NATIONAL ENERGY TECHNOLOGY LABORATORY

Role of Alternative Energy Sources: Geothermal Technology Assessment

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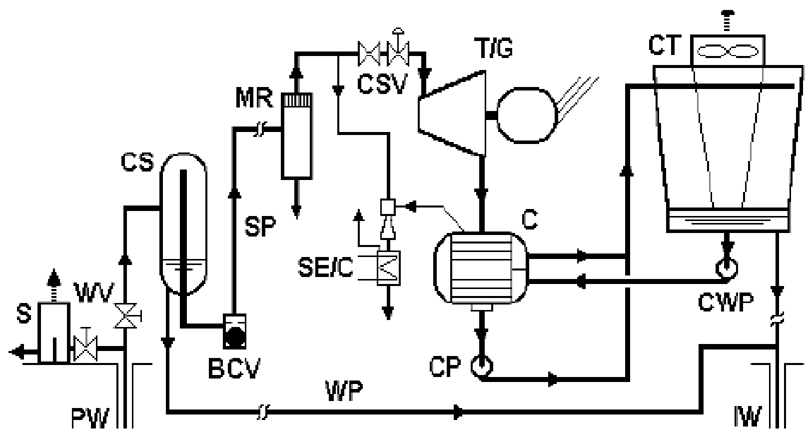
Agenda

- Technology Description
- Resource, Capacity, and Growth
- Environmental Analysis
- Cost Analysis
- Barriers to Implementation
- Risks of Implementation
- Expert Opinions

Steamboat 1 geothermal power plant in Nevada (EERE, 2012)

Technology Description: Geothermal Types

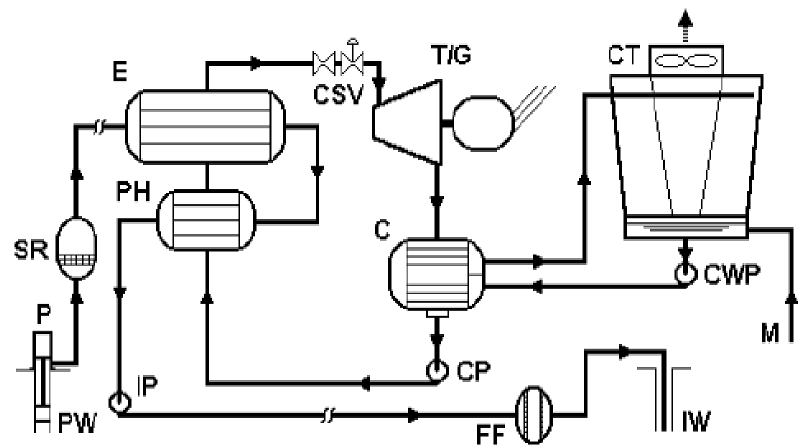
- **Flash Steam Geothermal**
  - Production wells contain hot water at high pressure
  - Water is brought to surface and expanded in a flash vessel to produce steam that is used to drive a turbine
  - Steam condensate from flash process is used to provide makeup water to power plant's cooling water system
  - Not necessary to withdraw cooling water from other sources
  - All water that is recovered from the system is returned to ground using injection wells



Single-flash Geothermal Power Plant (DiPippo, 1999)

Technology Description: Geothermal Types

- **Binary Geothermal**
  - Take advantage of lower energy reservoirs
  - Use heat exchangers to transfer heat from geothermal wells to a fluid that drives an organic Rankine cycle
  - Lower capacities than flash systems
  - Require the use of a heat exchange fluid
  - Since they do not have any steam condensate, must withdraw cooling water makeup from surface water or groundwater source



Basic Binary Geothermal Power Plant (DiPippo, 1999)

Technology Description: Geothermal Performance Characteristics

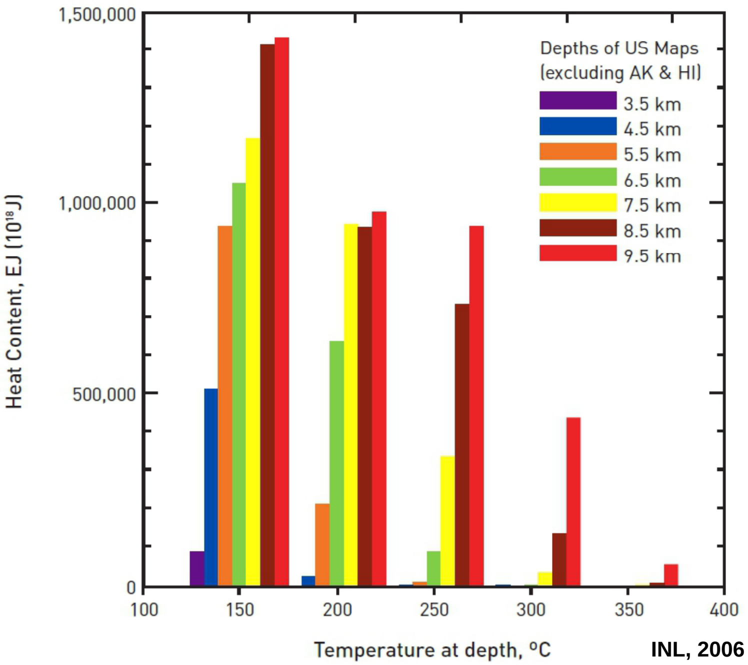
- **Analysis focuses on flash geothermal systems because they represent largest share of geothermal capacity additions in U.S. since 1985 (GEA, 2012)**
- **Data limitations of environmental and cost models of this analysis prevent accurate comparison between two types of geothermal technologies**
- **Geothermal power plant has a net capacity of 50 MW, representative of flash steam geothermal technology**
- **Plant requires 25 production wells and 10 injection wells**

