DOE's Innovative Exploration Technologies Program associated with Conventional Geothermal Systems

APEC WORKSHOP ON GEOTHERMAL ENERGY DEVELOPMENT

June 25, 2013

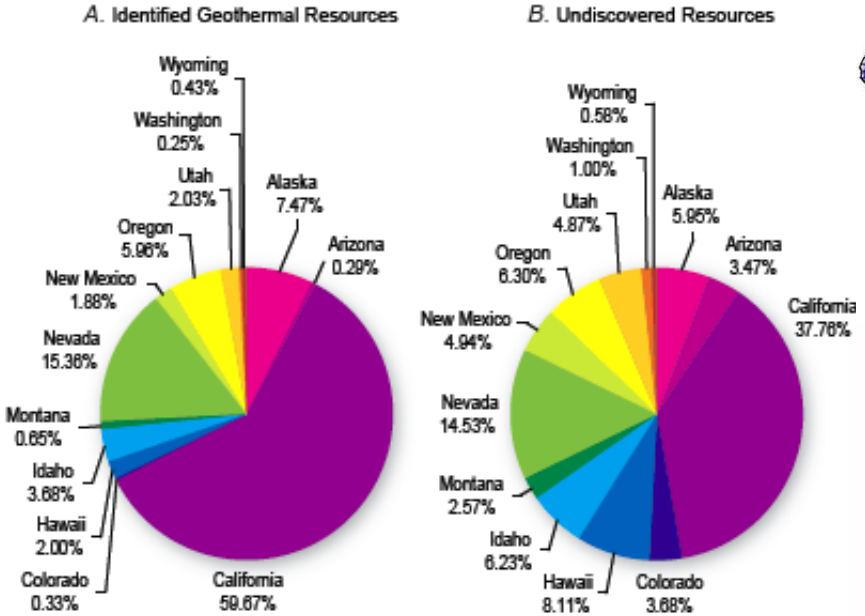
Patrick Dobson DOE/LBNL

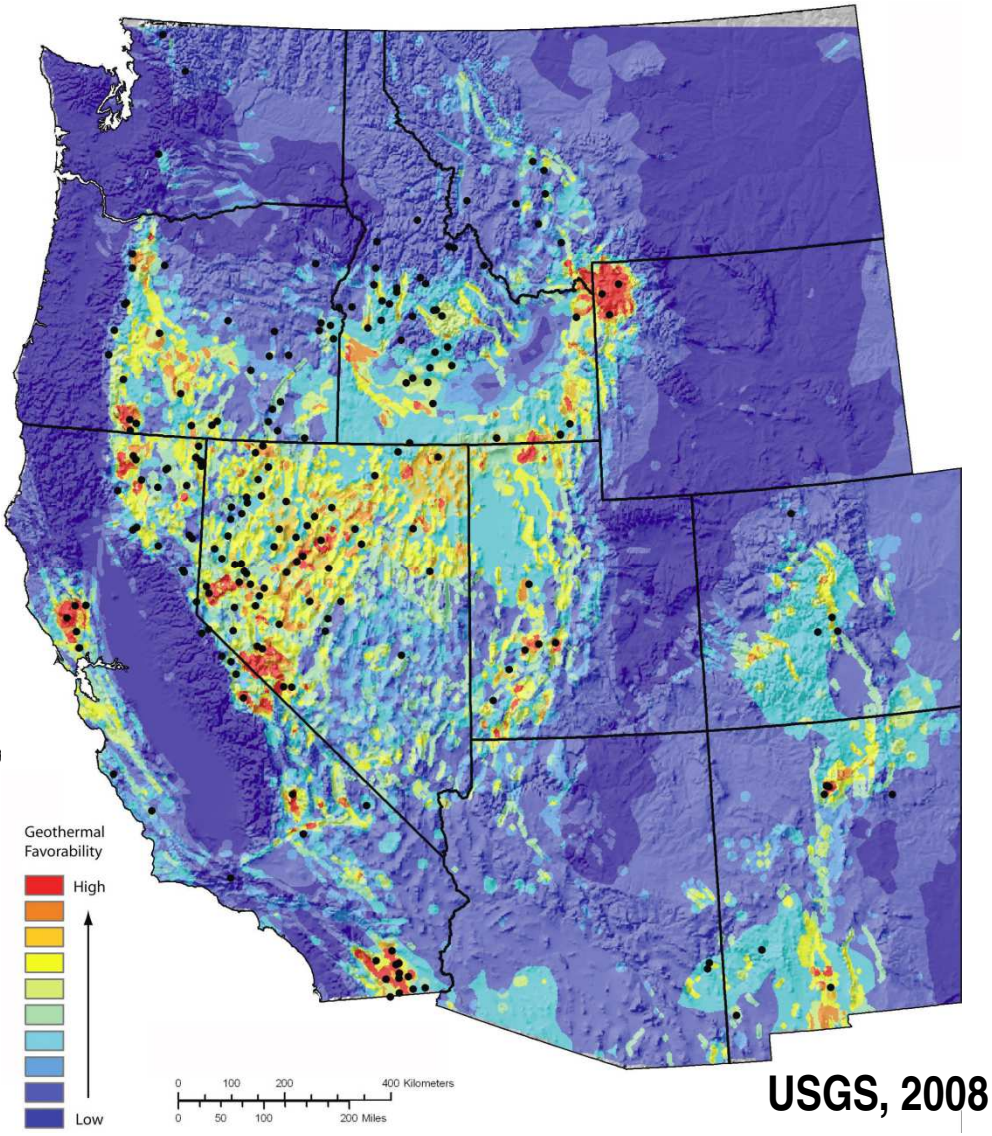
Potential Geothermal Resources

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

USGS Geothermal Favorability Map

- 9 GWe potential from identified resources (black dots)
- 30 GWe potential from undiscovered resources





