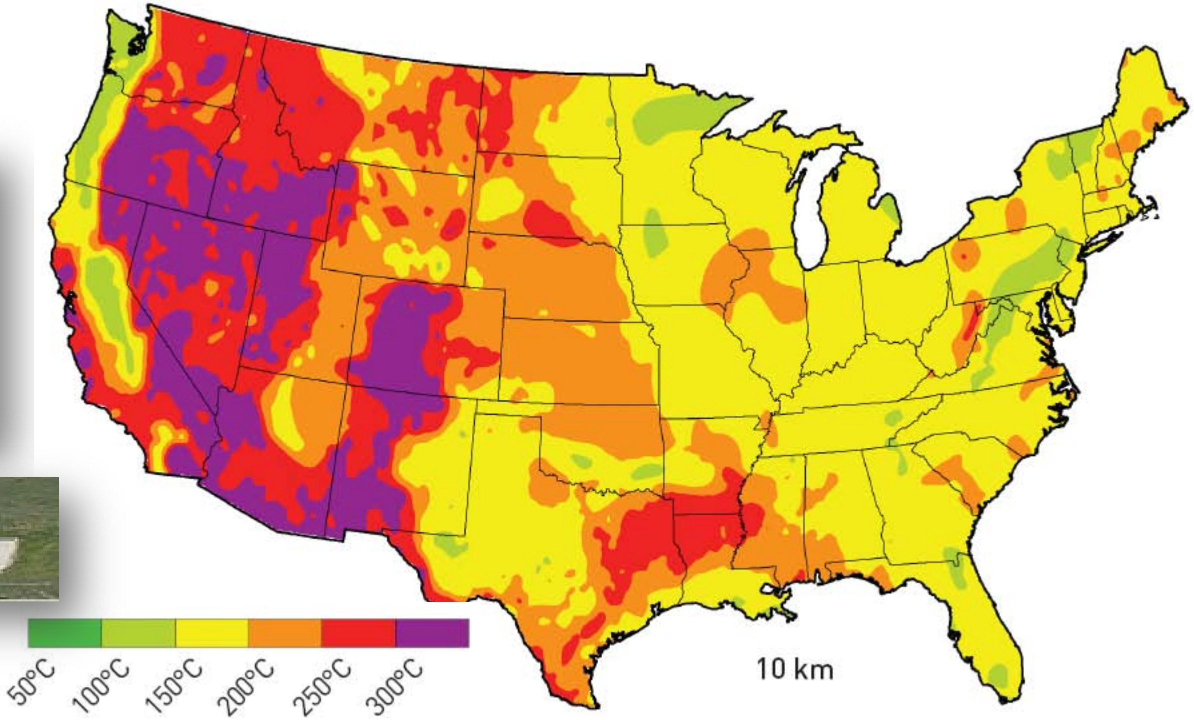

West Virginia University Department of Chemical Engineering | NREL | Iowa State University | Cornell University

Analysis of Low-Temperature Utilization of Geothermal Resources

May 19, 2010

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West Virginia University

Analysis, Data System and Education

Project Overview

- Timeline
  - Start Date: 01/29/10 (Conditional Award until 3/31/10)
  - End Date: 12/31/12
  - Percent Complete: 3%
- Budget
  - Total: $1,520,783
  - DOE Share: $1,206,330, Awardee Cost Share: $314,453
  - FY 10 Funding:
    - Planned expenditures: $214,543 DOE, $65,739 Cost Share
- Barriers
  - Analysis Models and Tools (*Y*)
  - Crosscutting Analysis: Technical and Economic Feasibility (*S,V,W,X*) and Resource and Infrastructure Analysis (*A,V*)
- Partners: West Virginia University, Cornell University, Iowa State University, NREL

Relevance/Impact of Research

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 existing energy assessment models such as SEDS, ReEDS, and NEMS to assess market penetration potential.

Scientific/Technical Approach

- 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 will require examination of more uses than traditional electricity generation
    - We will be 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.
  - 3 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

Scientific/Technical Approach

- Scientific/technical approach (cont.)
  - 3 case studies will be analyzed for the impacts of geothermal energy use in the form of:
    - Fossil fuel and CO_2 offsets
    - Generalized for non-specific sites
    - Integrated into regional energy analysis models such as SEDS, ReEDS, and NEMS
- 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 MIT EGS model
  - Geographic deployment models using ArcGIS
    - Coupled to resource assessment maps containing T at depth

