GEOTHERMAL ELECTRICITY TECHNOLOGY EVALUATION MODEL

GETEM Development

Project Officer: Jay Nathwani

Total Project Funding: $2,485K

April 22, 2013

Principal Investigator: Greg Mines (INL)

Track : Techno Economical Practices

Relevance/Impact of Research

- Objective: Provide a tool that can be used both by the GTO and the public to estimate the levelized-cost-of electricity (LCOE) from geothermal energy using an approach being standardized within the renewable programs
  - Improve functionality for public & GTO
  - Make less arduous to use & improve accessibility for public
- GETEM addresses those barriers & challenges that limit GTO's ability to quantify the benefits of its research
- Innovation: The model estimates costs and performance for all phases & elements of a project development and uses those estimates to project a LCOE
- It supports the DOE GTP's goals by
  - Identifying drivers for generation costs
  - Helping to prioritize R&D activities
  - Illustrating how R&D benefits cascade thru entire project
- Recent emphasis
  - Addressing industry concerns that GTO's estimates for new geothermal power production are too low
  - Showing the impact of resource variability on LCOE

Scientific/Technical Approach

- GETEM's LCOE estimates are based on 'user' input that define the scenario evaluated. This input is used to determine
  - Power sales or well field size
  - Plant size (geothermal pumping power and sales)
  - Costs for each phase of project
- To address recent concerns and improve the model's estimates
  - Identify both EGS and undiscovered hydrothermal resource scenarios to show the impact of resource variability on LCOE
  - Improve model inputs
    - Solicit industry input
    - Define unique set of inputs for each resource scenario
  - Determine sensitivity of generation costs to specific inputs to determine the relative importance/impact of those inputs
  - Make improvements to methods used in model estimates
    - Exploration and confirmation costs
    - LCOE calculation
    - Well costs

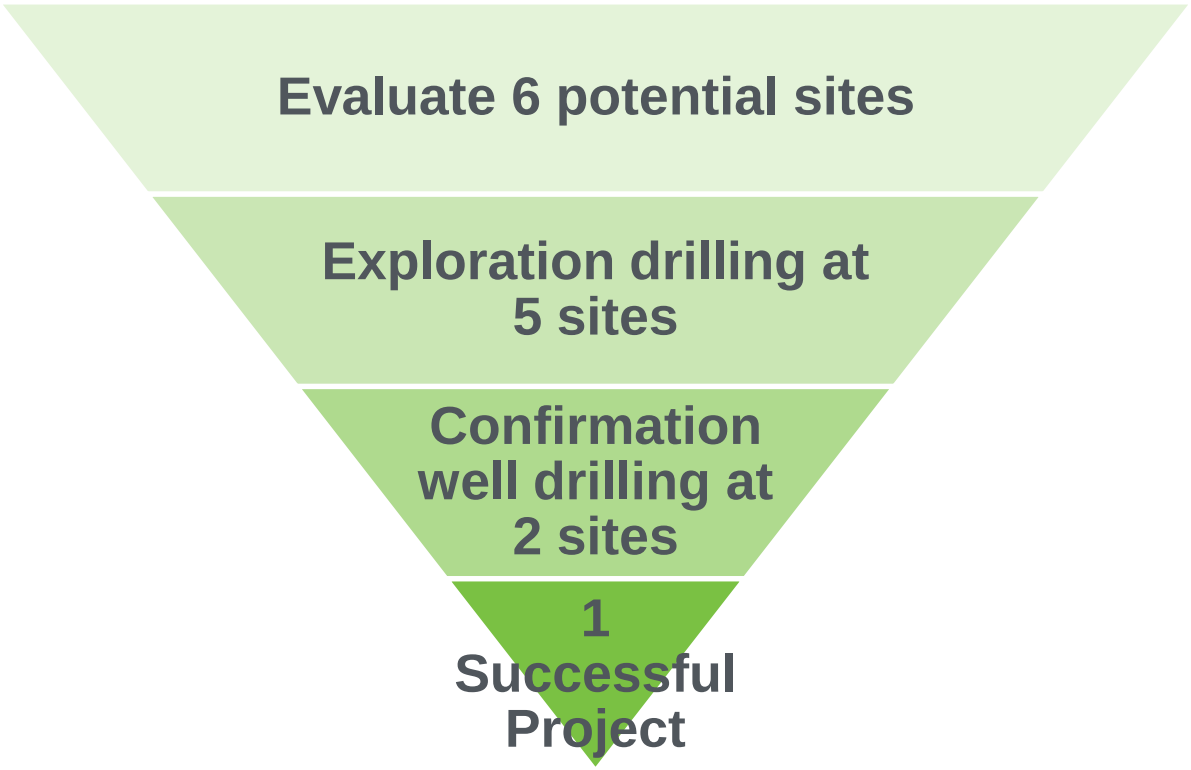
Scientific/Technical Approach (2)