USGS, 2008

Goals of Hydrothermal & Resource Confirmation Program

- Develop advanced exploration tools and technologies through supporting exploration R&D projects to accelerate the discovery and utilization of geothermal resources
  - Improve ability to accurately predict subsurface temperatures
  - Improve ability to identify permeable zones at depth
- Reduce the high level of exploration risk, lower the cost of geothermal power, and increase the economic viability of exploration technologies
- Generate useful data for the National Geothermal Data System
- Exploration R&D projects consist of application of innovative technologies
  - Green field exploration
  - Brown field exploration
  - Expansion of existing geothermal fields
- Other efforts include:
  - Develop exploration best practices and case histories on DOE's Open Energy Information (OpenEI) website
  - Data gap analysis

Hydrothermal Resource Confirmation

Innovative Exploration Technologies
Drilled in 2011

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

Performer	Project Site	Exploration Technologies	DOE Funds	Awardee Cost Share	TOTAL COST
Geysers Power Company, LLC	Northwest Geyser, CA	Geophysics	$5,000,000	$7,130,647	$12,130,647
Nevada Geothermal Power Company	Crump Geyser, OR	Geophysics	$1,764,272	$1,839,271	$3,603,543
ORMAT Nevada, Inc.	Wister, CA	Geophysics	$4,911,330	$5,575,229	$10,486,559
Presco Energy, Inc.	Pershing County (Rye Patch), NV	Geophysics	$2,277,081	$1,934,149	$4,211,230
Pyramid Lake Paiute Tribe	Pyramid Lake, NV	Geophysics	$4,845,534	$0	$4,845,534
Utah State University	Snake River Plain, ID	Geophysics, Geochemistry	$4,640,110	$1,804,488	$6,444,598

Hydrothermal Resource Confirmation

Innovative Exploration Technologies
Drilling 2012-2013

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


Pilgrim HS, AK


San Emidio, NV


Mountain Home AFB, ID

Performer	Project Site	Exploration Technologies	DOE Funds	Awardee Cost Share	TOTAL COST
Utah State University	Snake River Plain, ID	Geophysics, Geochemistry	$4,640,110	$1,804,488	$6,444,598
US Geothermal, Inc.	San Emidio, NV	Geophysics, Remote Sensing	$3,772,560	$3,451,878	$7,224,438
University of Alaska Fairbanks	Pilgrim Hot Springs, AK	Remote Sensing	$4,274,792	$1,851,345	$6,126,137
El Paso County	Ft. Bliss, NM	Geochemistry	$5,000,000	$4,812,500	$9,812,500
Pueblo of Jemez	Jemez Pueblo, NM	Geochemistry	$4,995,844	$100,000	$5,095,844
Oski Energy, LLC	Hot Pot, NV	Geophysics	$4,214,086	$3,985,570	$8,199,656

Hydrothermal Resource Confirmation

Innovative Exploration Technologies
Projected Drilling 2013-2014

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

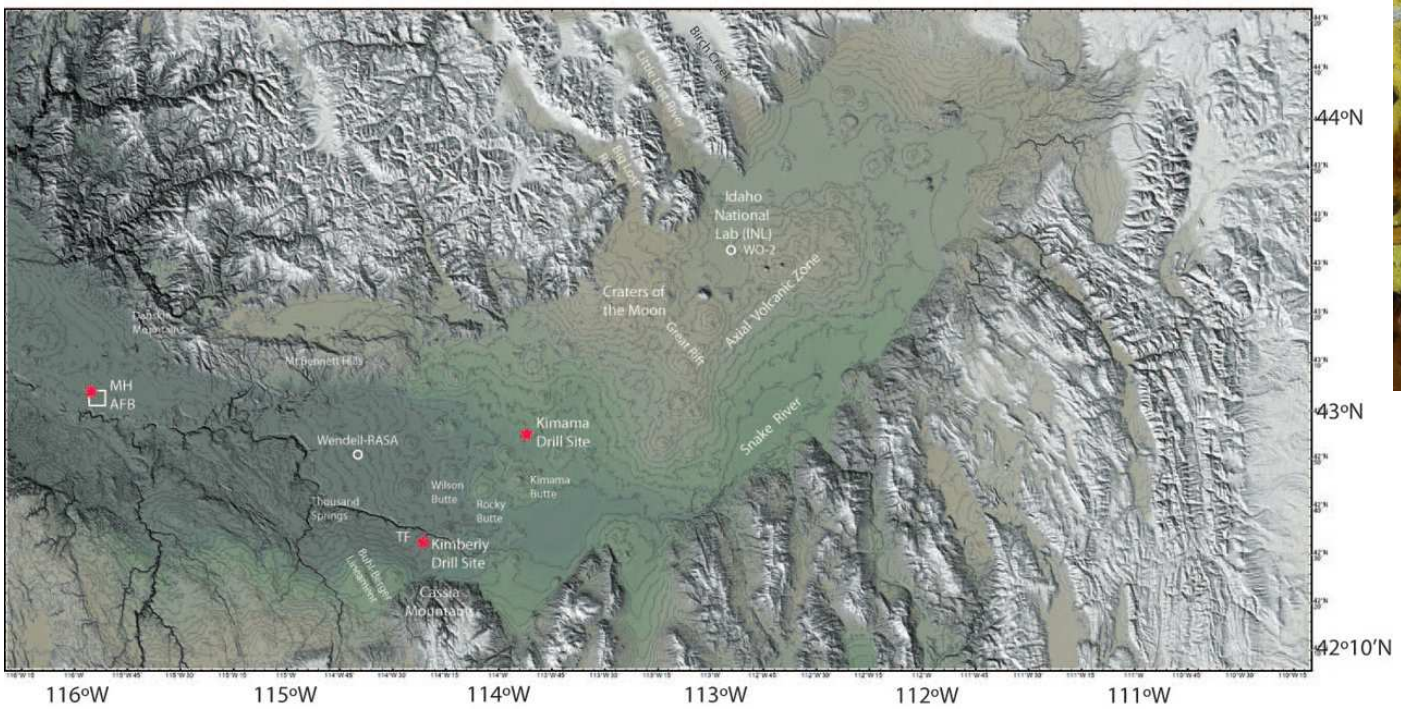
Performer	Project Site	Exploration Technologies	DOE Funds	Awardee Cost Share	TOTAL COST
Nevada Geothermal Power Company	Pumpernickel, NV	Geochemistry	$1,597,847	$1,597,847	$3,195,694
ORMAT Nevada, Inc.	Glass Buttes, OR	Remote Sensing	$4,475,015	$4,050,500	$8,525,515
Ram Power, Inc. (Sierra Geothermal)	Silver Peak, NV	Remote Sensing	$5,000,000	$7,356,546	$12,356,546
Ram Power, Inc. (Sierra Geothermal)	Alum, NV	Remote Sensing	$5,000,000	$7,356,546	$12,356,546
University of Kansas Center for Research Inc.	Fish Lake Valley, NV	Geochemistry	$2,299,237	$1,943,282	$4,242,519
Flint Geothermal LLC	Western Colorado	Remote Sensing	$4,778,234	$3,007,300	$7,785,534
ORMAT Nevada, Inc.	Maui, HI	Remote Sensing, Geochemistry	$4,377,000	$4,327,260	$8,704,260
Davenport Power, LLC	Newberry Volcano, OR	Geophysics	$5,000,000	$7,830,425	$12,830,425

