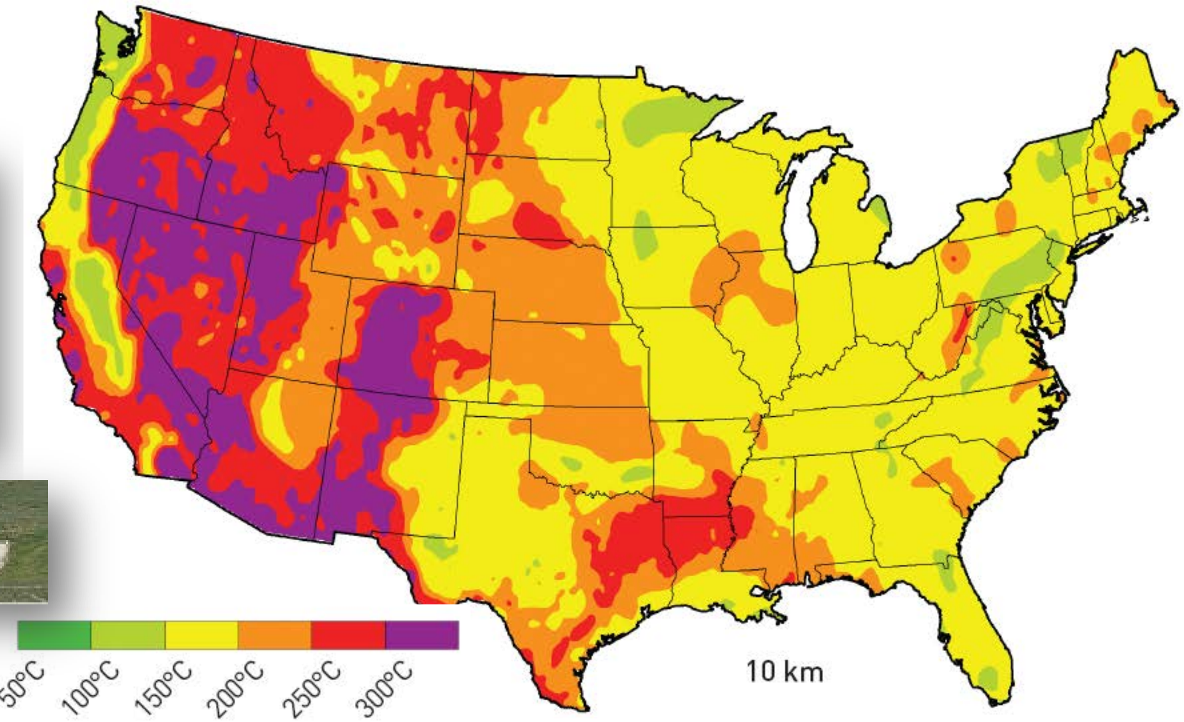
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



WestVirginiaUniversity Department of Chemical Engineering | NREL | IOWA STATE UNIVERSITY | Cornell University

Analysis of Low-Temperature Utilization of Geothermal Resources

Project Officer: Jay Nathwani
Total Project Funding: $1,206,330
April 22, 2013

Brian J. Anderson, PI
West Virginia University

Analysis: Techno Economical Practices
Track 3 – 11:15 a.m.

Relevance/Impact of Research

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Project Objectives

1. Techno-economic analysis of the potential of low-temperature (90-150°C) geothermal sources.
   – Innovative uses of low-enthalpy geothermal water will be designed and examined for their ability to offset fossil fuels and decrease CO_2 emissions.
2. Perform process optimizations and economic analyses of processes that can utilize low-temperature geothermal fluids.
   – These processes will include electricity generation using biomass, electricity and heat co-generation using biomass and district heating systems.
3. Develop a regionalized model of the utilization of low-temperature geothermal resources.
   – Implement into GIS-based regional and national-level models to assess market penetration potential.

Relevance/Impact of Research (2)

Overall objective of this project

- This project aims to provide a comprehensive assessment of the full potential of low-temperature geothermal energy utilization
- This project illustrates the vast potential for low-temperature geothermal energy deployment and determine the most cost-effective methods to produce low-*T* geothermal
- All potential utilization methods are being evaluated
  - Binary electricity production, direct use, hybrid biomass/geothermal systems
- One major product will be a supply curve for low-*T* geothermal
- Data created from this project will be integrated into the National Geothermal Data System (NGDS)
- Additionally, new data will be used from the State Geological Survey Contributions to NGDS Data Development, Collection and Maintenance - Project Number EE0002850

Scientific/Technical Approach

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- Scientific/technical approach
  - In-depth analysis of the low-temperature geothermal resources that dominate the eastern half of the United States.
    - “Low-grade” geothermal resources requires examination of more uses than traditional electricity generation
    - We are designing, assessing, and evaluating innovative uses for geothermal-produced water such as:
      - Utilization of geothermal in district heating for community redevelopment projects,
      - Hybrid biomass-geothermal cogeneration of electricity and district heating
      - Efficiency improvements to the pretreatment of carbon-based fuels, such as coal and/or biomass drying.
  - 4 Case Studies
    - A retrofit and expansion to a district heating system in a community redevelopment project at West Virginia University
    - A hybrid biomass-geothermal co-firing cogeneration and district heating system at Cornell University
    - A system for cellulosic biomass gasification and utilization at Iowa State University
    - A geothermal system (direct-use or cogen) within the West Virginia ‘hotspot’

Scientific/Technical Approach (2)