Resource Variability: Identified five EGS and five undiscovered hydrothermal scenarios (selection based on resource potential, geographical diversity and consistency with other GTO activities)

Scenario	Temperature (C)	Depth (km)	Flow (kg/s)	Conversion System	Power Sales (MW)
Hydrothermal A	140	1.5	100	Binary	15
Hydrothermal B	175	1.5	80	Flash	30
Hydrothermal C	175	1.5	100	Binary	30
Hydrothermal D	225	2.5	80	Flash	40
Hydrothermal E	140	2.5	100	Binary	15
EGS A	100	2	40	Binary	10
EGS B	150	2.5	40	Binary	15
EGS C	175	3	40	Binary	20
EGS D	250	3.5	40	Flash	25
EGS E	325	4	40	Flash	30

Scientific/Technical Approach (3)

Incorporated a methodology that accommodates down selection to a final site for commercial development, and includes costs associated with those sites evaluated and drilled but not developed.



Scientific/Technical Approach (4)

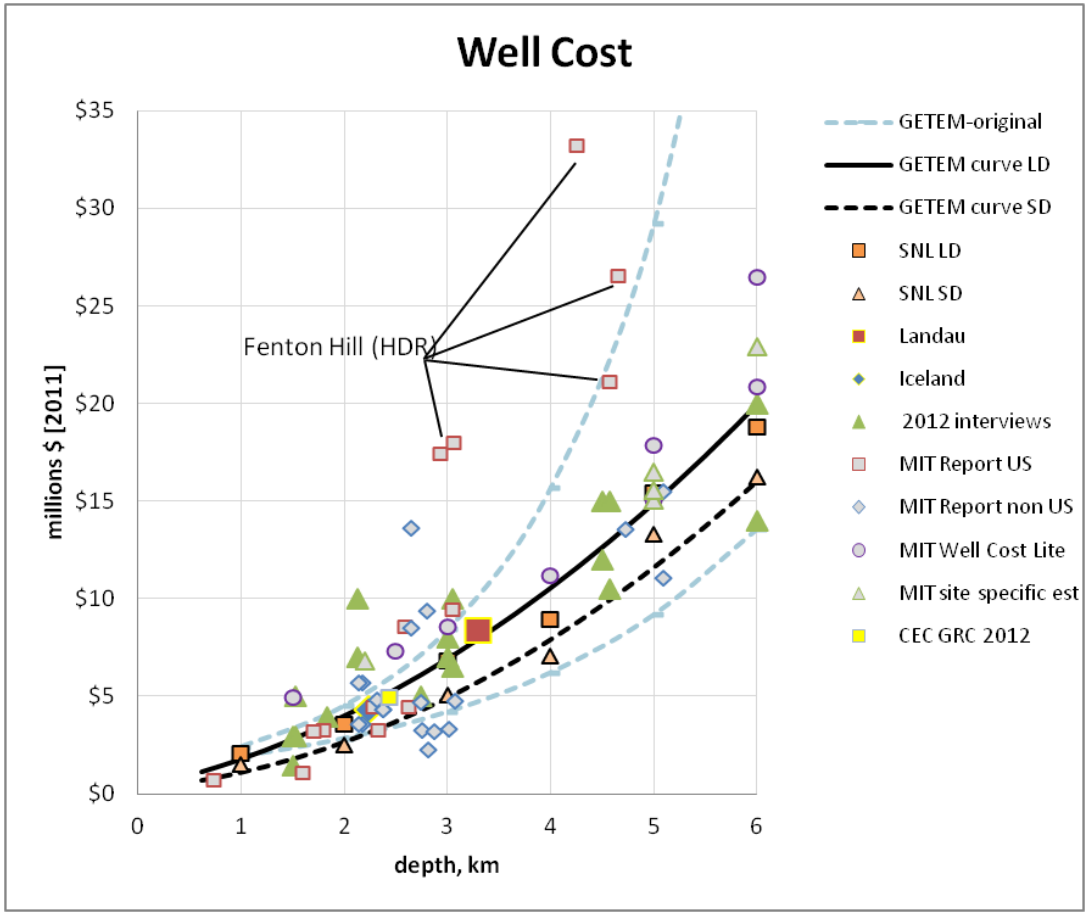
Incorporated an approach to calculate LCOE that is consistent with other renewable programs. It replicates discounted cash flow sheet and allows both duration and discount rate for each project phase to be varied – it is an additional way of incorporating early project risk