Snake River Plain, ID
Utah State University

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

3 wells drilled to evaluate region with elevated heat flow

- **Kimama** - 1912 m hole with 98 C BHT, penetrated mostly basalt, with thick cold aquifer down to 960 m
- **Kimberly** – 1958 m hole with thick isothermal section (55-60 C) below 400 m, penetrates margins of silicic caldera
- **Mountain Home** – 1821 m hole with artesian flow of 129 C from fluid entry at 1745 m; well penetrates basalts and lacustrine sediments

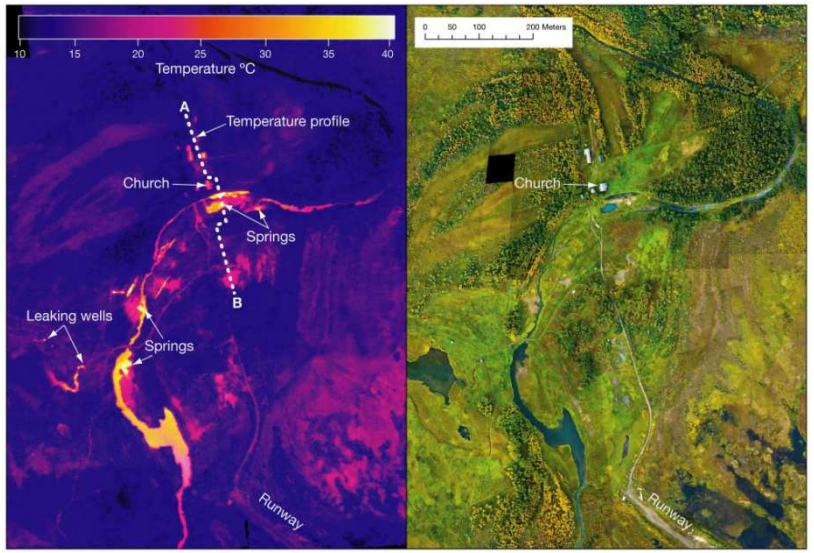


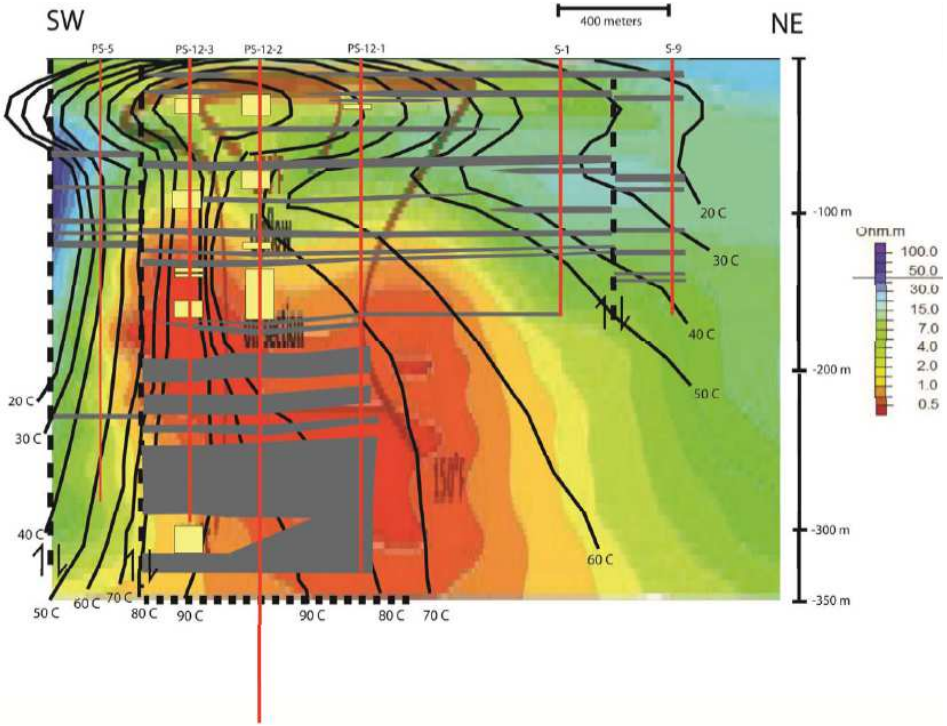
Shaded relief topographic map of Snake River Plain