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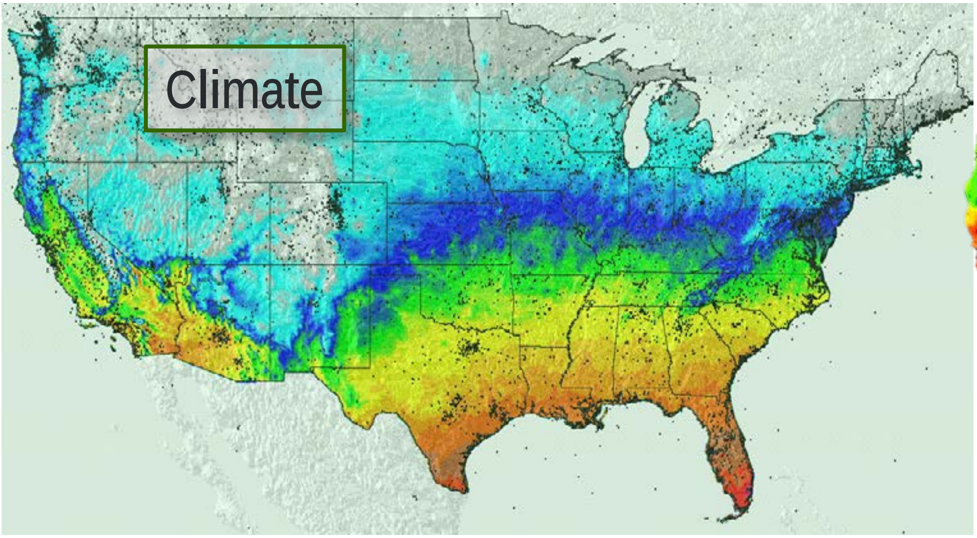
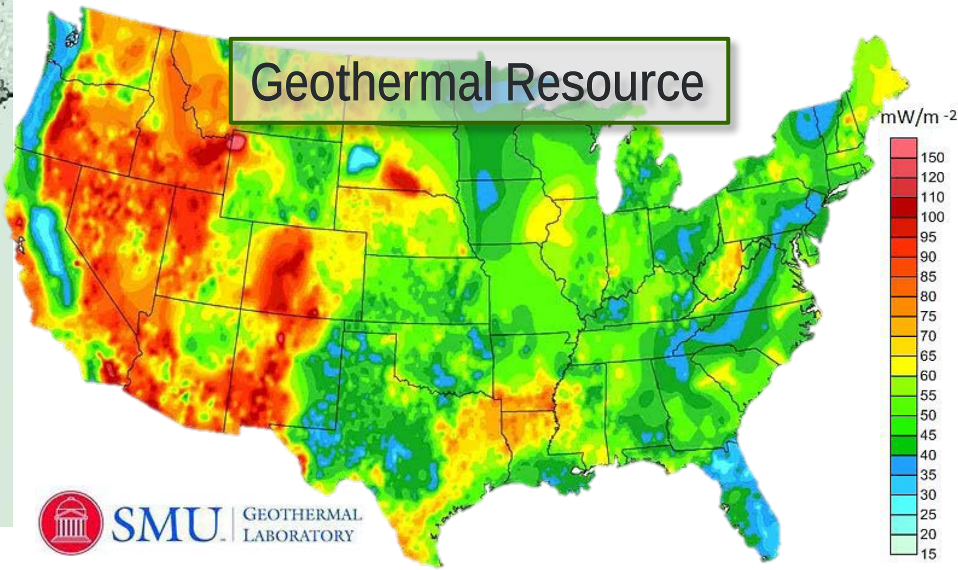
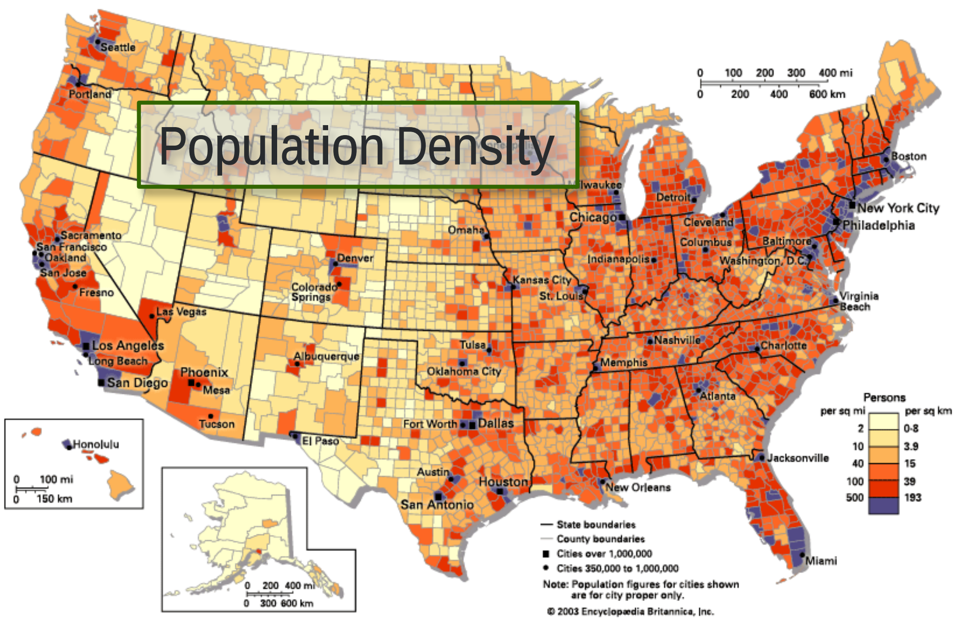
- Scientific/technical approach (cont.)
  - 4 case studies are being analyzed for the impacts of geothermal energy use in the form of:
    - Fossil fuel and CO_2 offsets
    - Generalized for non-specific sites
  - Case studies expanded and incorporated into GIS-based regional and national-level models to assess market penetration potential
- Project design
  - Detailed process modeling using Aspen Plus for surface plant evaluation
    - Integration into existing plant models for gasification
    - Hybrid biomass-geothermal and Organic Binary Rankine cycle configurations will be evaluated and sub- and supercritical conditions
  - Subsurface modeling using TOUGH2 and WVU's wellbore simulator
  - Economic modeling using GETEM and GEOPHIRES model
  - Geographic deployment models using ArcGIS
    - Coupled to resource assessment maps containing *T* at depth

Scientific/Technical Approach (3)

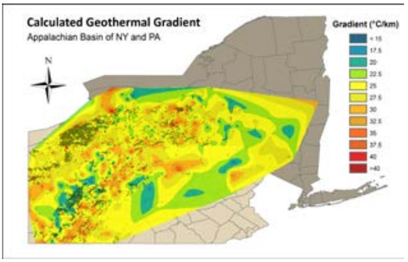






- National Supply Curve
  - Cost of supplied thermal energy is a function of:
    - Climate (degree days heating/cooling are utilized)
    - Geothermal Resource (drilling cost to temperature at depth)
    - Population density (demand profiles, piping costs)

Scientific/Technical Approach (4)



Resource Assessment

Geologic Data
- Well data (BHT/depth)
- Lithology and stratigraphy
- Thermal conductivity

Excel/VBA

Resource Estimates
- Geothermal gradient
- Surface heat flow
- Temperature at depth
- Depth to temperature

Interpolation in ArcGIS

Maps

Gradient maps

Place location (GeoID)

ArcGIS

GIS Data:
- Surface temp
- Roads data

Gradient at location

Surface temp at location

Roads at location

GEOPHIRES v1.0

Plant Calculations
- Drilling depth
- Nominal power
- Capacity factor

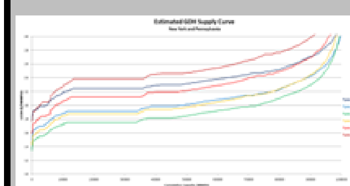
Cost Calculations
- Drilling/completion cost
- Well pumping cost