Flash Steam Geothermal Power (All Costs in 2007$)				
Parameter	**Units**	**Low**	**Expected Value**	**High**
Plant Capacity	net MW	50	50	50
Capacity Factor	%	85%	90%	98%
Trunkline Distance	miles (km)	5.0 (8.1)	25 (40)	50 (81)
Capital (Power Plant)	2007$/kW	2,000	3,000	5,000
Decommissioning	2007$/kW	209	346	591
Fixed O&M (annual)	2007$/MW-yr	82,320	164,600	247,000
Plant Life	years	20	25	30

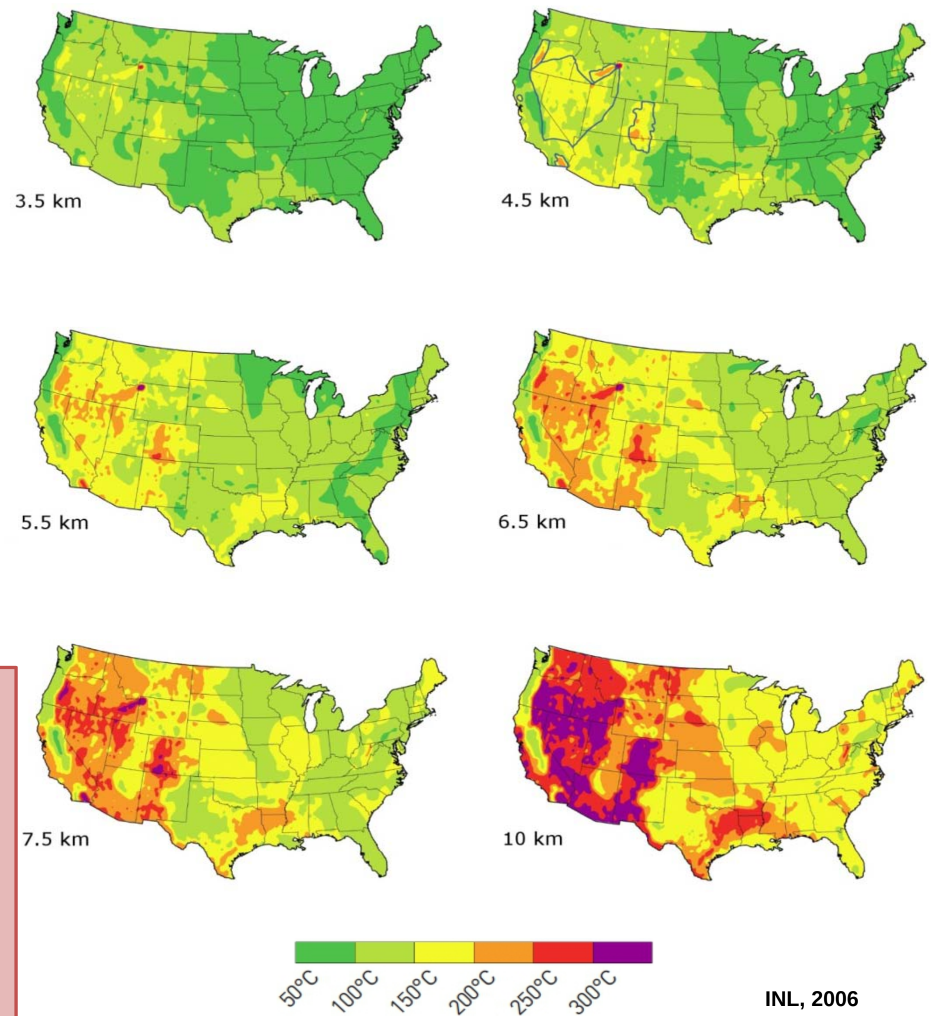
Resource, Capacity, and Growth

- **Absent any drilling constraints, if drilled to a sufficient depth, subsurface temperatures at essentially any location in U.S. could potentially yield geothermal resources sufficient to provide power generation**
- **Well depth is a key constraint, due to both technological and cost limitations**
- **Available geothermal resources are those located near enough to surface and can be reached by contemporary drilling techniques at a cost that is not prohibitive**
- **Ability of an existing geothermal resource to be developed can be constrained by various site-specific factors:**
  - Character of geologic formations on site
  - Temperature and depth of the resource
  - Proximity to available infrastructure, including power lines and access roads
- **These factors have historically posed significant limitations with respect to the ongoing development of domestic geothermal resources**