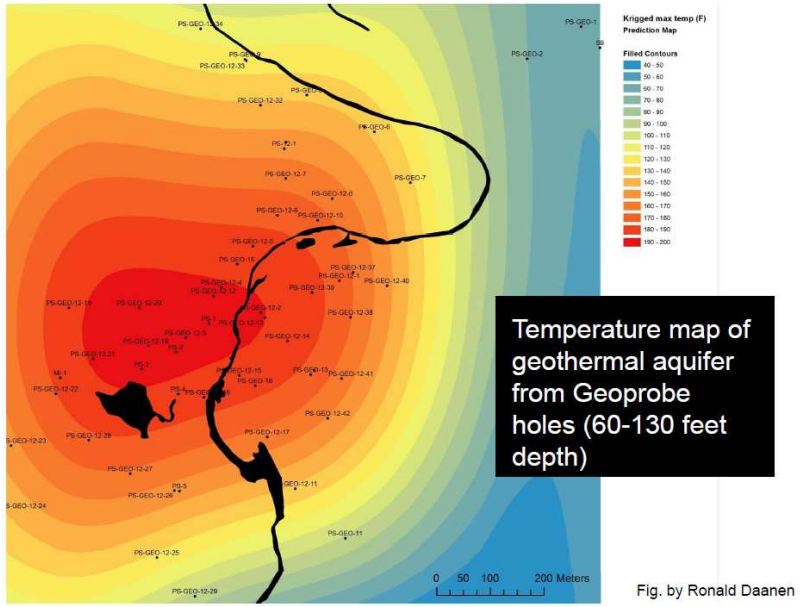
Artesian flow at Mtn. Home

Pilgrim Hot Springs, AK
University of Alaska, Fairbanks

- Forward looking infrared (FLIR) airborne survey used to identify extent of hot springs and hot ground
- Geoprobe holes (20-40 m) used to identify shallow outflow plume, pinpoint upflow location for deeper drilling targets
- Integrated geophysical data (MT, gravity, magnetics) with geology





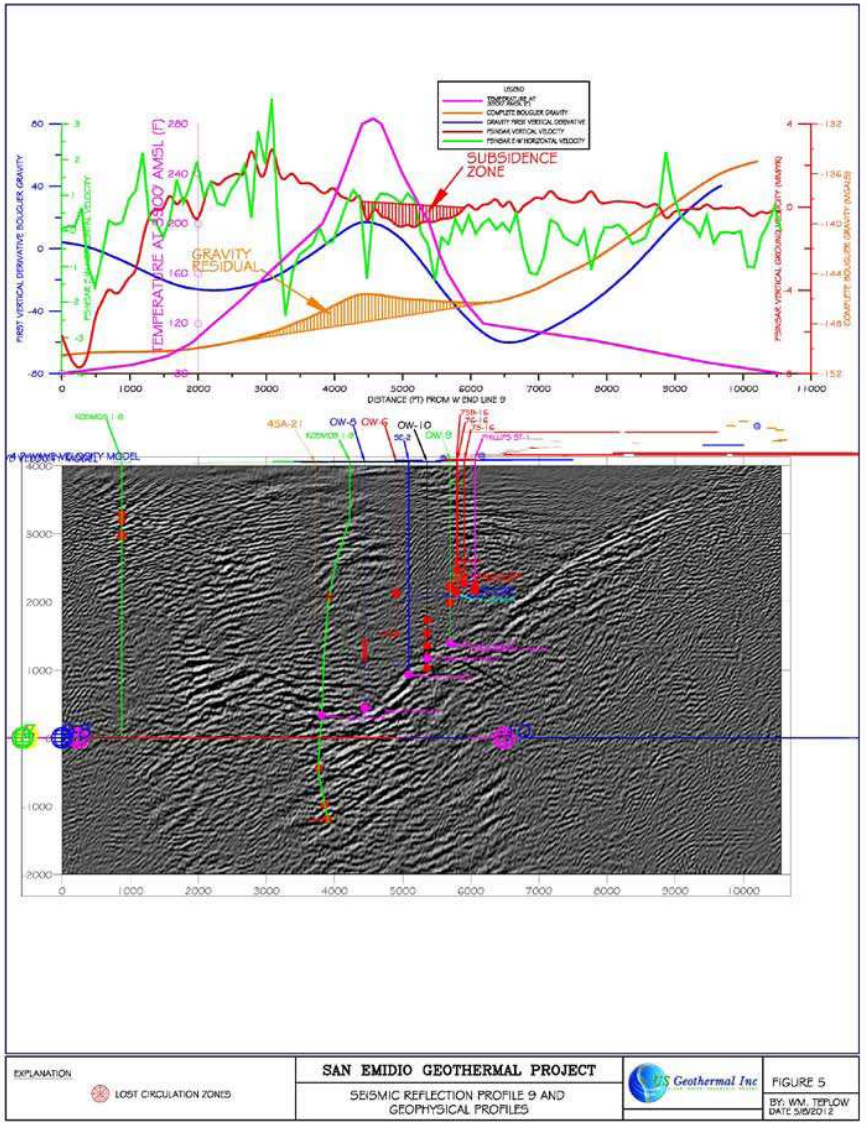


Temperature map of geothermal aquifer from Geoprobe holes (60-130 feet depth)

Fig. by Ronald Daanen

San Emidio, NV
US Geothermal, Inc.

- Used structural kinematic analysis, PSInSAR, gravity, magnetics, and reflection seismic techniques to identify and map Large Aperture Fractures (LAFs) and identify drilling targets
- Key accomplishments:
  - 4 out of 5 wells encountered commercially exploitable permeability and temperature
  - Added 2 MWe to currently operating wellfield
  - Expanded possible southern resource area by 2.6 km^2
  - Found resource with temperatures 6 to 11 C higher than previously observed