Phase	Discount Rate	Hydro Binary	Hydro Flash	EGS Binary	EGS Flash
Permitting – Exploration & Confirmation	30%	1 yr	1 yr	1 yr	1 yr
Exploration	30%	2 yr	2 yr	1 yr	1 yr
Confirmation*	30%	1.5 yr	1.5 yr	1.5 yr	1.5 yr
Utilization Permit – Field & Plant*	15%	1 yr	1 yr	1 yr	1 yr
Well Field Development/Completion**	15%	1.5 yr	1.5 yr	1.5 yr	1.5 yr
Power Plant Construction**	7%	2 yr	1.5 yr	2 yr	1.5 yr
Total Pre-Operational Activities		6.5 yr	6 yr	5.5 yr	5 yr
Operations	7%	30 yr	30 yr	20 yr	20 yr

* & ** – concurrent activities

Scientific/Technical Approach (5)

- Issue: Identifying representative well costs given the considerable variation in drilling costs with depth
- Updated the well drilling cost curves using estimates from Sandia National Lab – estimates made for either larger diameter well (LD) or smaller diameter well (SD)

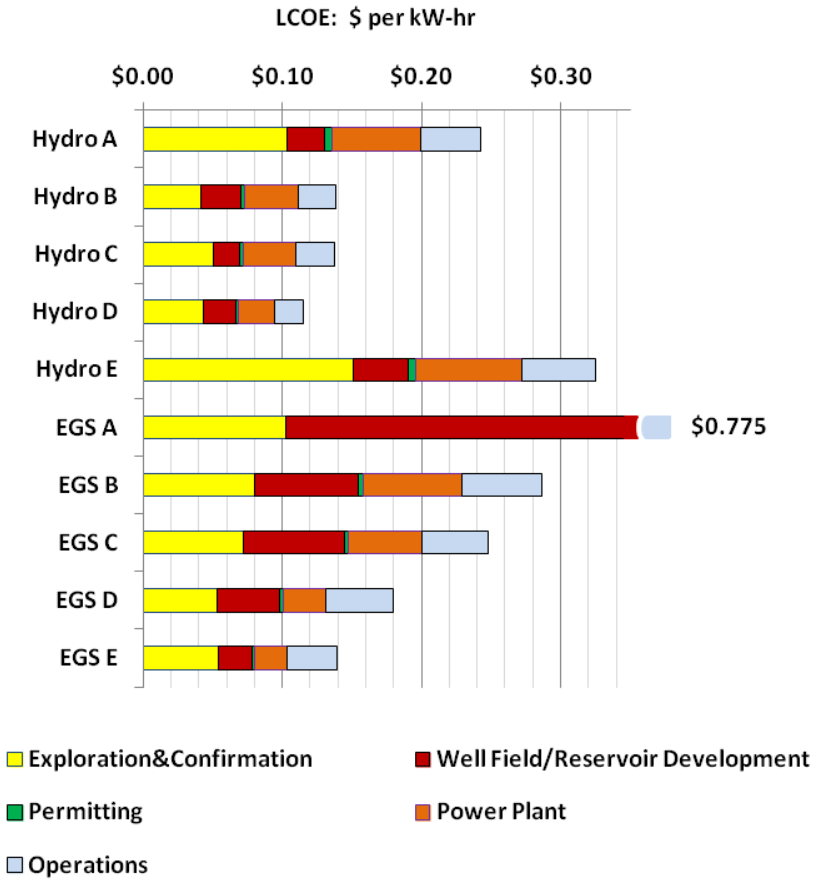


Accomplishments:

- The GTO identified scenarios that show the impact of the variability in the resource conditions on the LCOE
- Revised exploration/confirmation characterization to include down-select to final site used for commercial development
- Examined the impact of uncertainty in model inputs on cost and performances estimates for each scenario
- Updated model's well cost estimates (using information from Sandia National Laboratory)
- Incorporated an alternative methodology for estimating the LCOE
  - Consistent with other renewable programs
  - Replicates discounted cash flow analysis
  - Allows both time required and discount rate to be varied for each phase of the project development – assigns additional cost to early activities where risk is greatest

Accomplishments, Results and Progress (2)

Estimated Current LCOE at nth project (no learning curve effect)



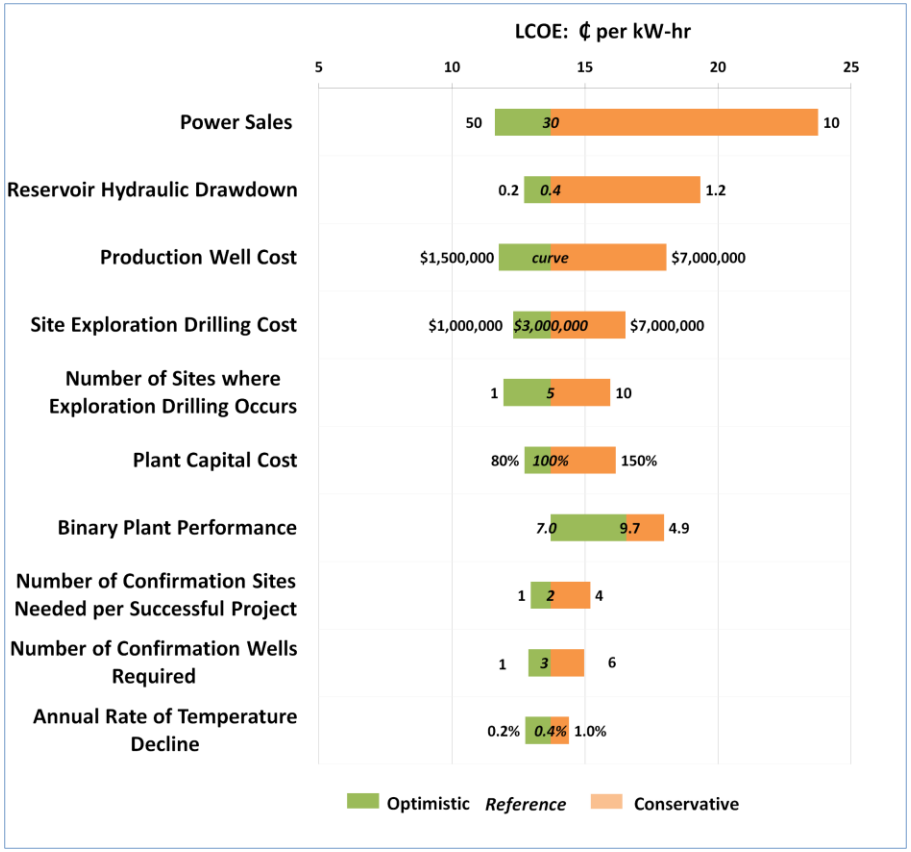
	Temperature (C)	depth (km)	Well flow rate (kg/s)	Sales	Plant Size	Exploration sites - # with drilling in ( )	Confirmation sites	# production wells	Well Cost ($M) – Injection well $$ in ( )	Stimulation Cost ($M)	Total Cost ($M)
Hydro A	140	1.5	100	15	18.4	6 (5)	2	4.7	$3.2	$0.0	$159
Hydro B	175	1.5	80	30	32.0	6 (5)	2	9.2	$3.2	$0.0	$213
Hydro C	175	1.5	100	30	34.2	6 (5)	2	6.1	$3.2	$0.0	$189
Hydro D	225	2.5	80	40	41.2	6 (5)	2	6.1	$6.1	$0.0	$240
Hydro E	140	2.5	100	15	18.6	6 (5)	2	4.2	$6.1	$0.0	$217
EGS A	100	2.0	40	10	13.5	3 (2)	1.5	21.5	$4.5	$2.5	$347
EGS B	150	2.5	40	15	15.7	3 (2)	1.5	7.6	$6.1	$2.5	$192
EGS C	175	3.0	40	20	20.4	3 (2)	1.5	7.9	$7.8	$2.5	$223
EGS D	250	3.5	40	25	26.0	3 (2)	1.5	6.4	$7.2 ($9.7)	$2.5	$181
EGS E	325	4.0	40	30	30.7	3 (2)	1.5	4.2	$8.9 ($11.9)	$2.5	$158