Resource, Capacity, and Growth



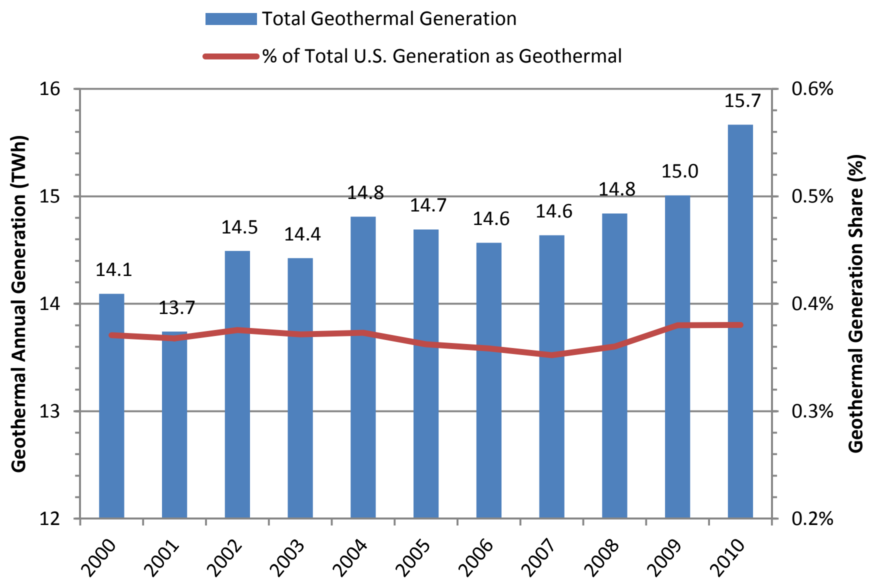
INL, 2006



INL, 2006

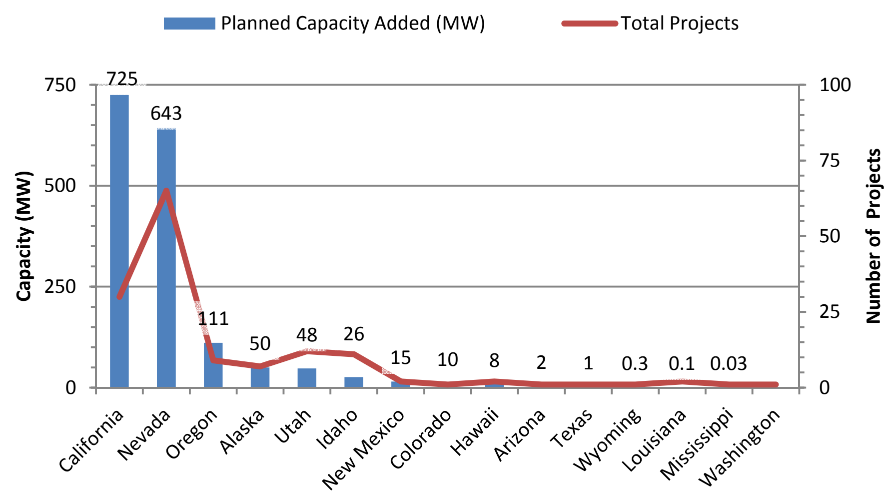
- Best geothermal resources at the shallowest depths are available in the Western U.S. - high tectonic heat flow, low conductivity
- Between 3.5 and 7.5 km in the 150 degrees C range, there is a resource base of 13 billion GJ
- Developing 1% of that would be equivalent to over 1,000 times the annual primary energy consumption in the U.S. (INL, 2006), but there are barriers to accessing the resource base

Resource, Capacity, and Growth



- Geothermal share of U.S. power generation remained constant since 2000, fluctuating from approximately 0.36% to 0.38%
- Geothermal power generation has increased from approximately 14.1 TWh in 2000, to approximately 15.7 TWh in 2010 (1.1% growth) (EIA, 2011)
- Dry steam technology is 50% of installed geothermal capacity, but has not grown since 1985 due to limited resources (GEA, 2012)
- Flash steam represents 28% of total geothermal capacity and is preferred technology for new geothermal power since 1985 (GEA, 2012)

