea is blessed with a robust geothermal resource, a strong history of development, the lack of a federal nexus requiring NEPA compliance, a supportive community and landowner, opportunities for developing lithium and other minerals, and a state RPS that encourages the development of new renewable energy projects. However, despite these relative advantages, geothermal development at the Salton Sea remains slow. In areas without these advantages, geothermal developers need to position their project in the best possible circumstance to be economically viable.

Like all renewable energy resources, geothermal energy can only be developed where the resource exists. Geothermal resources are limited in geographic locations, primarily throughout the Western United States. While not specific to a geographic location, ensuring that the geothermal resource is as well-situated for development as possible includes taking the recommended steps presented in the following sections.

9.1 Understand and Outline the Permitting Process and Timeline

Prior to initiating the project, the developer must derive a common understanding of state and federal permitting processes. If the project is on federal lands and requires NEPA compliance, the developer should make sure that the applicable area management plan allows for geothermal development. The developer should also work with the USACE to identify any jurisdictional waters that may require CWA Section 404 compliance.

The CEQA process is a good example of a process that is well known and well understood. CEC has umbrella authority for permitting and authorizing all projects over 50 MW in capacity and has the authority to delegate this authority as appropriate for projects less than 50 MW in capacity. As shown in MAGE, reducing the time associated with permitting has far more impact on the LCOE than the costs associated with permitting. Working with the appropriate permitting agency(ies) to develop a schedule early in the process can reduce potential delays.

9.2 Acquire Necessary Water Rights

At the Salton Sea, IID is both the utility in the area and the landowner in most areas proposed for future geothermal development. IID owns the water rights in the area and has set aside sufficient future water rights necessary to support geothermal development. In other locations, it is unlikely that the utility will also be the landowner. In these cases, the utility or developer should ensure that water rights are obtainable prior to proceeding with exploration. For areas that have substantial existing agricultural, municipal, or industrial water use, or in arid locations where surface water and groundwater are limited, this may be a substantial expense that should be factored into the process.

9.3 Ensure That the Transmission System Has Capacity to Support the Project

One of the biggest barriers to energy development is the lack of a sufficient transmission system to export the power to load centers. Prior to proceeding with even the geothermal exploration process, sufficient transmission capacity should exist, or a plan should be in place for constructing this capacity.

9.4 Survey and Avoid Resource Conflicts Early in the Process

If endangered or sensitive species may exist in the project area, either consider moving the project area or conduct a biological assessment. Development of a biological assessment and receiving a biological opinion from the FWS or the National Marine Fisheries Service can be a time-consuming and lengthy process. Development on disturbed lands and/or brownfield sites can be a good way to minimize potential take associated with sensitive species.

Conducting a comprehensive cultural resources survey early in the process can also streamline the development process by identifying resources that need to be avoided or for whom effects might need to be mitigated as part of the development of the project. Ranging from a reconnaissance (Class I) to an intensive (Class III) survey, this process can help to inform developers, regulators, tribes, and other stakeholders of the existence of cultural or historic resources that exist in the project area. Conducting such a survey can streamline development by identifying areas for exclusion or avoidance prior to the initiation of construction.

9.5 Inform State/Federal Governments of the Benefits of Geothermal Energy

As discussed in Section 5.3.3, geothermal energy has ancillary benefits to grid reliability and flexibility that benefit the electric system as a whole, and that are not necessarily encompassed within the LCOEs or PPAs between geothermal developers and power purchasers.

Ideally, the benefits of geothermal development to the power system would be understood by local, state, and federal governments, and government support and subsidies would flow organically to geothermal development. At both the state and federal levels, certain benefits of geothermal energy appear to be well understood in part, but the financial support for it lags behind that for solar and wind energy. Continuing to inform lawmakers of the benefits of geothermal energy development may result in future incentives that can even the playing field for geothermal development relative to solar, wind, hydro, nuclear, and nonrenewable energy.

At specific areas such as the Salton Sea, using federal funding through the GTO can support partnerships for site development. Such funding could be used for comprehensive area-wide surveys (such as described in Section 9.4). Funding could also be used to support national laboratories, USGS, and others to perform site characterization efforts at specific locations. Site characterization could include geophysical or geological efforts that could help to characterize the reservoir and/or provide well-drilling data that could subsequently streamline future development.

9.6 Engage the Public and Stakeholders

One important aspect of successful energy project siting is to ensure that stakeholders are engaged and informed of the benefits of the project. This can include outreach related to the following:

- economic benefits (jobs and tax revenue) associated with geothermal construction and operation
- grid reliability and flexibility
- limited air emissions and water use requirements
- limited land use requirements
- clean domestic energy
- limited resource conflicts
- potential reduction in large seismic activity
- engagement of disadvantaged communities.

Many stakeholders at the Salton Sea are supportive of the potential environmental justice and economic opportunities for geothermal development and lithium co-location. Proceeding through the permitting and environmental compliance processes (whether NEPA is required or not) is substantially simplified when relevant stakeholders understand the full range of benefits of a geothermal project.

9.7 Consider the Availability and Benefits of Co-Location with Minerals Development

Regardless of a project's location, geothermal brines will continue to need to be prepared for injection back into the geothermal reservoir. Developing a separate revenue stream for the minerals that already need to be removed from the geothermal brine can provide a huge benefit to the economics of a project. Construction of a co-located minerals facility can be a relatively simple add-on that does not require substantial additional capital expense.

As lithium technologies continue to mature, and if lithium demand continues to increase, development of a viable co-located lithium plant could drastically change the economics of geothermal development at the Salton Sea. The results of the co-located lithium plant at the Hell's Kitchen geothermal project will provide valuable data on the potential profitability of mineral extraction from geothermal brines. While lithium is unlikely to be viable in many other locations proposed for geothermal development, other valuable minerals may exist for extraction.

Because renewable energy development projects and mineral development projects often fall under different federal and state agency jurisdictions, early outreach to determine a lead agency and applicable roles and responsibilities is important.

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