Progress in US DOE Programs: Low Temperature Geothermal Mineral Recovery and Play Fairway Analysis

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US DOE Geothermal Technologies Office

Power Plays: Geothermal Energy in Oil and Gas Fields
Southern Methodist University, Dallas TX
May 19-20, 2015

OUTLINE

1. DOE Geothermal Technologies Program

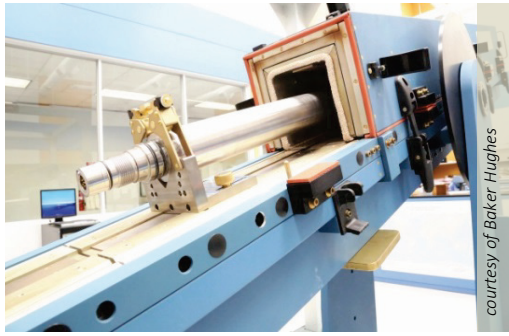
   - Planning philosophy

2. Progress of two initiatives
   - Play Fairway Analysis Program (PFA)
   - Critical Materials Recovery Program

3. TWO Requests for Information (RFI)
   - Geothermal Concepts and Approaches to Validate Mineral Recovery (closes June 8)
   - Play Fairway Analysis for Industry (closed but comments still accepted)


courtesy of FastCAP Systems

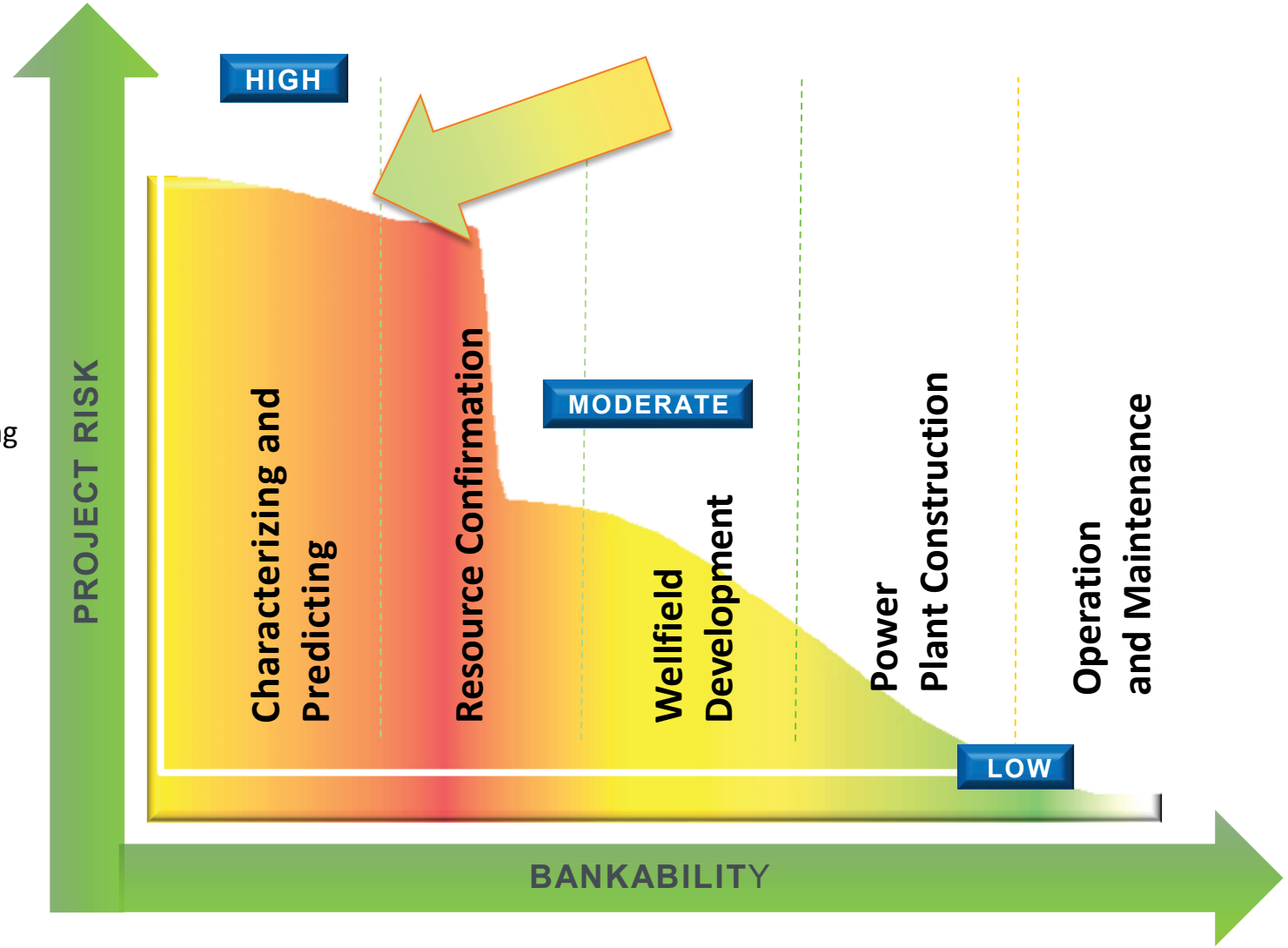

courtesy of Geothermal Resources Council


courtesy of Baker Hughes

Geothermal Lifecycle Costs and Risk: Stages to Deployment

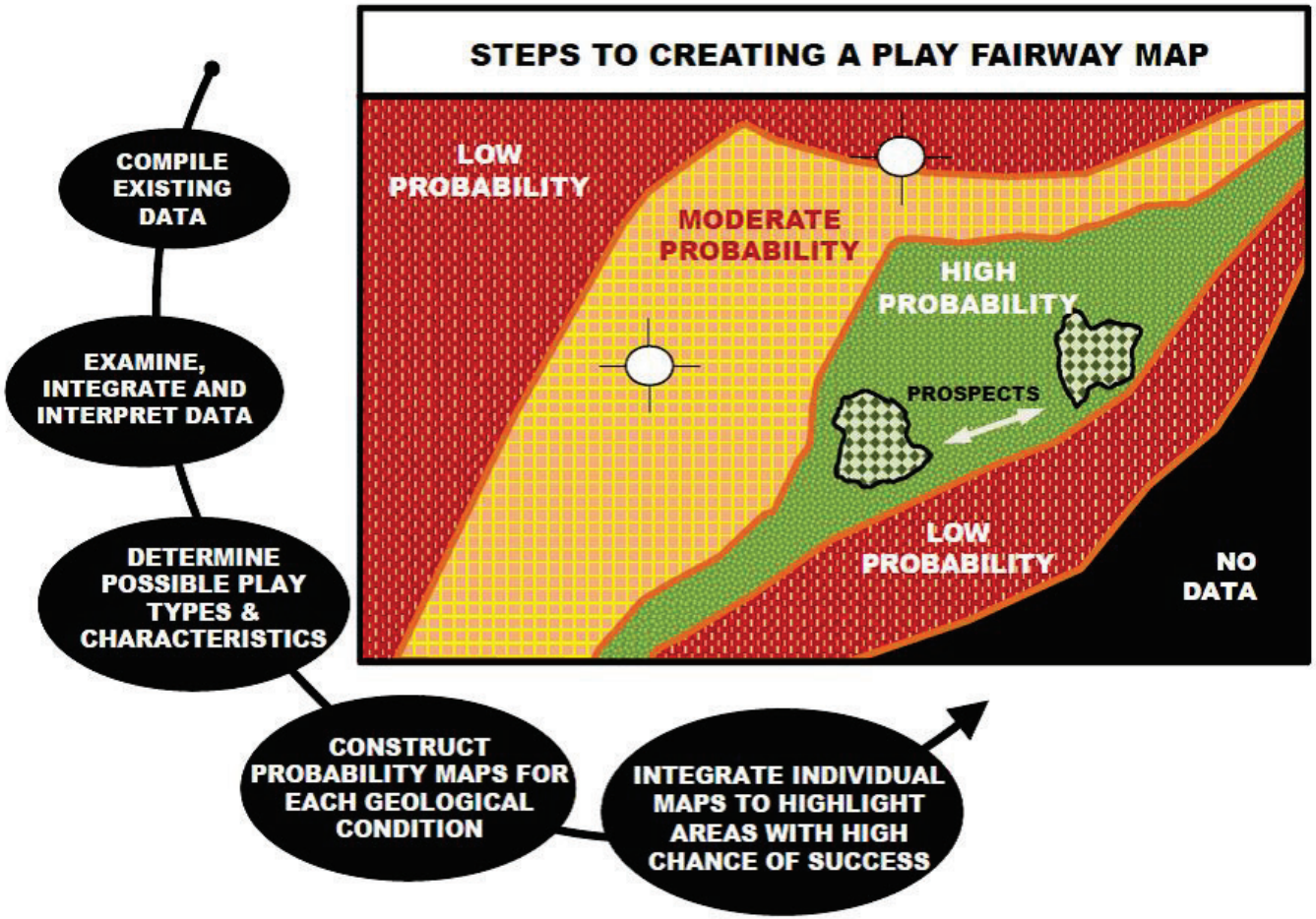
Address geothermal challenges at every stage of development

- Projects to accelerate the adoption of geothermal energy:
  - Better targeted drilling
  - Improved under-standing of the subsurface
  - Innovate new tools, techniques and income streams to improve the value equation
  - Lower the upfront costs