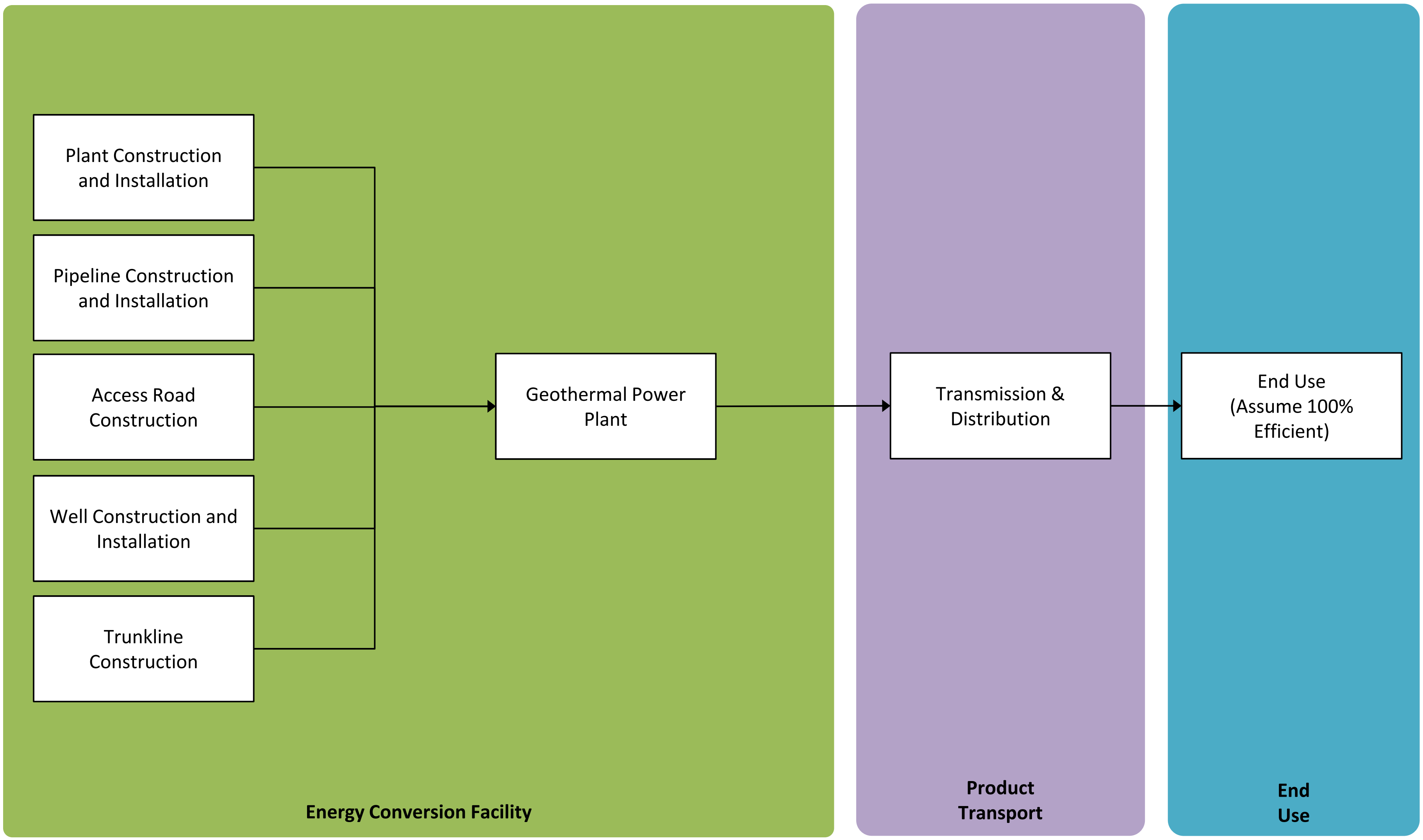
- All known geothermal projects within the U.S. as of April, 2011 (GEA, 2011)
- 46 proposed geothermal projects have reached at least initial planning and scoping phases.
- 1.6 GW of new capacity, equivalent to 53% of existing U.S. geothermal capacity as of 2010
- Supported by renewable portfolio standards
- Based on conventional geothermal technologies, primarily flash steam and binary