Scientific/Technical Approach

- Year 1 (1/29/10 – 12/31/10) Tasks
  - Task 1.1 Evaluation of integration potential of geothermal and biomass energy
    - Analysis of the integration potential of low-temperature geothermal sources for biomass processing, conversion, and utilization.
  - Task 1.2 Develop models of geothermal reservoirs for conditions near case-study sites
    - Develop models of geothermal reservoirs near case-study sites to provide *T* and m for $\dot{m}$ ange of depths and geothermal gradients.
  - Task 1.3 Analysis and estimation of geothermal system costs at base case sites, drilling costs in particular
    - Drilling costs will be estimated based on the lithology, well depth, and casing program by consulting drilling companies. GETEM will be modified to estimate drilling and stimulation costs only.
  - Task 1.4 Characterize heat demand profiles and process model for direct-use
    - Characterize heat demand profile for district heating networks and develop an Aspen model for direct geothermal heat utilization of geothermal fluids

Scientific/Technical Approach

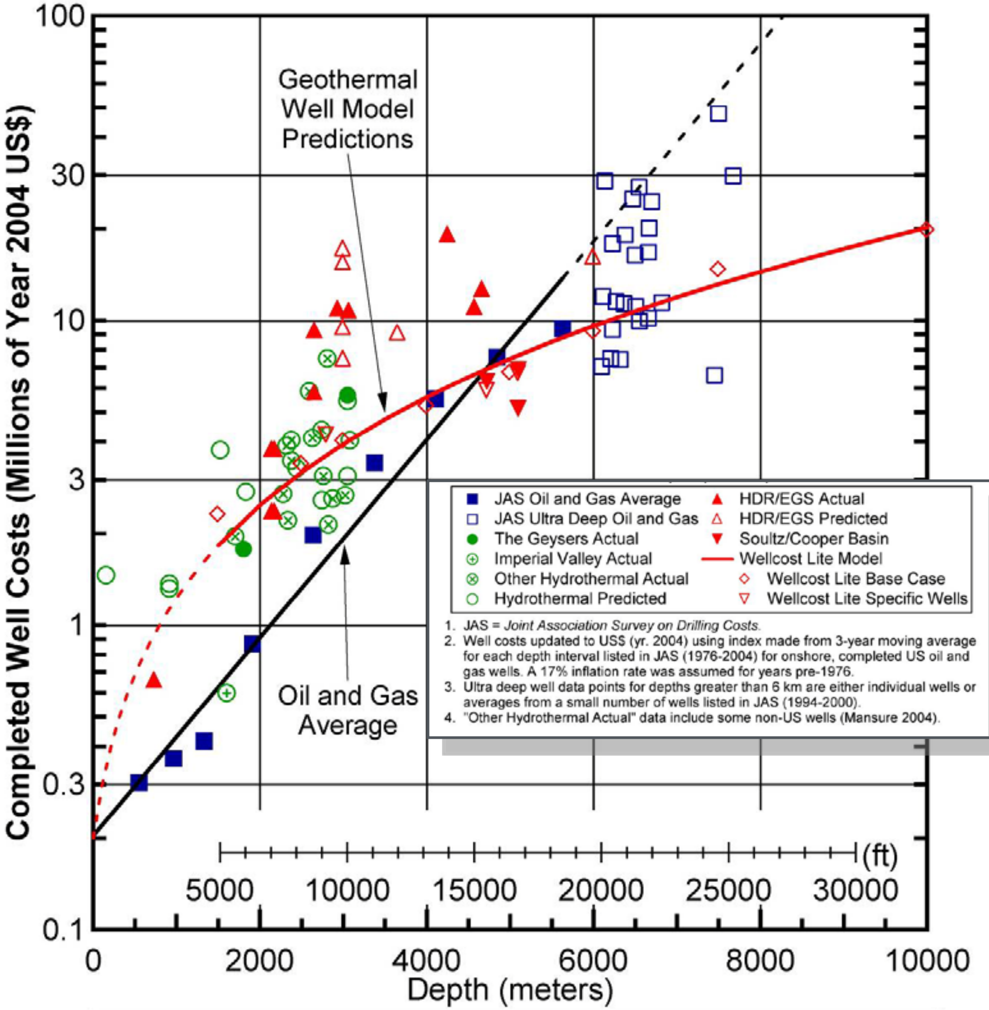
- Year 1 (1/29/10 – 12/31/10) Tasks
  - Task 1.5 Facilitation of geothermal system costs into base case models
    - GETEM will be modified to accept costs of the hybrid systems and used to estimate overall project costs. Sensitivity of project economics to production well flow rate and the rate of thermal drawdown of the geothermal reservoir system will be explored.
  - Task 1.6 Analyze direct-use cases with steady-state parametric studies
    - Analyze direct heating cases with steady-state parametric studies covering the case-study resources and site conditions.
  - Task 1.7 Develop an Aspen model for electric power generation
    - Select a representative set of organic working fluids and develop an Aspen model for geothermal electric power generation using an organic Rankine cycle.
  - Task 1.8 Selection of most promising integration strategies
    - This analysis will weigh potential capital investments, operating costs, and energy savings, along with thermodynamic feasibility. Initial steps will also be taken to assess the local geothermal potential of the region.
    - At the end of Phase 1, the most promising integration strategies of low-temperature geothermal energy will be identified and selected.