GTO Identified Scenarios

Results

Sensitivity of LCOE to Input

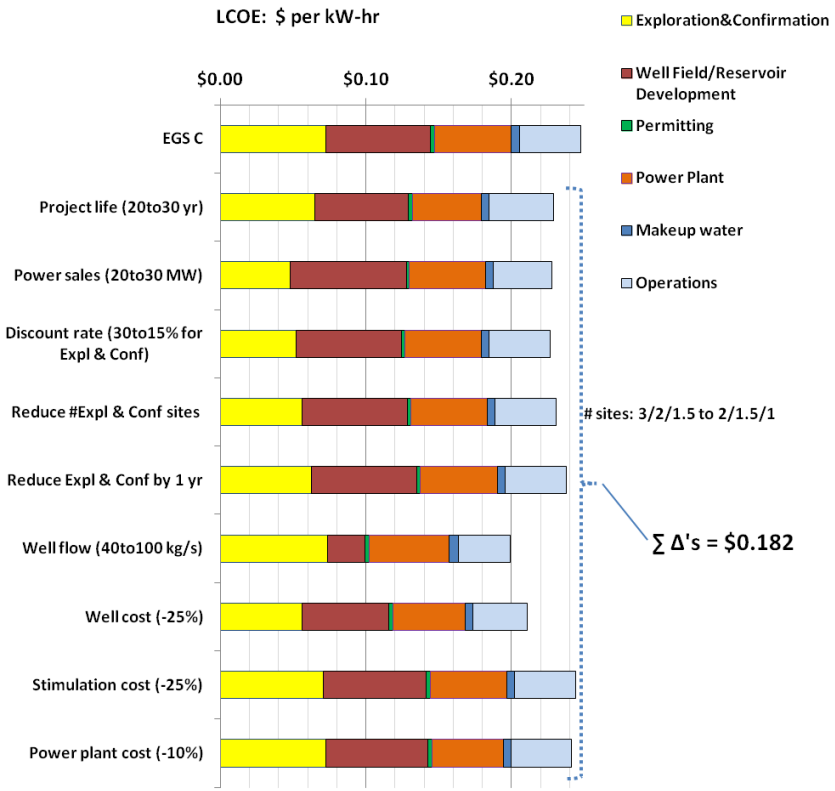
Hydrothermal C



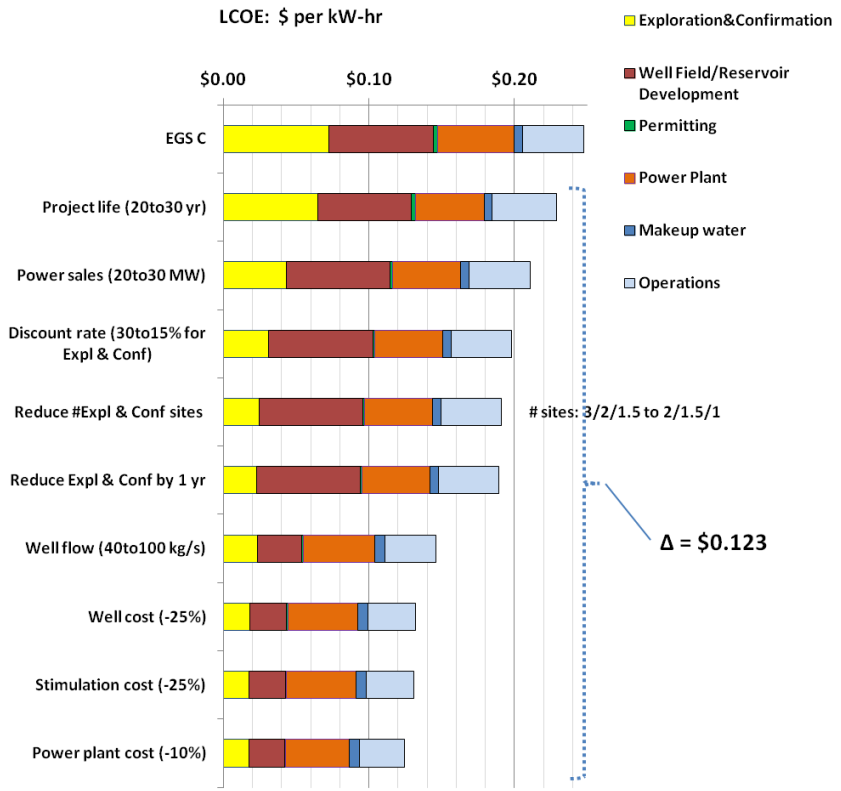
EGS C

'What If' - Effect Improvements on EGS C

Individual

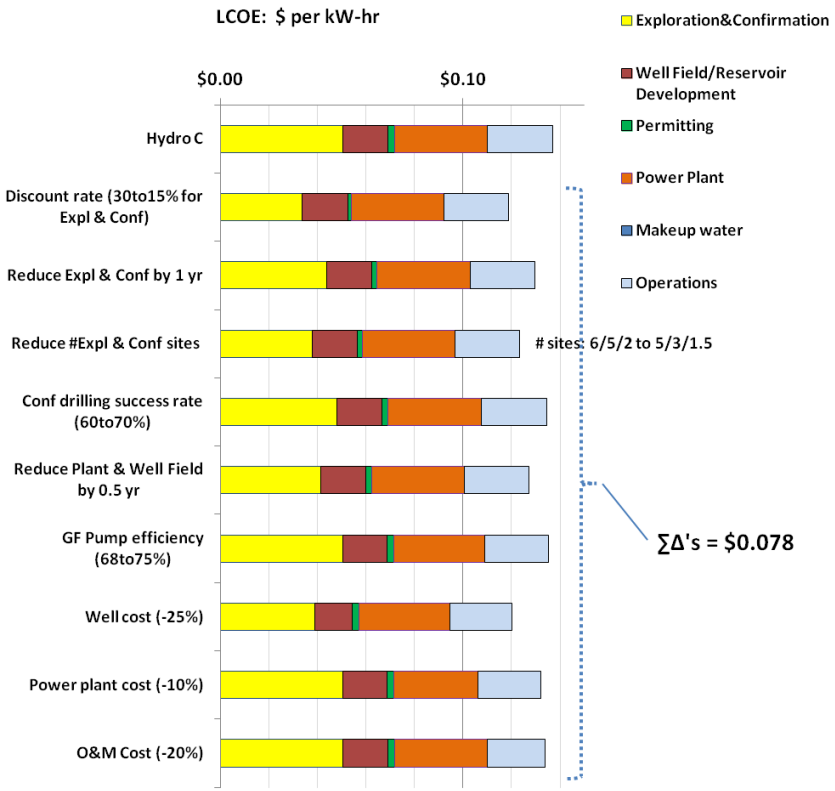


Cumulative



Effect Improvements on Hydrothermal C

Individual



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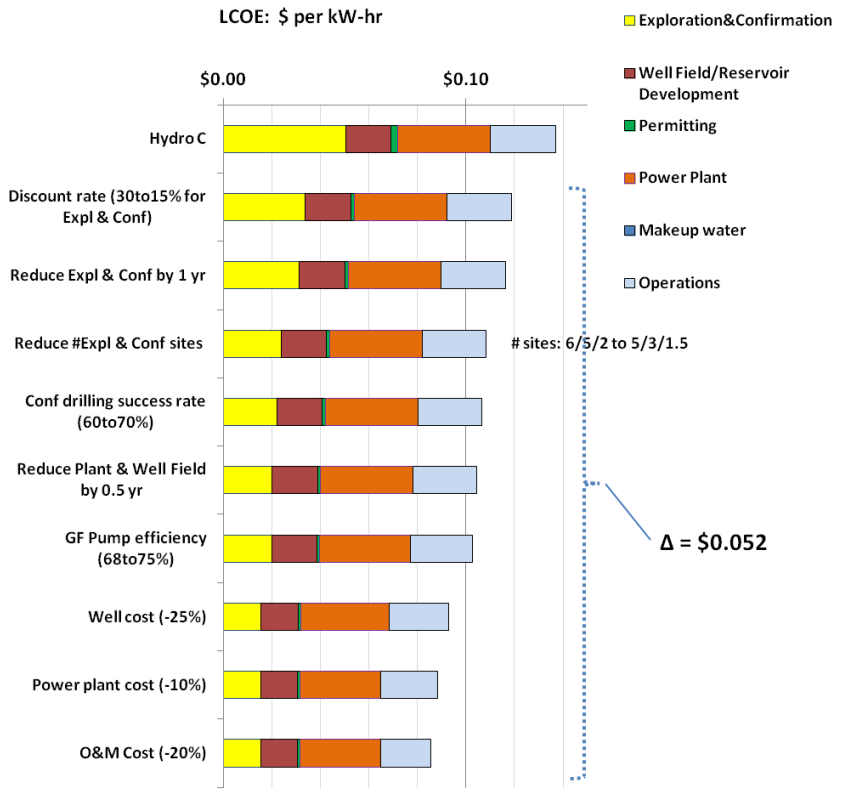

Accomplishments, Results and Progress (6)

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Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Complete definition of hydrothermal and EGS scenario inputs – December 2012	Complete definition of hydrothermal and EGS scenario inputs	March 2013
Integrate SNL well cost model into GETEM – January 2013	SNL cost estimates made the basis for the GETEM cost curves – January 2013 ; SNL methodology has been incorporated into a more detailed cost model (Feb 2013) but it has not integrated into GETEM	
Complete modifications to the model to allow for drilling individual make-up wells, water-cooled binary plants, … September 2013		
Identify new platform for GETE model – March 2013	Expect to complete in May 2013	