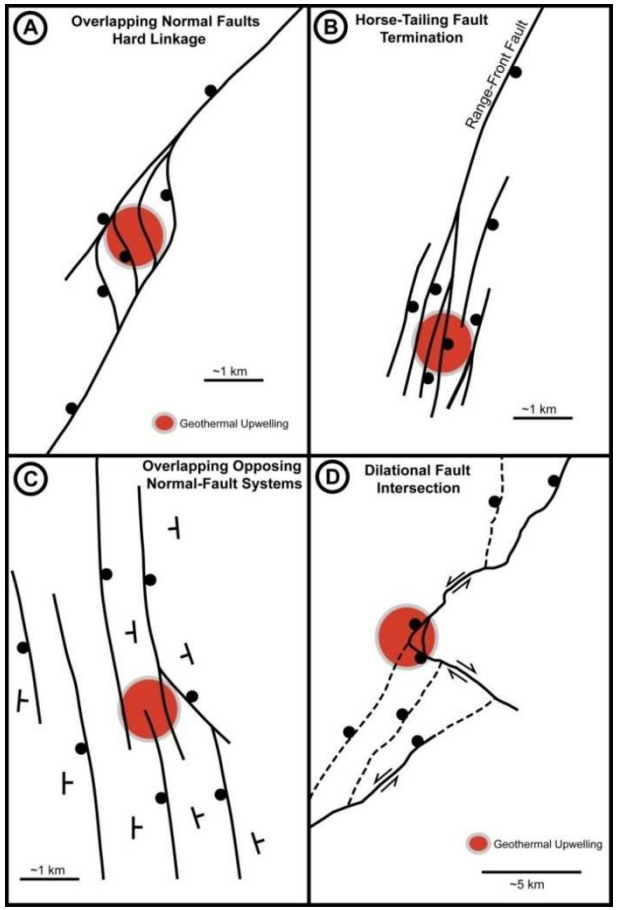


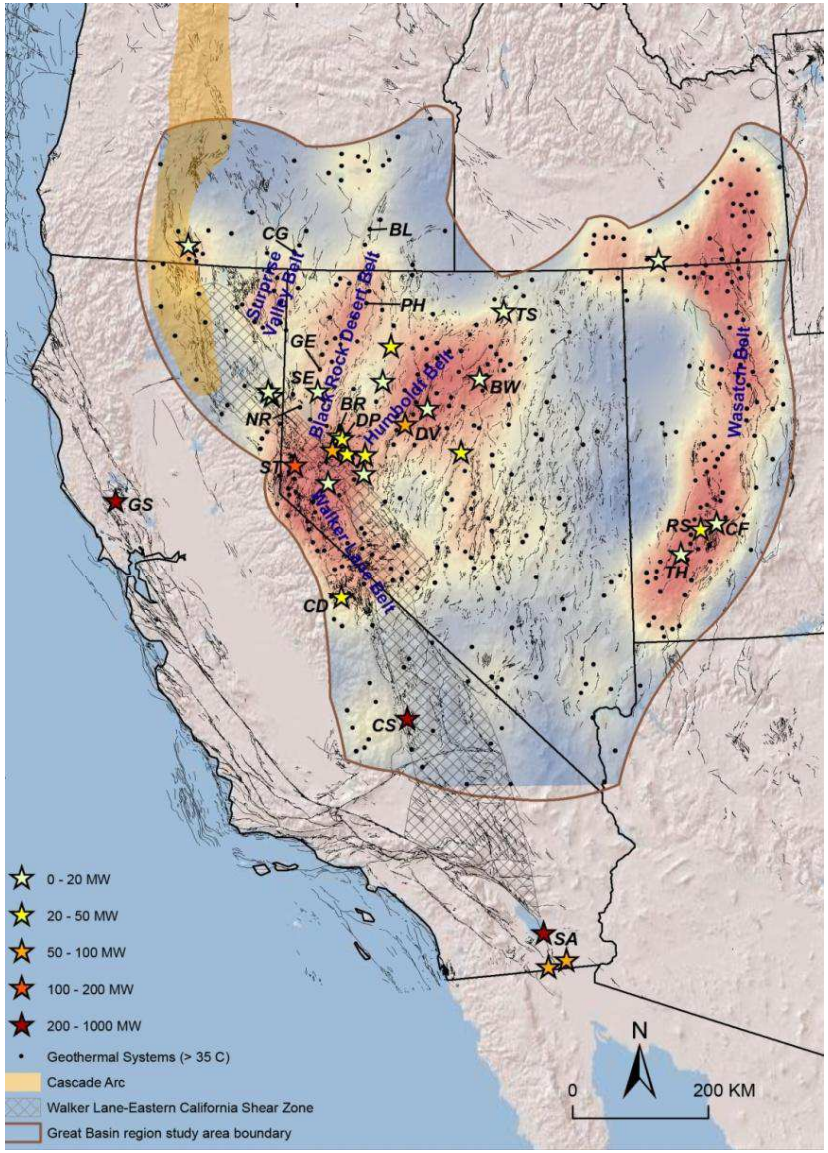
Structural Controls of Geothermal Systems (Faulds, 2013)

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

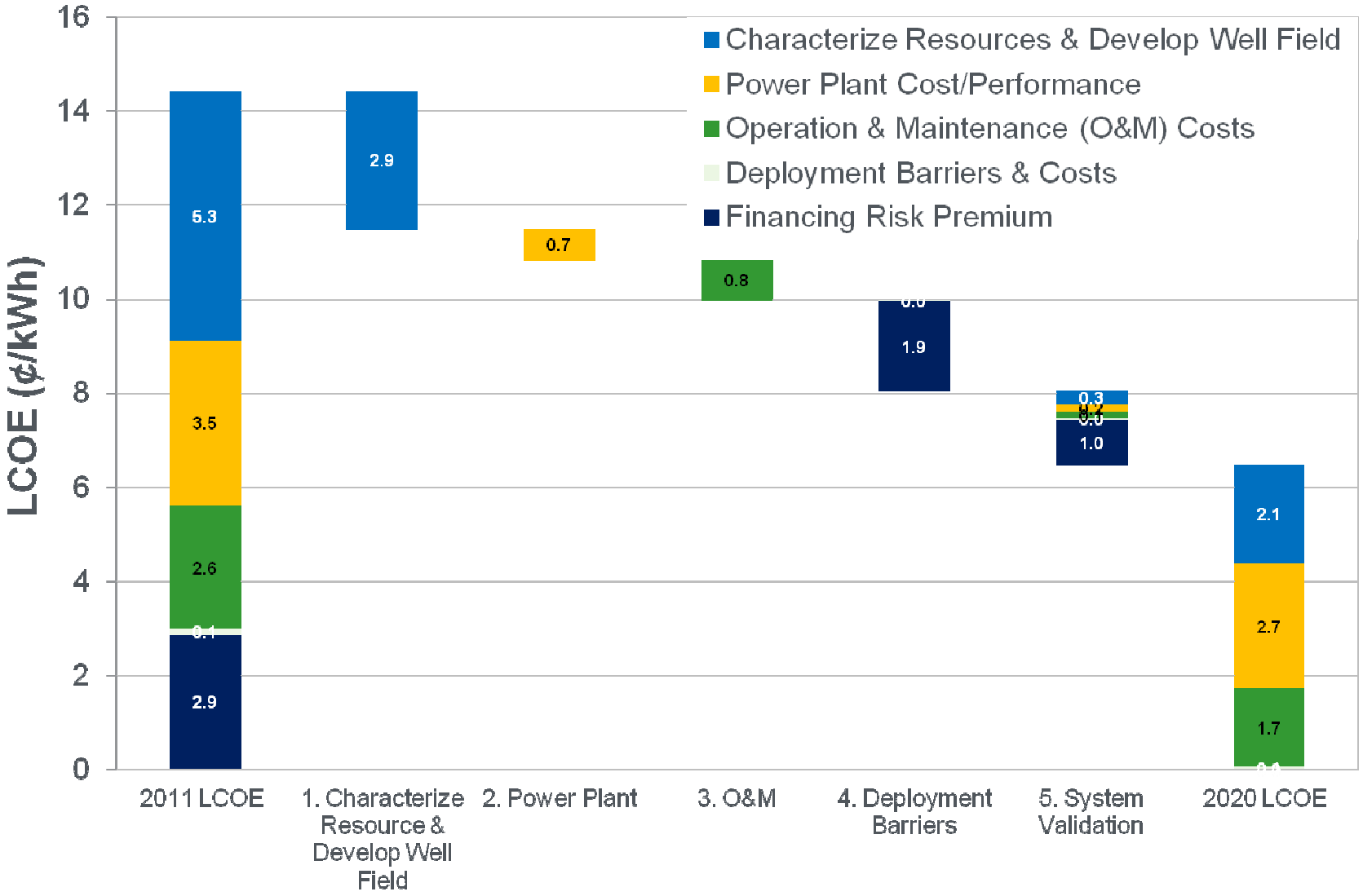
Geothermal 'fairway' of high fracture permeability and fluid flow where:

- Co-location of critically stressed fault segments
- High fault intersection density

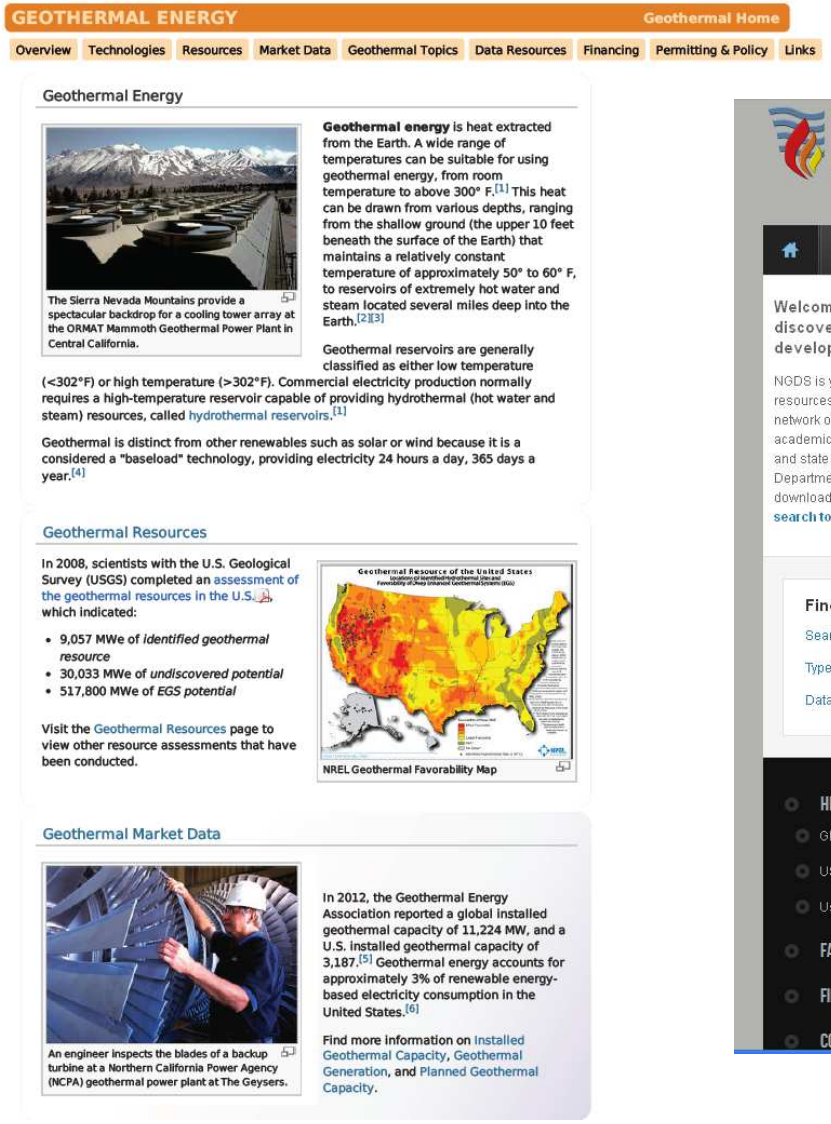




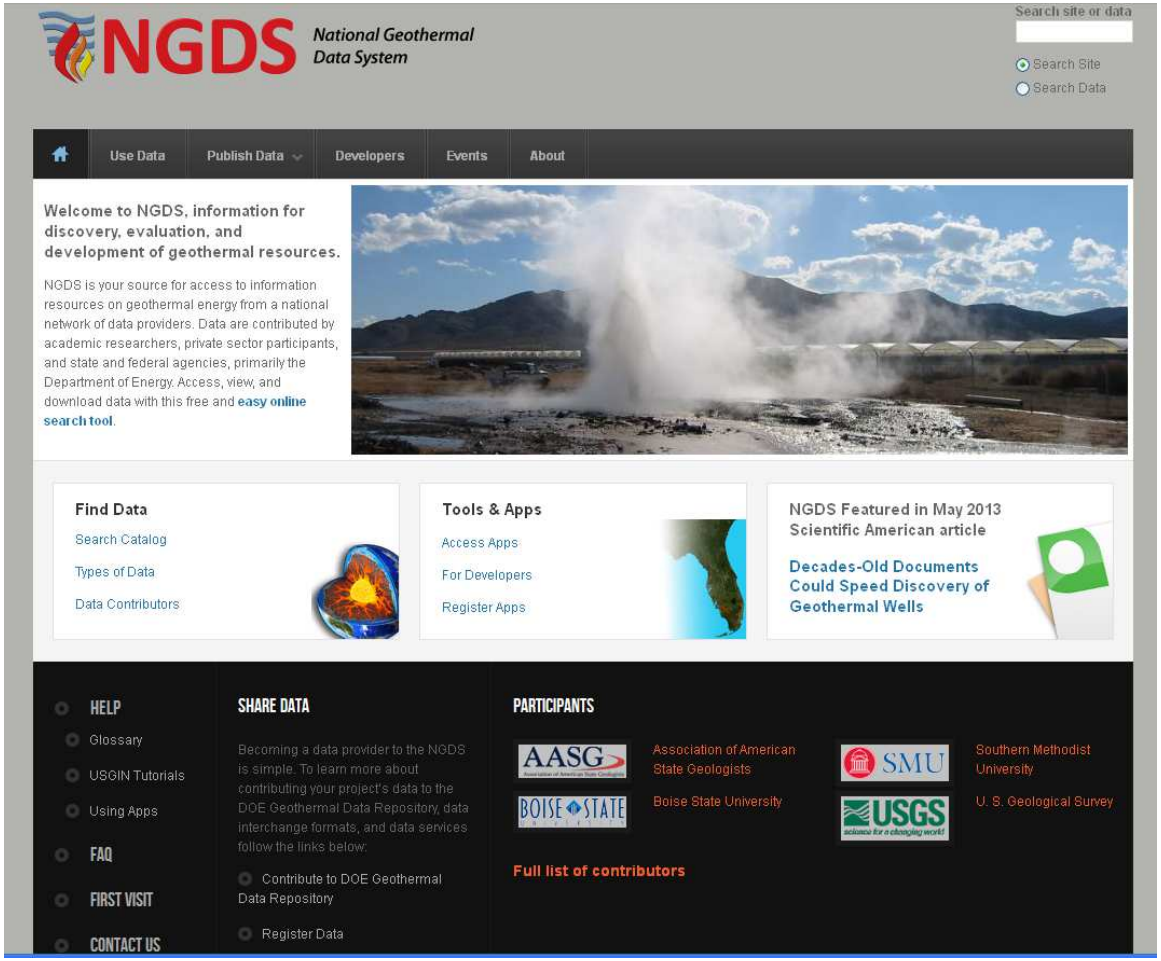
Hydrothermal Cost-Reduction Cascade



Information Collection, Sharing, and Analysis OpenEI and NGDS



en.openei.org/wiki/Gateway:Geothermal#



http://geothermaldata.org

Workshop Results
Priority technology needs (1 of 2)

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

CROSS-CUTTING	• Conceptual Models • Structural Evaluation of Geothermal Systems • 3D Visualization and Modeling Software • Database of Case Histories and Analysis Tools • Geothermal Potential Maps