- Update drilling depth to reach desired production temperature
- Update capacity factor of EGS plant based on nominal power and demand profile

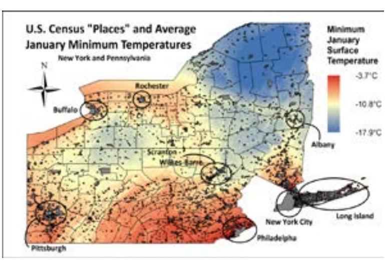
Primary Output:
LCOH ($/MMBTU)

Repeat for:
- Each location
- Varying inputs

Final Output:
SUPPLY CURVE(S)



- Surface Costs
- Demand Estimates
- User-Defined Inputs



Demand Assessment

"Place" Data
- Population / area
- Housing units / types
- Commercial buildings
- GeoID

Demand Estimates
- Temperature curve
- Daily demand
- Yearly demand total
- Peak demand

MATLAB

Census Averages
- Square footage
- Space heat intensity
- Hot water demand

Estimated piping length

MATLAB

Required flow rate

User-Defined Inputs
- Production Temperature
- Radiator operating temps
- Well mass flow rate
- Lifetime of plant
- Fixed annual charge rate

Surface Cost Assessment

Calculations
- Reinjection temp
- Pipe diameter
- Heat exchanger size
- Pumping energy

Cost Data
- Piping costs
- Pump costs
- Heat exchanger costs
- Electricity price
- Maintenance costs

MATLAB

Surface Costs
- Total surface capital cost
- Yearly O&M cost

Accomplishments, Results and Progress

Task	FY11 Q1	FY11 Q2	FY11 Q3	FY11 Q4	FY12 Q1	FY12 Q2	FY12 Q3	FY12 Q4	FY13 Q1	FY13 Q2	FY13 Q3	FY13 Q4	FY14 Q1
1. Analysis of integration/utilization potential of low-T geothermal sources													
1.1 Evaluation of integration potential of geothermal and biomass energy	Task	Task	Task										
1.2 Develop models of EGS geothermal reservoirs for conditions near case-study sites	Task	Task	Task										
1.3 Analysis and estimation of EGS costs at base case sites, and drilling costs in particular	Task	Task	Task										
1.4 Characterize heat demand profiles and process model for direct-use	Task	Task											
1.5 Facilitation of EGS costs into base case models		Task	Task	Task									
1.6 Analyze direct heating cases with steady-state parametric studies			Task	Task									
1.7 Develop an Aspen model for geothermal electric power generation			Task	Task									
1.8 Selection of most promising integration strategies			Selection point	Go/No-go decision									
2. Process optimization and economic analysis													
2.1 Collect and improve accuracy of analytical input parameters				Task	Task	Task							
2.2 Perform reservoir simulations of sites at varying depths, temperatures, and flowrates				Task	Task	Task							
2.3 Characterize biomass feedstock types					Task	Task							
2.4 Analyze organic binary Rankine cycles configuration performance					Task	Task							
2.5 Low-temperature EGS resource characterization					Task	Task	Task	Task					
2.6 Development of GIS-based national-level model to incorporate low-T EGS resources									Task	Task	Task		
2.7 Develop preliminary conceptual design of hybrid co-gen systems							Task	Task					
2.8 Analyze biomass-geothermal hybridization cases at steady-state							Task	Task					
2.9 Detailed optimization of selected integration strategy						Task	Task	Go/No-go decision					
3. Regionalization/generalization and scale-up of results													
3.1 Generalization of EGS costs by region								Task	Task	Task			
3.2 Development of supply curves									Task	Task	Task	Task	
3.3 Identify regional opportunities for large-scale supply and utilization										Task	Task	Selection point	
3.4 Develop optimization strategies for direct heating, electric, and hybrid co-gen								Task	Task				
3.5 Preliminary economic evaluations of promising heating, electric, and hybrid co-gen								Task	Task				
3.6 Perform techno-economic analysis for specific scale-up opportunity									Task	Task	Task		
3.7 Modeling of market penetration of low-temperature EGS in national models										Task	Task	Task	Task
3.8 Determine fuel savings and CO_2 reductions achieved for each configuration									Task	Task			