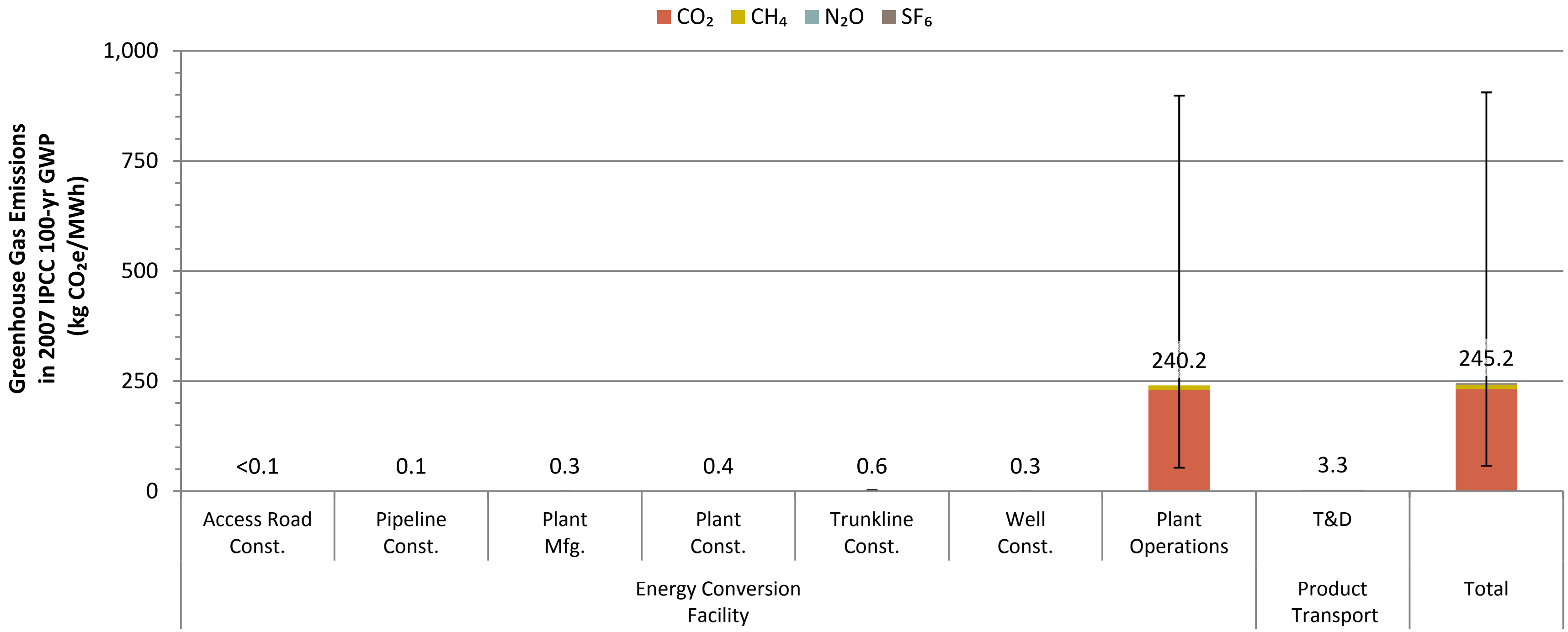
Environmental Analysis of Geothermal

- **Life Cycle Analysis (LCA) completed for geothermal power**
  - Screening level analysis involved select data development for geothermal power construction and operation, plus reliance on similar/proxy data for specific components (i.e., well drilling, balance of plant construction, and trunkline construction and operation)
- **Model broken into life cycle stages**
  - Stage 1 & 2: Raw Material Acquisition and Transport (not relevant to geothermal)
  - Stage 3: Energy Conversion – construction and operation of the geothermal power plant, including geothermal well installation, pipelines to transfer hot water, balance of plant construction, etc. Output is energy ready for transmission
  - Stage 4: Transmission and Distribution – grid transmission and associated loss of 7%
  - Stage 5: Electricity use by consumer – no losses or environmental burdens
- **Model comprised of interconnected network of processes**