Accomplishments, Expected Outcomes and Progress

- Progress to Date:
  - Recruited 5 students to work on individual tasks
  - Currently disseminating subcontracts (to ISU, Cornell, NREL)
  - Case study models are being built
    - Aspen Plus and TOUGH2
  - Full team meeting scheduled for May 26-27
- Qualifications:
  - PI Anderson was MIT Geothermal Report panelist and developed EGS deployment models. Current Methane Hydrate Reservoir Simulator Code Comparison PI.
  - Co-PI Tester, Associate Director, Energy Programs of CCSF has decades of experience in geothermal system and supercritical fluid research
  - Co-PI Augustine developed the MIT Drilling Cost Index and is member of the Technology Systems and Sustainability Analysis Group in the Strategic Energy Analysis Center at NREL
  - Co-PI Brown is the Director of the Center for Sustainable Environmental Technologies and is an international expert in biomass gasification

Economic Advantage of Direct-Use Geothermal

- Direct-use geothermal is able to capitalize on low-T resource
  - T = 110, 130, 150° C at
    2.5, 3.0, 3.5 km (40° C/km)
    5.0, 6.0, 7.0 km (20° C/km)
- Assuming \$300/kW$_{th}$ for heat exchangers and piping
- Doublets (1 injector, 1 producer)
  - 2004 US\$ and 2·(2004 US\$)
  - 500 m separation
  - 7-inch diameter
- Debt/equity rates
  - 5%, 10%, 15%
  - 20-year project life
- Assume 80 kg/s in producer



1. JAS = *Joint Association Survey on Drilling Costs.*
2. Well costs updated to US$ (yr. 2004) using index made from 3-year moving average for each depth interval listed in JAS (1976-2004) for onshore, completed US oil and gas wells. A 17% inflation rate was assumed for years pre-1976.
3. Ultra deep well data points for depths greater than 6 km are either individual wells or averages from a small number of wells listed in JAS (1994-2000).
4. "Other Hydrothermal Actual" data include some non-US wells (Mansure 2004).

Accomplishments, Expected Outcomes and Progress

40° C/km Geothermal Gradient

- *T* = 110, 130, 150° C at
  2.5, 3.0, 3.5 km
- Total costs include redrilling the reservoir

- 2004 US$ Drilling Costs/well
  - $3.5, $4.1, $4.7 million
- 2x2004 US$ Drilling Costs/well
  - $7.0, $8.2, $9.4 million

Electricity Production (¢/kWh)

2004 Drilling Costs	T (°C)	5%	10%	15%
	150	13	21	29
	130	24	40	55
	110	99	159	217

2X2004 Drilling Costs	T (°C)	5%	10%	15%
	150	18	31	42
	130	34	57	79
	110	135	228	315

District Heating ($/MMBtu)

2004 Drilling Costs	T (°C)	5%	10%	15%
	150	0.414	0.557	0.719
	130	0.399	0.528	0.673
	110	0.393	0.507	0.636

2X2004 Drilling Costs	T (°C)	5%	10%	15%
	150	0.540	0.762	1.012
	130	0.509	0.707	0.931
	110	0.487	0.661	0.856

Accomplishments, Expected Outcomes and Progress

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

20° C/km Geothermal Gradient

- *T* = 110, 130, 150° C at
  5.0, 6.0, 7.0 km
- Total costs include redrilling the reservoir

- 2004 US$ Drilling Costs/well
  - $6.2, $10.3, $12.6 million
- 2x2004 US$ Drilling Costs/well
  - $12.4, $20.6, $25.2 million

Electricity Production (¢/kWh)

2004 Drilling Costs	T (°C)	5%	10%	15%
	150	27	68	98
	130	52	141	204
	110	257	451	644

2X2004 Drilling Costs	T (°C)	5%	10%	15%
	150	55	103	152
	130	115	215	316
	110	366	668	970