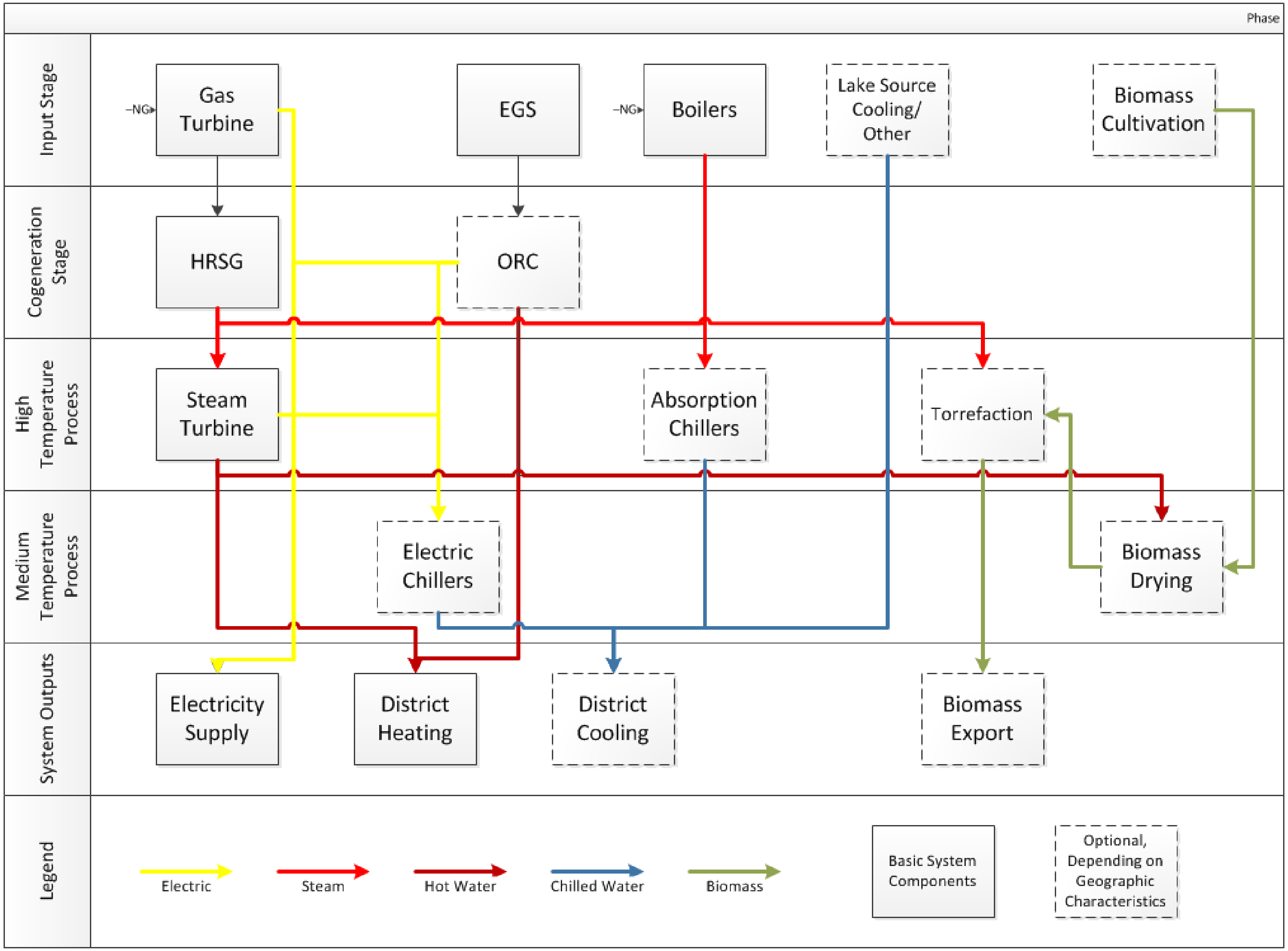
Task
Selection point
Go/No-go decision

Current Status (between FY13 Q2 and FY13 Q3)

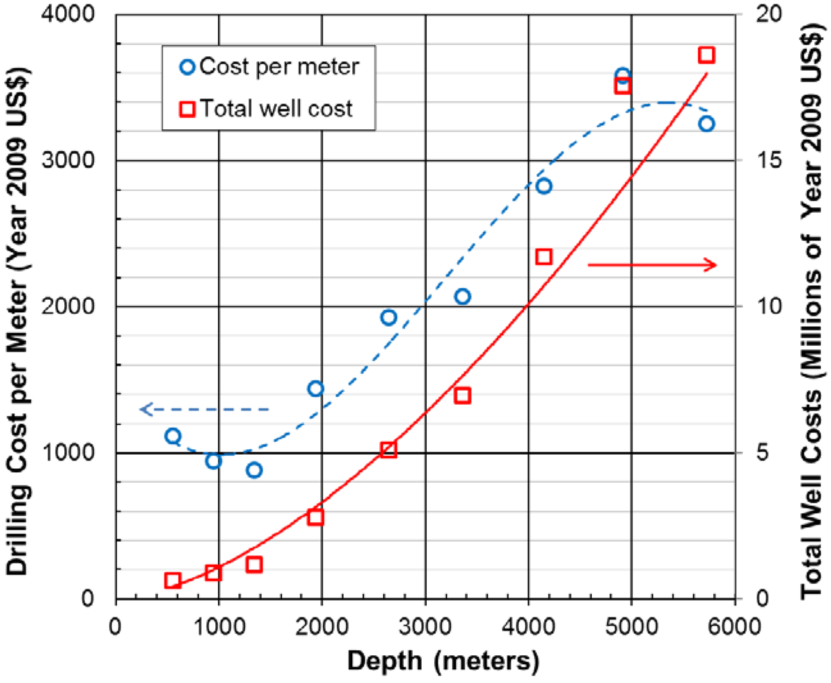
Hybrid System Design

Component	Advantages	Disadvantages
Natural Gas Turbines	Cheap, proven, dependable	Fossil fuel, on/off function only
EGS	Low emissions, baseline load	Investment uncertainties
Peaking Boilers	Fully adjustable load	
Absorption Chillers	Heating to Cooling conversion	Cooling tower requirements
Electric Chillers/Heaters	Peak & Dip management between energy outputs	Added Control Complexity
ORC/RC	Clean electricity conversion	Dependent on EGS temperature
District Energy Networks	Heating/Cooling delivery	Capital and operation costs
Biomass Processing	Clean fuel production	Large land requirements
District Energy Storage	Peak shaving, output balancing	Capital costs
Biomass Export	Provides fuel for areas DH network cannot reach	Consumer side fuel handling