Identifying the play fairway

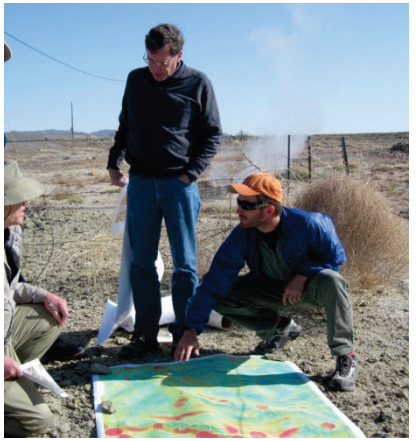
Before disturbing the ground, PFA reduces uncertainty and grades levels of geothermal prospectivity



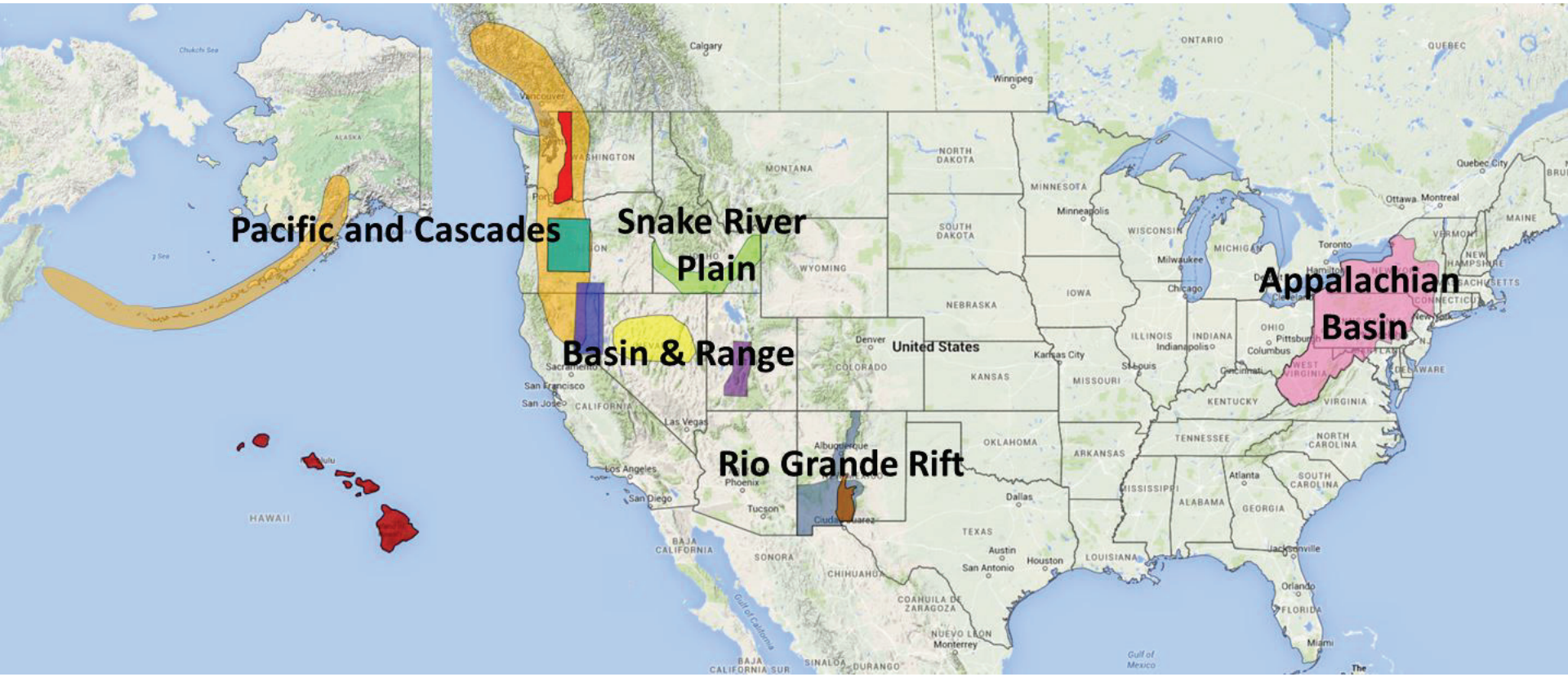
Play Fairway Analysis (PFA)

Considering wide range of geothermal resources: e.g. traditional and blind hydrothermal, EGS targets, low-temperature

- PARAMETERS:
  - ONLY public/private data, no new data
  - 13 months, up to $500k DOE cost share
- APPROACH :
  - Identify locations with highest probability of success
  - Integrate known and conceptual data
  - Focus mostly on **un**explored and **under**explored known geothermal regions
  - Innovative analysis methods