GEOLOGY/STRUCTURE STRESS/STRAIN	• Core Log Analysis • Stress/Strain Data Mapping • Basic Geologic Setting and Permeability • Coupled Transport Modeling • District Mapping • Rock Property Data-Data Set
NON-INVASIVE GEOPHYSICS	• Gravity Tools and Techniques • Inverse Methods • Seismic (reflection seismic, passive, source) • EM Improvements • 3D EM Interpretation Techniques • High Density Data Acquisition Instruments

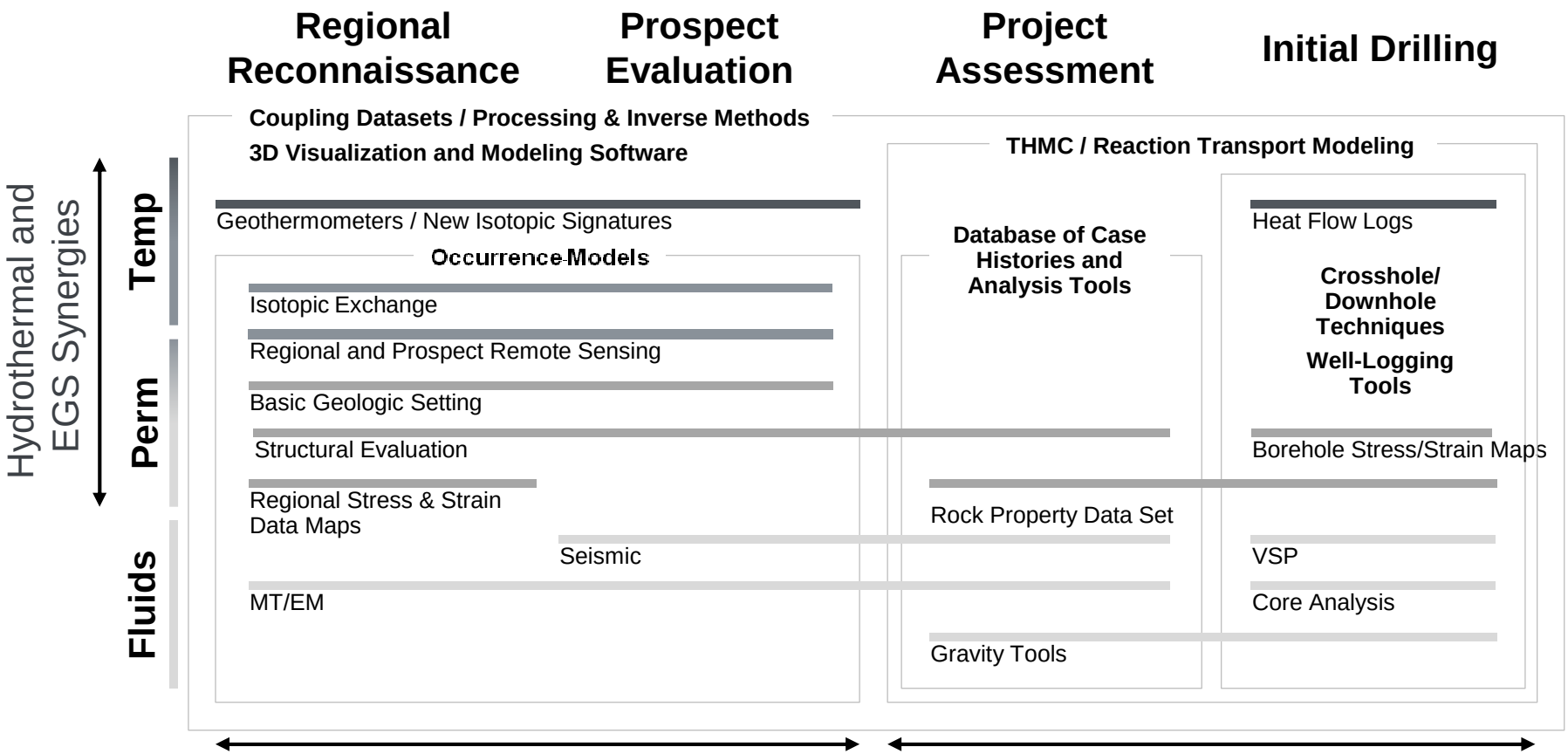
Workshop Results
Priority technology needs (2 of 2)