Hybrid System Design

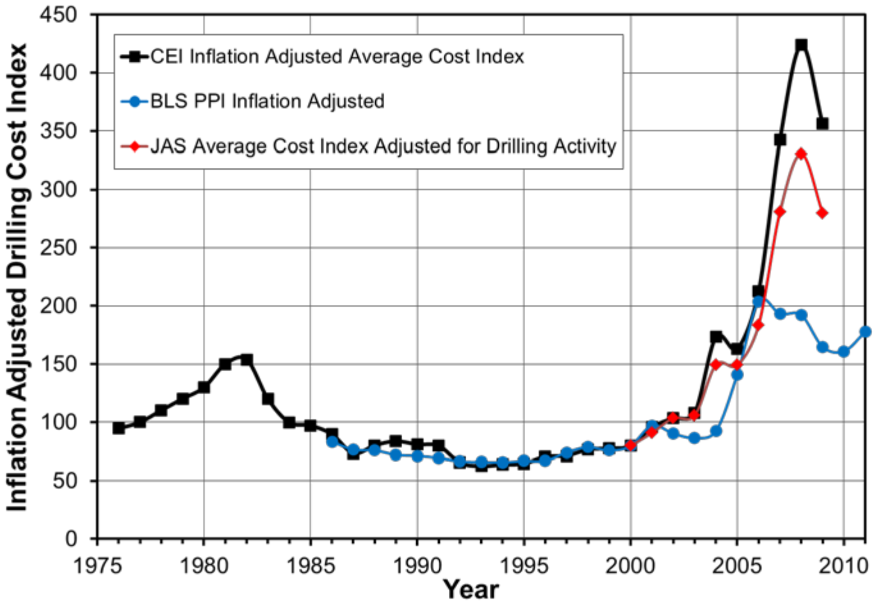


Drilling Cost Analyses



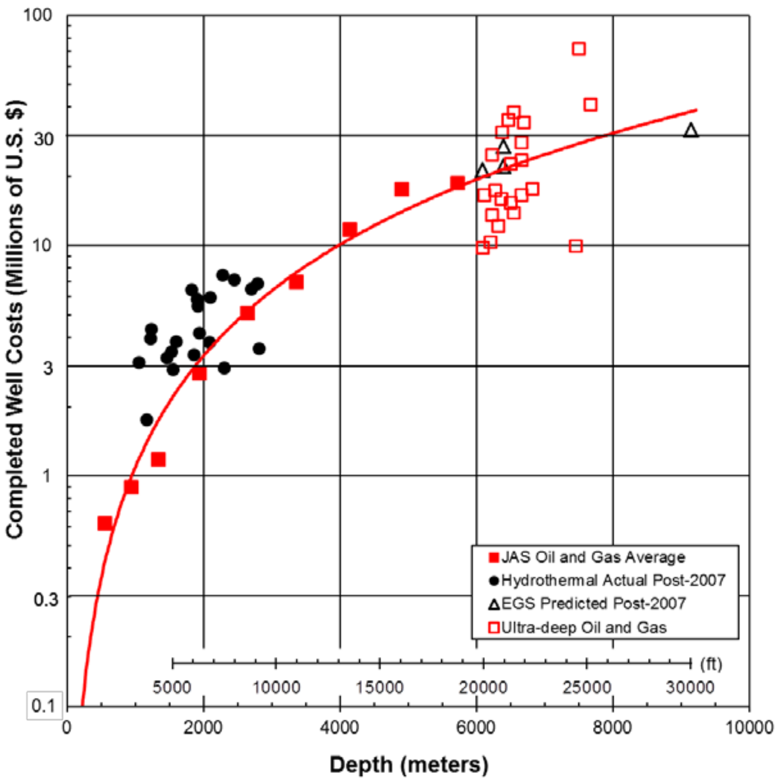
Drilling costs of U.S. onshore oil and gas wells in 2009

Comparison of CEI Average drilling cost index before adjusting it for changes in drilling activity with two other indices: Bureau of Labor Statistics Producer Price Index for Oil, Gas, Dry and Service Wells (BLS PPI), and JAS Activity Adjusted Index



2010 JAS Data was released Dec, 2012 – 58% decrease in onshore drilling costs

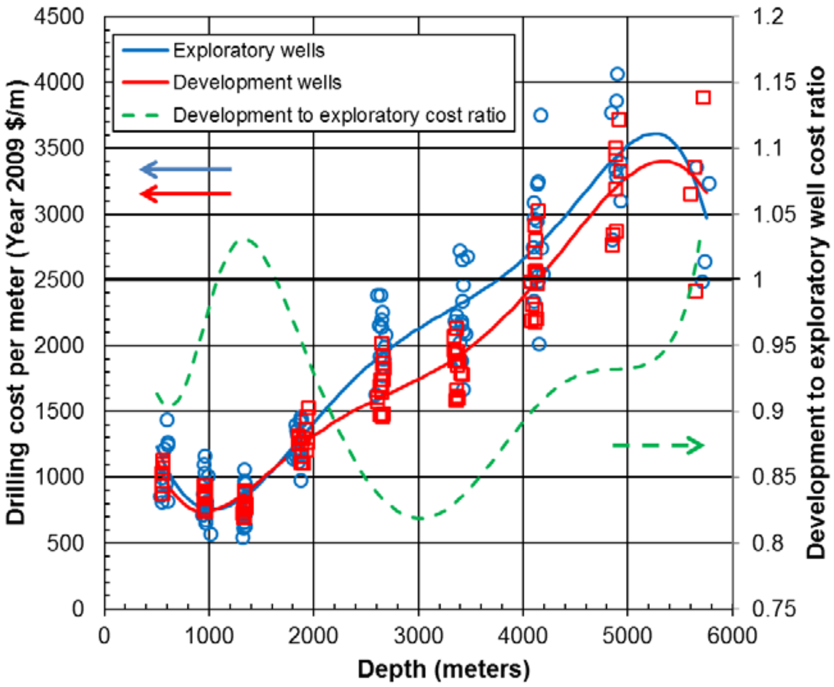
Drilling Cost Analyses



1. JAS is Joint Association Survey on Drilling Costs (2009).
2. Actual costs of hydrothermal wells were not normalized to yr. 2009 and are presented in nominal U.S.$ (2008-2012).
3. Costs of EGS wells are predicted using WellCost Lite or obtained from Thermasource Inc. EGS well costs are presentes in nominal U.S.$ (2008-2012).

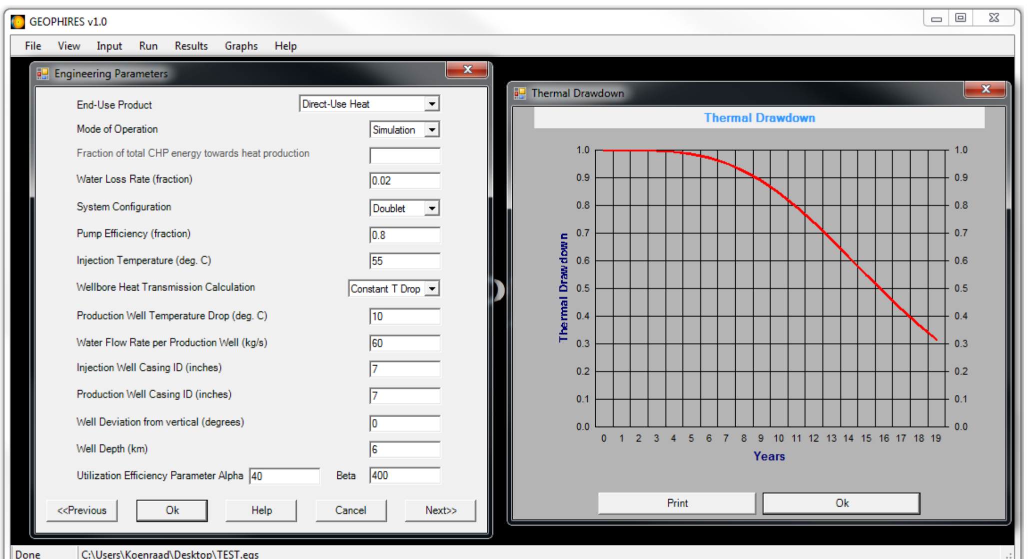
Geothermal well drilling costs compared to oil and gas well completion costs

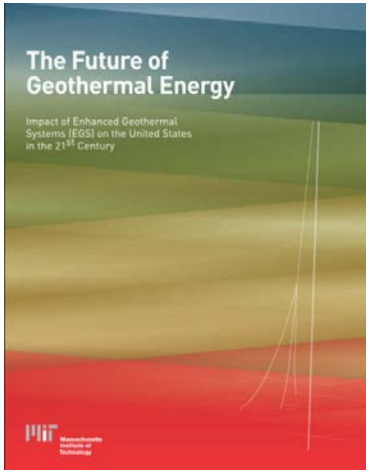
Average drilling costs per meter of exploratory and development wells. Correlation is based on 1989-2009 JAS data. Costs of onshore oil and gas wells were normalized to 2009 using the CEI drilling cost index