Environmental Analysis of Geothermal: LCA Modeling Structure



Environmental Analysis:
GHG Results for Flash Steam Geothermal Power

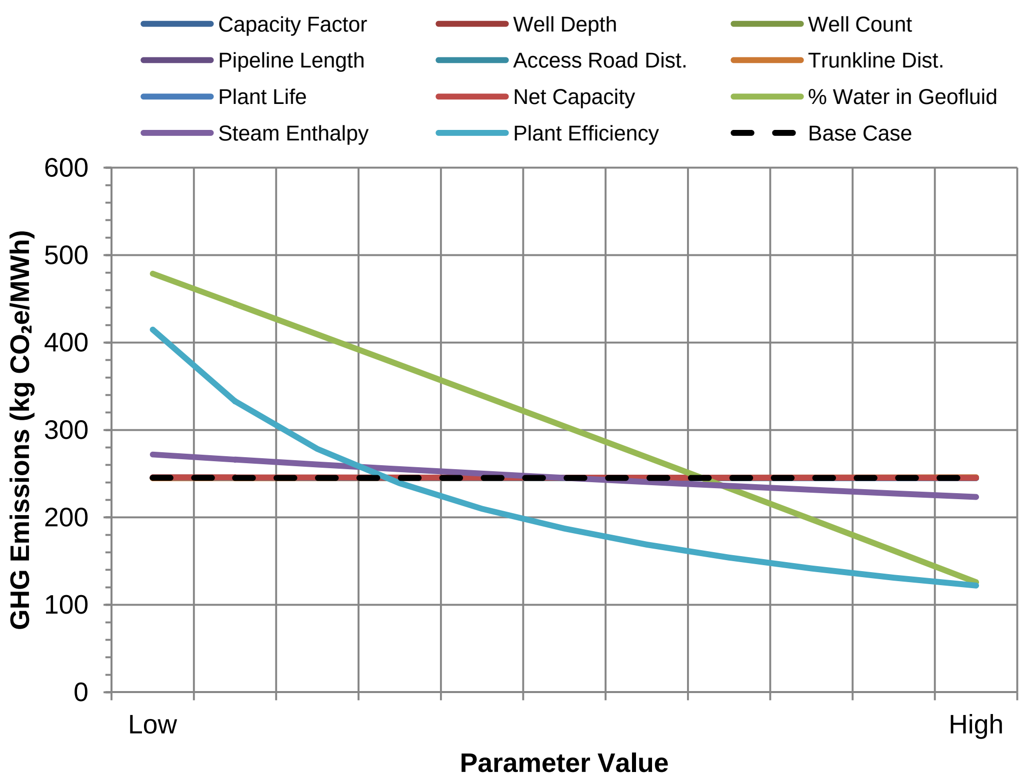


- Values do not include emissions from land use (addressed later in this presentation)
- GHG profile dominated by carbon dioxide (CO_2), released during the operations in the energy conversion facility (LC Stage #3)
- CO_2 is 93.6% of the GHG profile geothermal power

Remainder of GHG profile for geothermal power includes:

- CO_2 from installation of geothermal power plant (including the wells) and supporting infrastructure
- Sulfur hexafluoride (SF_6) released during operation of trunkline and during T&D of electricity

Environmental Analysis: Sensitivity



Parameter	Low Value	Expected Value	High Value	Units
Net Capacity	30	50	50	MW
Capacity Factor	85	90	98	%
Depth per Well	9,540 (2,910)	10,600 (3,230)	11,660 (3,554)	ft (m)
Well Count	15	35	35	count
Pipeline Length	1.50 (2.42)	4.25 (6.84)	7.00 (11.3)	miles (km)
Access Road Distance	0.50 (0.81)	4.75 (7.64)	9.0 (14.5)	miles (km)
Plant Life	20	25	30	years
Trunkline Distance	5 (8.05)	25 (40.2)	50 (80.5)	miles (km)
Steam Enthalpy	2.097	2.330	2.563	MJ/kg
Plant Efficiency	10	17.1	35	%
Volumetric Composition of Water in Geofluid	98	99	99.5	%

- Expected base case result of 245 kg CO_2e/MWh is shown for reference
- Possible range of GHG results for conventional hydropower: 122 to 479 kg CO_2e/MWh depending on the value of parameters

- Most sensitive parameters are volumetric composition of water in geofluid, efficiency of the plant, and enthalpy of the steam
- Other parameters exhibit little sensitivity relative to the base case

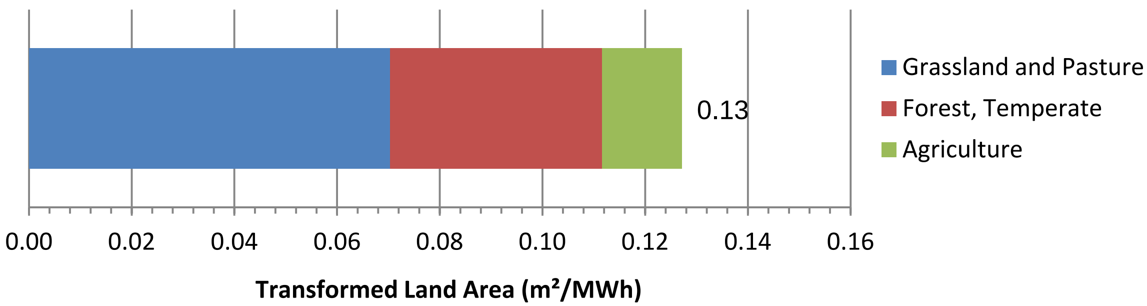
Environmental Analysis: Land Use

- Transformed land area metric was assessed using data available from U.S. Bureau of Land Management
- GHG emissions due to land use change were evaluated based upon the U.S. EPA's method for quantification of GHG emissions, in support of RFS2
- GHG emissions from indirect land use were quantified only for displacement of agriculture, and not for displacement of other land uses
- EPA's GHG emission factors for land use conversion were applied to indirect land transformation values

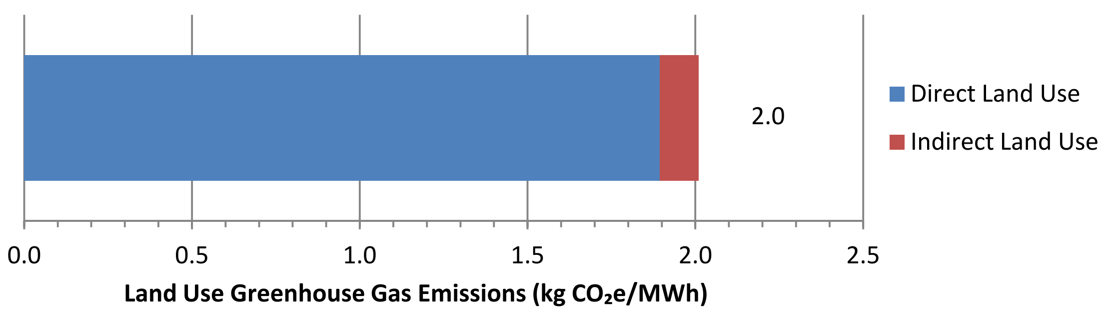
Metric Title	Description	Units	Type of Impact
Transformed Land Area	Area of land that is altered from its original state to a transformed state during construction and operation of the advanced energy conversion facilities and biomass production.	square meters (acres)	Direct and Indirect
Greenhouse Gas Emissions	Emissions of GHGs associated with land clearing/transformation, including emissions from aboveground biomass, belowground biomass, soil organic matter, and lost forest sequestration.	kg CO_2e (lbs CO_2e)	Direct and Indirect