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

INVASIVE GEOPHYSICS	• Well Logging Tools • Crosshole/Downhole Techniques • Vertical Seismic Profiling (VSP) • EM Improvements • Heat Flow Logging
AIRBORNE EXPLORATION	• MT/EM Tools/AFMAG • Gravity Tools • Regional Remote Sensing Data Collection • Synthesis of Multiple Data Sets • Processing Methods • Single Source Database
GEOCHEMISTRY	• Reaction Transport Modeling • Isotopic Exchange/Permeability Distribution • New Signal Detection Tools • Geothermometers • Fracture Detection Tools • Improved Consistent Thermodynamic and Kinetic Database

Technology Needs
Categories and Priorities

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



Tech Priorities

Play Fairway Analysis
New Signatures
Data Processing
Data Gap Filling

Laboratory Verification
Case Studies

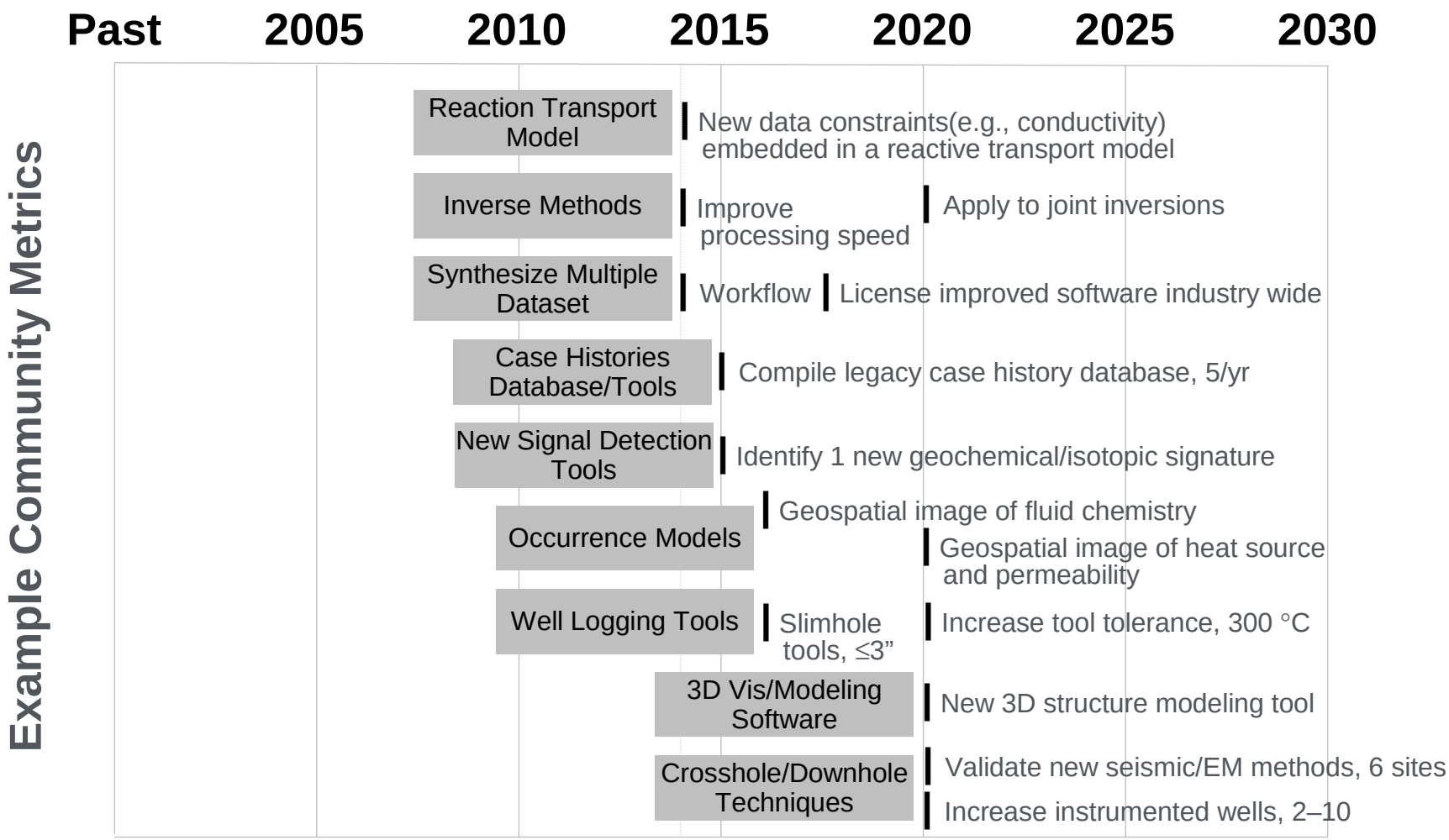
Tech Metrics

Playbooks
Sensitivity
Analysis Time
Resolution

Uncertainty Reduction
Tool Hardiness
Resolution

Workshop Results
Metrics proposed

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



Concluding Remarks

- DOE's Hydrothermal & Resource Confirmation Program has supported many field R&D projects over the past 3 years to test innovative exploration technologies
  - Identify and develop blind hydrothermal resources
  - Lower exploration risk
  - Lower geothermal power cost
- Data collection and analysis critical to maximizing project benefits
- Roadmapping work used to identify technology barriers, focus future R&D efforts of program
- Many aspects of this program are applicable to EGS, coproduction, and low temperature resources