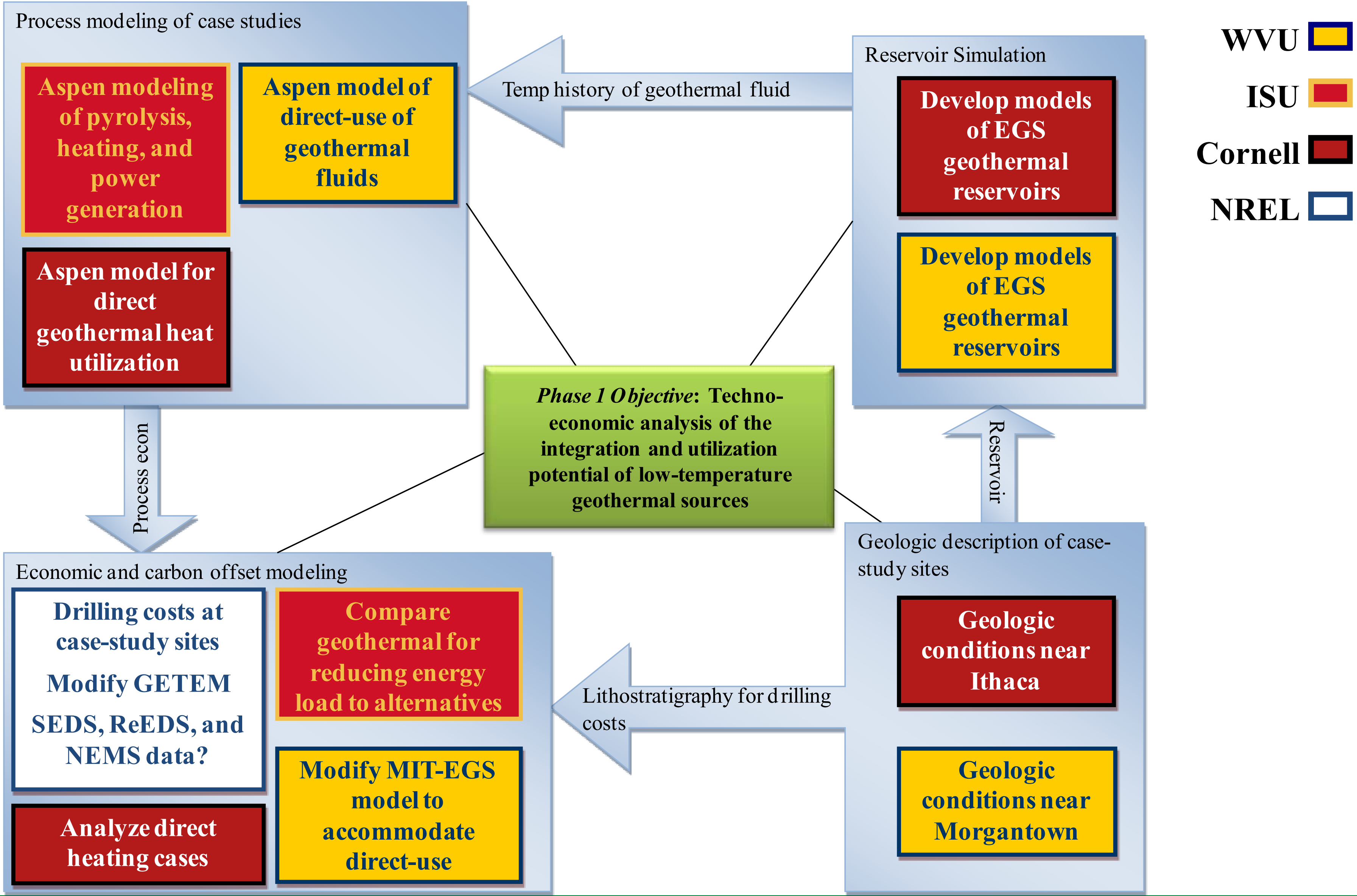
District Heating ($/MMBtu)

2004 Drilling Costs	T (°C)	5%	10%	15%
	150	0.8305	1.2363	1.6936
	130	0.7351	1.0762	1.4606
	110	0.5560	0.7733	1.0180

2X2004 Drilling Costs	T (°C)	5%	10%	15%
	150	1.2676	1.9491	2.7169
	130	1		2.3096
	110	0		1.5339

04/30/10 NYMEX
$3.920/MMBtu

Project Management/Coordination



Process modeling of case studies

- **Aspen modeling of pyrolysis, heating, and power generation**
- **Aspen model of direct-use of geothermal fluids**
- **Aspen model for direct geothermal heat utilization**

Temp history of geothermal fluid

Reservoir Simulation

- **Develop models of EGS geothermal reservoirs**
- **Develop models of EGS geothermal reservoirs**

Process econ

***Phase 1 Objective*: Techno-economic analysis of the integration and utilization potential of low-temperature geothermal sources**