Profile or LC Stage No.	Facility	Location
LC Stage #3: Energy Conversion Facility	Geothermal Wells and Energy Conversion Facility	U.S. West: California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah
LC Stage #4: Product Transport	Geothermal Trunkline	U.S. West: California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah

Environmental Analysis: Land Use Results



- Transmission line installation (64% of total transformed land area), drilling and well field development (13% of total), road improvement and construction (8.6% of total), power plant construction (6.7% of total), and installation of wellfield equipment including pipelines (5.3% of total)
- Total transformed land use for the 50 MW facility was approximately 374 acres



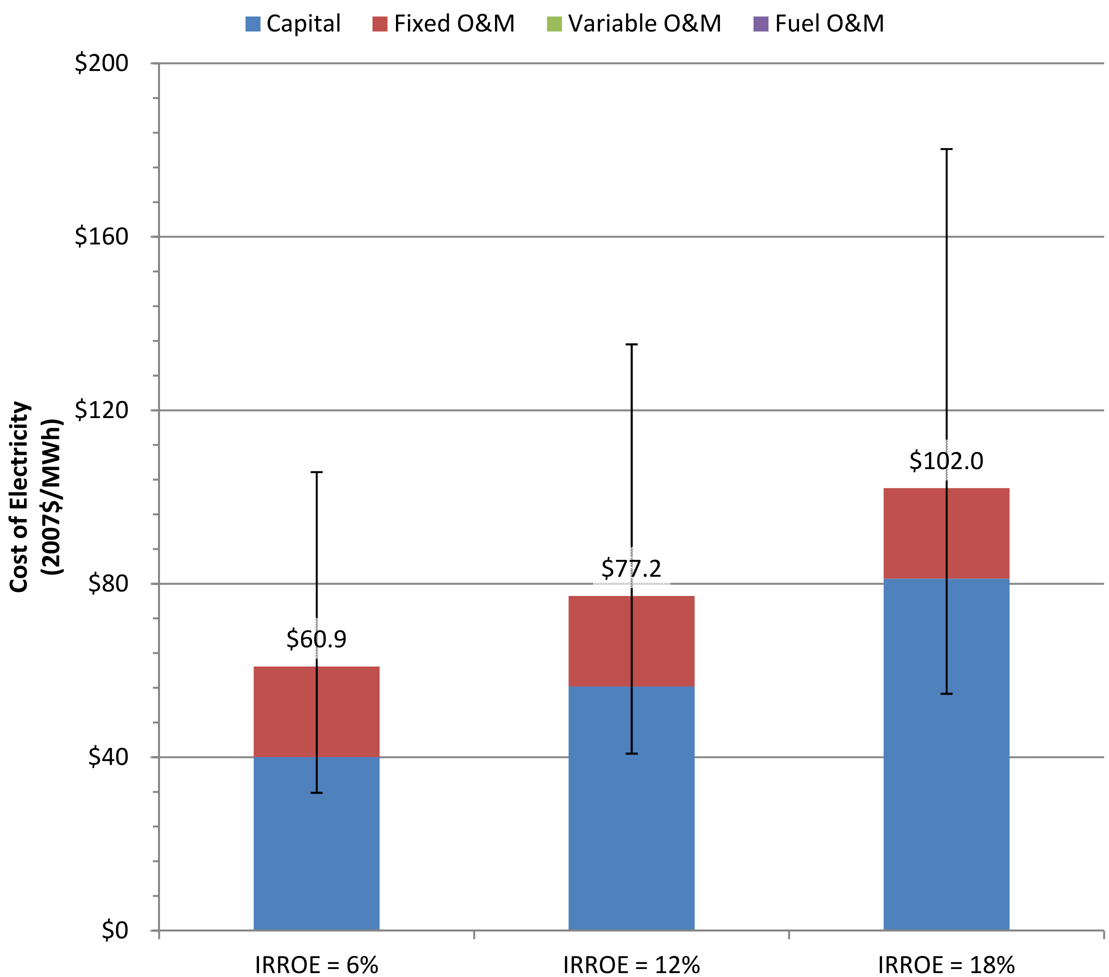
- Indirect land use is comparatively unimportant due to the low proportion of agricultural use within the geothermal facility's disturbance area
- Direct land use GHG emissions result primarily from loss of forestland on site, and to a lesser extent grassland/pasture