GEOPHIRES

- "**GEO**thermal energy for the **P**roduction of **H**eat and **E**lectricity **E**conomically **S**imulated"
- Estimate LCOE and/or LCOH of EGS





LANL (1970's) → HDR Model (1982) → MIT-HDR Model (1990) → EGS Modeling for Windows (2000) → MIT-EGS Model (2006) → GEOPHIRES (2013)

Beckers et al., "Introducing GEOPHIRES v1.0 : Software Package for Estimating LCOE/LCOH from Enhanced Geothermal Systems", Proceedings, 38th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA, Feb 11-13, 2013

Integration potential of low-T (180ºC) geothermal resources for use in a biorefinery

- Aspen Plus; technoeconomic analysis
- Feedstock: corn stover, $75/ton; 2,000 tonne/day plan
- Baseline fuel cost: $5.14/GGE

Cost of Geothermal Heat	**Fuel cost ($/GGE): geotherm for process steam**	**Fuel cost ($/GGE): geotherm for process steam and electricity generation via ORC**
$0/MMBTU	$5.02	$4.83
$10/MMBTU	$5.36	$5.18
$12/MMBTU	$5.42	$5.24
$15/MMBTU	$5.51	$5.34
$20/MMBTU	$5.66	$5.50

- Geothermal resources can be used in the present biorefinery with comparable cost effects.
- GHG emissions to generate purchased steam are eliminated.

- Case study (WVU) – AspenPlus models of the heating distribution system and absorption chilling system constructed and analyzed.

He, X., Anderson, B.J., "Low-Temperature Geothermal Resources for District Heating: An Energy-Economic Model of West Virginia University Case Study," SGW, 2012, SGP-TR-194

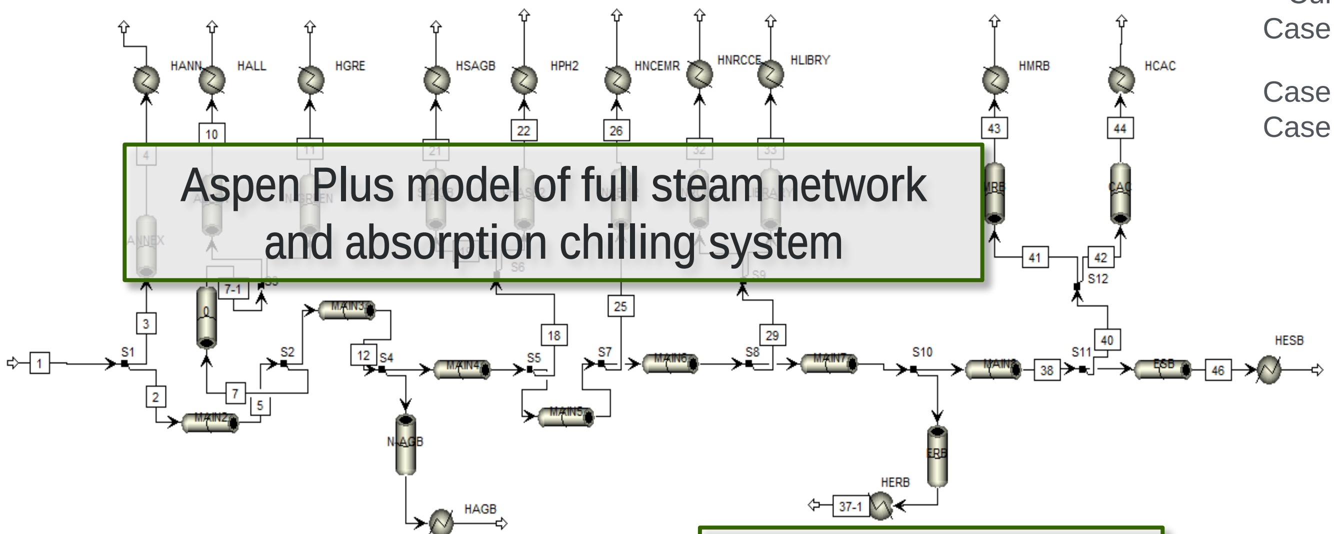
Case	Heating (MW_{th})	Cooling (MW_{th})	Levelized Energy Cost ($/$MMBtu_{th}$)
1	16.24	9.93	11.70~12.72
2	16.24	9.93	8.46~9.50
3	16.08	9.93	5.30~6.37

* Current steam costs are ~$12/MMBtu

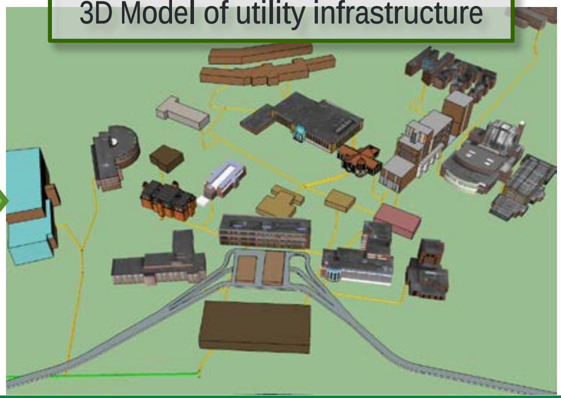
Case 1: Full costs, complete retrofit, no tax breaks

Case 2: Public entity bond rates, tax incentives

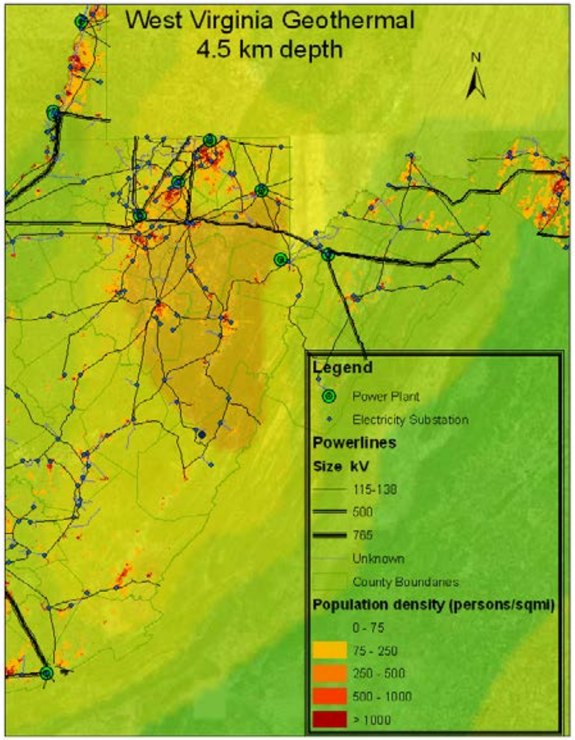
Case 3: Lower retrofit costs, using hot water not steam