Reservoir

Economic and carbon offset modeling

- **Drilling costs at case-study sites**
  Modify GETEM
  SEDS, ReEDS, and NEMS data?
- **Compare geothermal for reducing energy load to alternatives**
- **Analyze direct heating cases**
- **Modify MIT-EGS model to accommodate direct-use**

Lithostratigraphy for drilling costs

Geologic description of case-study sites

- **Geologic conditions near Ithaca**
- **Geologic conditions near Morgantown**

WVU 🟨

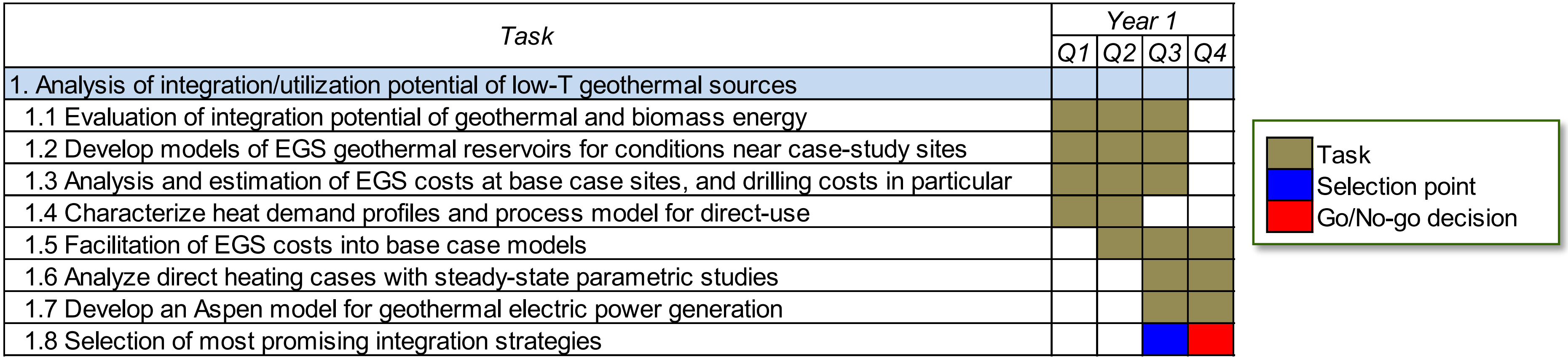
ISU 🟥

Cornell 🟥

NREL ⬜

Project Management/Coordination

- Project management plans
  - – Regularly-scheduled webinars with rotating presentation schedule
    - Yearly (at least) in-person meetings
  - – Working subgroups meet more frequently
    - Subgroups defined previously
  - – Data-sharing via “wiki”-style project site (under construction)
    - Currently using an sftp server hosted at WVU



Task	*Year 1*			
	Q1	*Q2*	*Q3*	*Q4*
1. Analysis of integration/utilization potential of low-T geothermal sources				
1.1 Evaluation of integration potential of geothermal and biomass energy	🟫	🟫	🟫	
1.2 Develop models of EGS geothermal reservoirs for conditions near case-study sites	🟫	🟫	🟫	
1.3 Analysis and estimation of EGS costs at base case sites, and drilling costs in particular	🟫	🟫	🟫	
1.4 Characterize heat demand profiles and process model for direct-use	🟫	🟫		
1.5 Facilitation of EGS costs into base case models		🟫	🟫	🟫
1.6 Analyze direct heating cases with steady-state parametric studies			🟫	🟫
1.7 Develop an Aspen model for geothermal electric power generation			🟫	🟫
1.8 Selection of most promising integration strategies			🟦	🟥

🟫 Task
🟦 Selection point
🟥 Go/No-go decision

Future Directions

- In Year 2, we will perform detailed optimizations of selected integration strategies and economic analyses through the following milestones:
  - Complete reservoir simulations of sites at varying depths, temperatures, and flowrates,
  - Modification SEDS, ReEDS and NEMS model to incorporate low-temperature geothermal resources,
  - Analysis of organic binary Rankine cycles configuration performance

- In Year 3, we will perform a regionalization/generalization and scale-up of results and complete the following milestones:
  - Generalization of geothermal system costs by region
  - Development of supply curves,
  - Modeling of market penetration of low-temperature geothermal systems in national models, and
  - Determine fuel savings and CO_2 reductions achieved for each low-temperature geothermal configuration.

Summary

- Project Focus: 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.
- Develop a regionalized model of the utilization of low-temperature geothermal resources.
  - Implement into existing energy assessment models such as SEDS, ReEDS, and NEMS to assess market penetration potential.
- Preliminary 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 competitive

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