Cost Analysis: Financial and Cost Parameters

Financial Parameter	Low Cost Case	Expected Cost Case	High Cost Case
Financial Structure Type	Low-Risk Investor-Owned Utility with Low Return on Equity	Low-Risk Investor-Owned Utility	Low-Risk Investor-Owned Utility with High Return on Equity
Debt Fraction (1 - Equity), %	50%	50%	50%
Interest Rate, %	4.5%	4.5%	4.5%
Debt Term, Years	15	15	15
Plant Lifetime, Years	20	25	30
Depreciation Period (MACRS)	20	20	20
Tax Rate, %	38%	38%	38 %
O&M Escalation Rate, %	3.0%	3.0%	3.0%
Capital Cost Escalation During the Capital Expenditure Period, %	3.6%	3.6%	3.6%
Base Year	2007	2007	2007
Required Internal Rate of Return on Equity	6.0%	12%	18%

Cost Parameter	Units	Low Cost Case	Expected Cost Case	High Cost Case
Capital (Power Plant)	2007$/kW	2,000	3,000	5,000
Capital (Trunkline)	2007$/kW	91.2	456	912
Decommissioning	2007$/kW	209	346	591
Variable O&M (Grid Integration)	2007$/MWh	N/A	N/A	N/A
Fixed O&M (Annual)	2007$/MW-yr.	82,320	164,640	246,960
Plant Life	Years	30	25	20
Net Plant Capacity	MW	50	50	50
Capacity Factor	%	98.0%	90.0%	85.0%

Cost Analysis: Life Cycle Cost Results for Flash Steam Geothermal Power



- Geothermal power does not require the purchase of fuel , so the O&M costs for geothermal power are low in comparison to power technologies that use fossil fuel or other non-renewable energy sources
- Capital costs dominate the COE for geothermal power, comprising 73% of the COE of geothermal power
- The cost characteristics are site specific, which contributes to the uncertainty in COE
- The uncertainty in COE for geothermal power includes ranges in capital costs, plant lifetimes, O&M costs, and capacity factors
- For the 12% IRROE, uncertainty results in a COE range of $40.8 to $135.2/MWh

Barriers to Implementation

- **Resource Availability, State of Technology, and Cost**
  - Easily accessible (near surface) resources are extremely rare
  - Resource availability depends on accessibility of the potential resource, the temperature of the potential resource, and the depth of the potential resource
  - Binary plants can be engineered to utilize relatively low temperature geothermal resources
  - Resources are located in granitic, basaltic, or other hard rock formations that are physically hard to drill
- **Grid Connection**
  - Best resources are in many cases located distant from existing population centers and distant from existing power transmission lines
  - Many high quality geothermal resources in the western U.S. are expected to remain untapped for the foreseeable future, because new transmission facilities are (1) expensive to construct and (2) difficult to permit (Smith & Bruvsen, 2010)

Risks of Implementation

- **Water Degradation**
  - Long term degradation of groundwater quality due to geothermal power production has not been widely documented
  - Short term groundwater degradation may occur during the construction process
- **Seismic Activity**
  - Potential for induced seismicity is the greatest in areas of existing faulting (which is relatively common in areas with geothermal resources), and for installations of EGS (enhanced geothermal systems)
- **Resource Sustainability**
  - As heat is extracted from the resource, if natural replenishment does not meet the rate of extraction, a gradual net decrease in heat value can occur over time. This could potentially result in a partial reduction in power production capacity
  - According to a geothermal trade association, a geothermal project showing a capacity decline after 30 years of operation will restore itself after a century of inactivity (GEA, 2008)

Expert Opinions

- **Geothermal industry is optimistic about the potential of newly discovered geothermal resources**
  - 180 degrees C resource, found in 2010 in West Virginia, at a depth of 3.9 km, that is theoretically capable of supporting nearly 19 GW of new geothermal power capacity (WVU, 2011)
  - Coproduced hot water from petroleum and natural gas wells is a potential geothermal resource in Texas, Louisiana, Mississippi, and North Dakota (TG, 2010)
- **Energy analysts say the future of geothermal power depends on investments in research, development, and demonstration projects**
  - Nearly $450 million has been invested by the American Recovery and Reinvestment Act of 2009 and the U.S. DOE's Geothermal Technologies Program
  - Tax incentives are crucial to the success of geothermal power; investment tax credits for geothermal power are currently in effect through 2016 (DOE, 2011)
- **Scientists estimate that the U.S. has enough are sufficient deep geothermal resources in the U.S. to provide over 517 GW of power production capacity (USGS, 2008).**
  - This projection is based on advanced technology that is still under development.
  - Full scale implementation will not begin to occur for another 15 years (MIT, 2006)

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