Move model to new platform – FY2014		

Future Directions

FY2013-FY2014

- The detailed well cost model has been revised – integrate into GETEM if it meets GTO needs
- Modifications to model
  - Provide for drilling single make-up wells to offset productivity decline
  - Extend project life beyond current maximum of 40 yr and allow for building new plants on an existing reservoir
  - Other conversion systems (water-cooled binary, hybrid flash-binary)
  - Improve model's estimates for water usage and cost (ANL)
  - Address limitations: high geothermal temperatures (>~300ºC); fixed 10ºC design temperature for air-cooled binary plants; binary plant size
- Make decision as to which elements of the model to retain or remove
- Migrate model to new platform
  - Select new platform for model
  - Initiate move
  - Develop prototype of web based application for DOE
  - Examine potential to make model more robust

Summary Slide

Several updates & improvements have been made to GETEM

- Demonstrate the variability of resource conditions on power costs
  - Scenarios and their specific inputs have been defined for 5 Hydrothermal and 5 EGS resources.
  - Provide reference points from which the GTO can evaluate technology improvements
- Exploration & Confirmation – depicted as a down-select process with costs included for unsuccessful/not selected sites
- Well costs have been updated/improved
- Model methodology for calculating LCOE has been updated/improved
  - Consistent with other renewable programs
  - Allows the GTO to show impact of project duration and finance risk on LCOE

Efforts are planned to address GETEM's limitations & to make it amenable to use by public

Project Management

- INL has monthly internal reviews of cost, schedule and status – variances must be explained/justified
- Project behind schedule as result of extended effort to complete definition of scenarios
- Leverage other work
  - INL binary plant cost and performance work from 2002-2005
  - SNL well cost estimates from 2012
- Interface with industry
  - Resource scenario inputs based on conversations with industry
  - Model available on GTO web site
  - Model workshop at GRC
  - Presentations: Stanford Workshop (2013)

Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Actual /Est. End Date
7/1/2009	9/30/2014	7/1/2009	9/30/2014

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
$2,485,000	$0	$1,640,000	$1,554,000	$1,492,500	$931,000