Aspen Plus model of full steam network and absorption chilling system

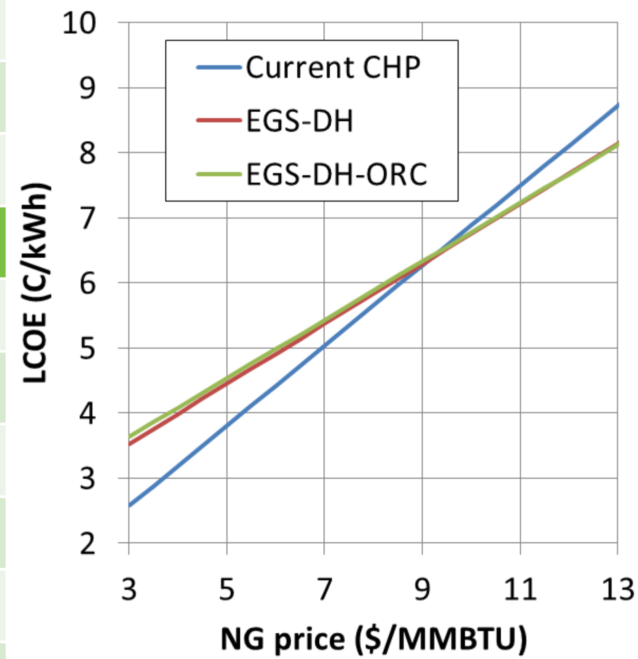


3D Model of utility infrastructure



Accomplishments, Results and Progress

Scenario	Current System	DH	DH-ORC
Share of district heat supplied by			
Natural gas	100%	75%	75%
EGS	0%	24%	24.9%
Biomass	0%	1%	0.1%
Performance metrics			
LCOE, □/kWh$_e$	3.5	4.22	4.31
Capital investment, M$	-	22	34
Produced electricity, GWh$_e$	221	192	200.3
Purchased electricity, GWh$_e$	29	58	49.7
Net annual CO_2 emissions, t/yr	175,000	152,000	149,500
Reduction in CO_2 emissions	-	13.2%	14.7%
Heat losses from the whole DH network	18%	15.7%	16%



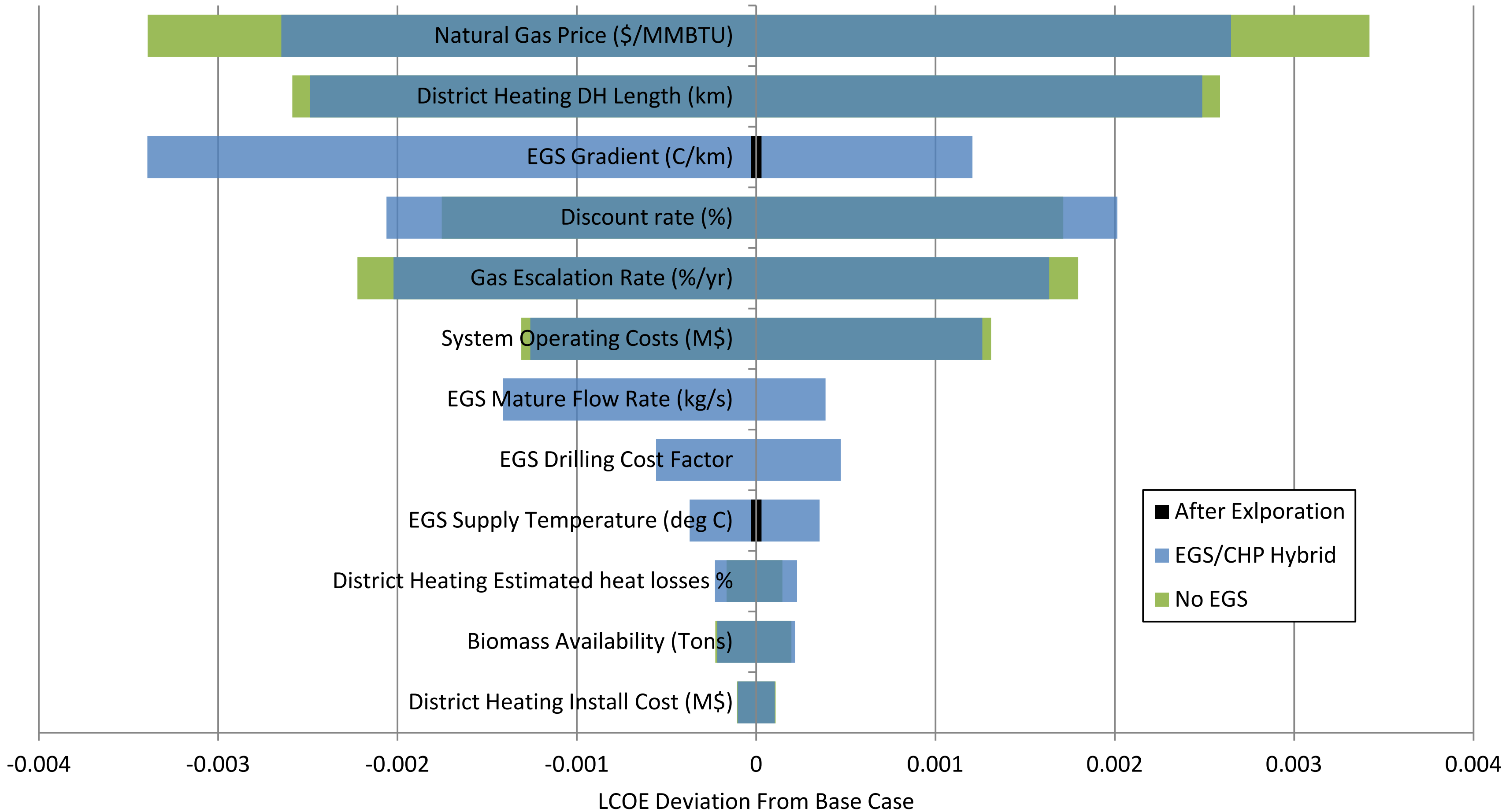
National Case-Study Results:

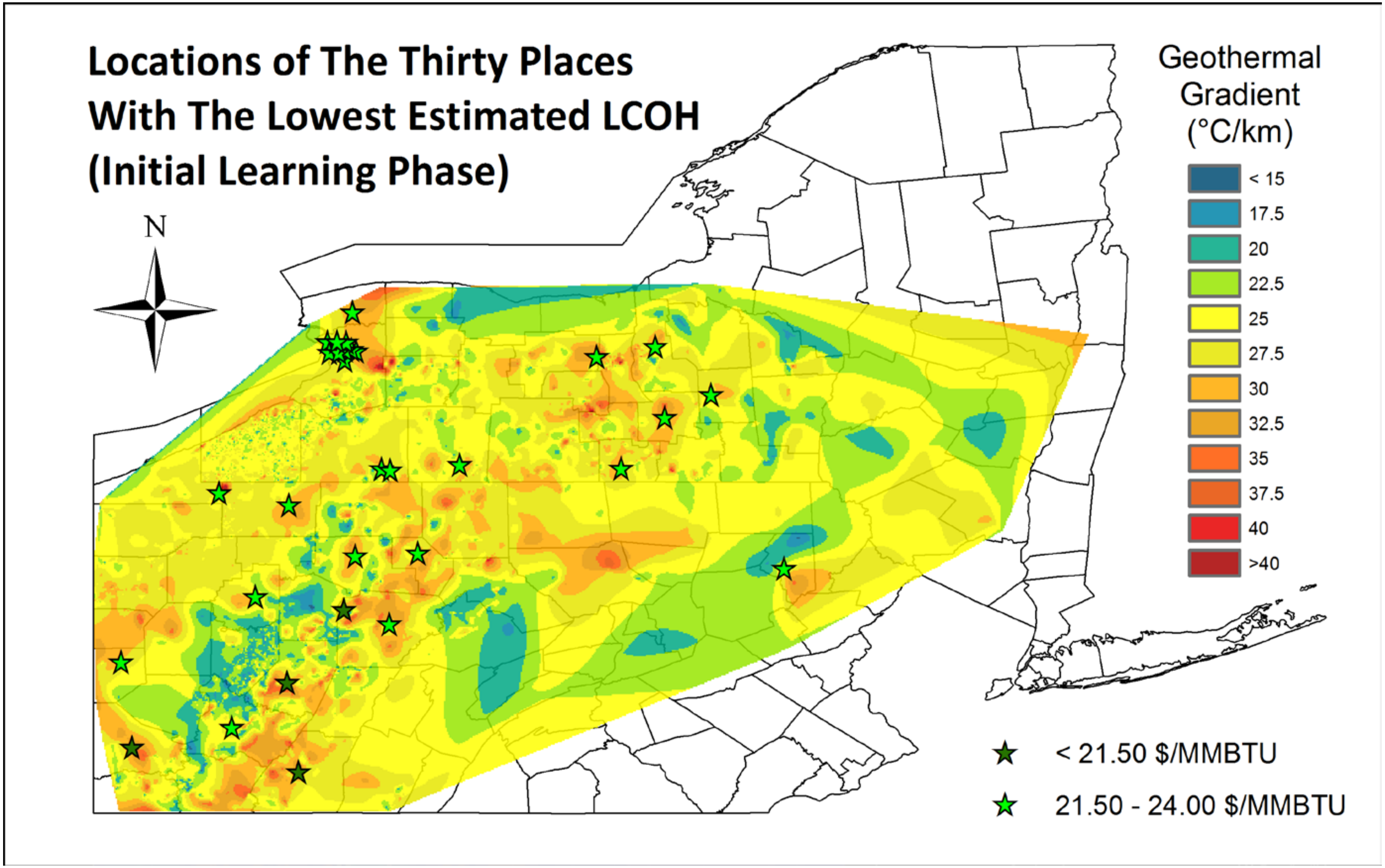
Location	*HDD*	*CDD*	*LCOE $/kWh*	*EGS share %*	*Fuel eff. %*	*CO_2 g per kWh*	*Notes*
Spokane, WA	6842	398	0.041	33%	128%	172	50°C gradient, new 60°C DH
Santa Rosa, CA	3016	145	0.048	38%	133%	198	50°C gradient, new 60°C DH
San Antonio, TX	1644	2996	0.043	29%	137%	181	50°C gradient, high building density

Notes:

- When tri-generation is applied, climate plays small role
- Including EGS can be cheaper when building a new system

Results: Before and After hybrid geothermal system




Locations of The Thirty Places
With The Lowest Estimated LCOH
(Initial Learning Phase)
N
Geothermal Gradient (°C/km)
< 15
17.5
20
22.5
25
27.5
30
32.5
35
37.5
40
>40
< 21.50 $/MMBTU
21.50 - 24.00 $/MMBTU

Future Directions

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- In the rest of FY13, finalize a regionalization/generalization and scale-up of results and complete the following milestones:
  - Development of GIS-based national-level model to incorporate low-T geothermal resources,
  - Development of supply curves, and
- In Q1 FY14, we will finalize the modeling of market penetration of low-temperature geothermal systems in our national GIS-based model.

Milestone or Go/No-Go	Status & Expected Completion Date
2.6 GIS-based national-level model to incorporate low-T resources	66% completed – 7/1/13 complete
3.2 Development of supply curves	50% completed – 9/1/13 complete
3.3 Identify regional opportunities for large-scale supply and utilization	25% completed – 9/1/13 complete
3.7 Modeling of market penetration of low-temperature EGS in national models	25% completed – 12/31/13 complete

Summary

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- Economic modeling suggests that direct-use geothermal at 110-150°C can be economically-competitive to natural gas
  - Electricity generation from low-*T* resources is not currently competitive

- Project Focus: techno-economic analysis of the potential of low-temperature (90-150°C) geothermal sources.
  - Innovative uses of low-enthalpy geothermal fluid designed and examined for ability to offset fossil fuels and decrease CO_2 emissions.

- A regionalized model of the use of low-*T* geothermal has been developed
  - Will be implemented into a GIS-based, low-temperature geothermal resource supply model used to develop a series of national supply curves.

Project Management

Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
01/01/10	12/31/12	04/01/10	12/31/13

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
$1,206,330	$306,906	$1,520,783	$845,215	$1,210,589*	$361,115

* Value of work completed based on 80% of tasks completed and total value of project

- Integrated project management
  - Leveraged multiple teaching assistantships and other funding sources
  - Integrated with Project Number EE0002850: State Geological Survey Contributions to NGDS Data Development, Collection and Maintenance
  - Regularly-scheduled webinars with rotating presentation schedule
    - » Yearly (at least) in-person meetings
    - » Working subgroups meet (virtually) more frequently
- No-cost extension to 12/31/13
  - All students started in August 2010
  - Developing own GIS-based model