Areas of Study

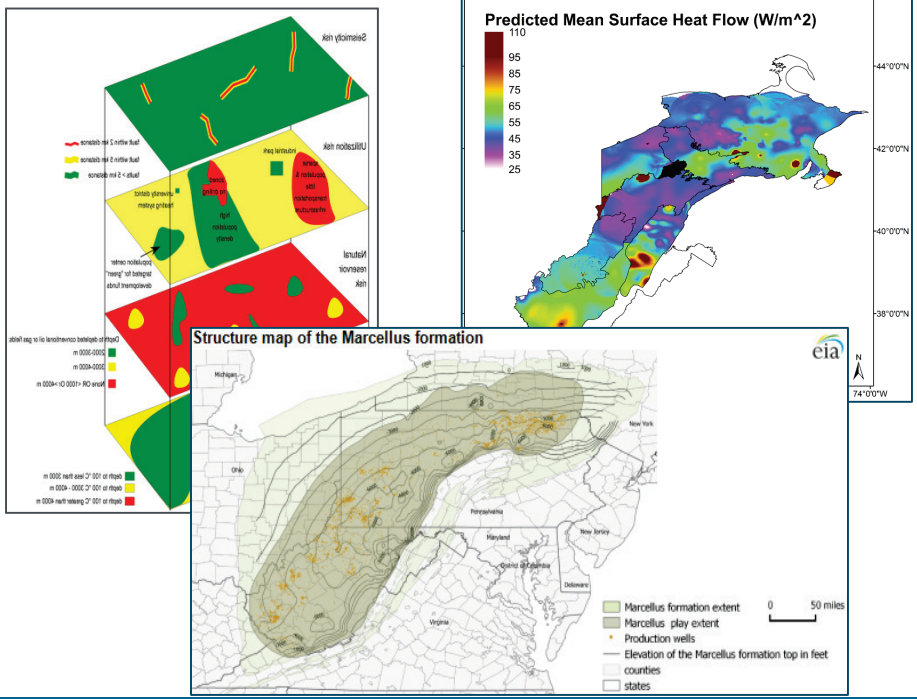


Play Fairway Analysis Awards

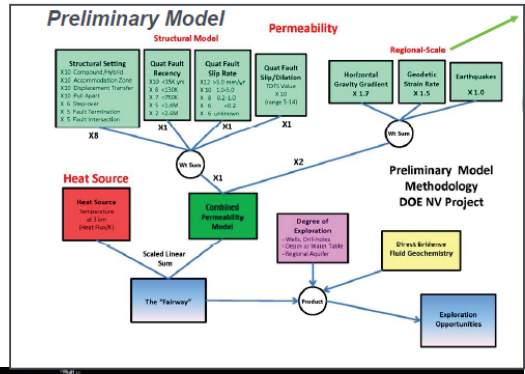
AWARDEE & TEAM	REGION
Cornell University/Southern Methodist U., West Virginia U.	Appalachian Basin
Nevada Bureau of Mines and Geology, UNR plus 5 others	Transect in the Nevada Great Basin
University of California – Davis, LBNL	California, Nevada and Southern Oregon
University of Utah	Eastern Great Basin, Utah
Atlas Geosciences	Washington Cascades and the Aleutian Arc
Washington Div. of Geology and Earth Resources, AltaRock, others	Mount St. Helens and Wind River Valley, Washington
University of Hawaii, UN-Reno	Hawaii
U of Utah, Oregon State U, LBNL	Cascade Mountains, Oregon
Ruby Mountain, Inc., SMU, Ohio State	Tularosa Basin, Nevada
Los Alamos National Lab.	Rio Grande Rift, New Mexico
Utah State U., USGS, LBNL, NREL	Snake River Plain, Idaho

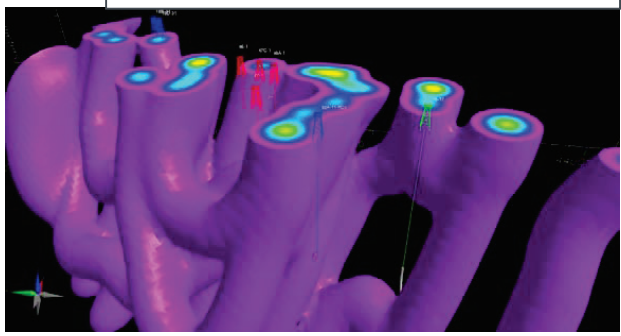
Play Fairway – Recent Results

- **Cornell University, SMU, West VA U: Appalachian**
  - Spatial variations map of 4 risk factors: Heat resource, reservoir rock, seismicity, utilization including permitting & regulatory risks
  - Sedimentary basin focus



- **Nevada Bureau of Mines and Geology: Great Basin**
  - Identify areas with high potential for hosting blind systems
  - Incorporates 10 parameters; multiple data sets with hierarchal weighting

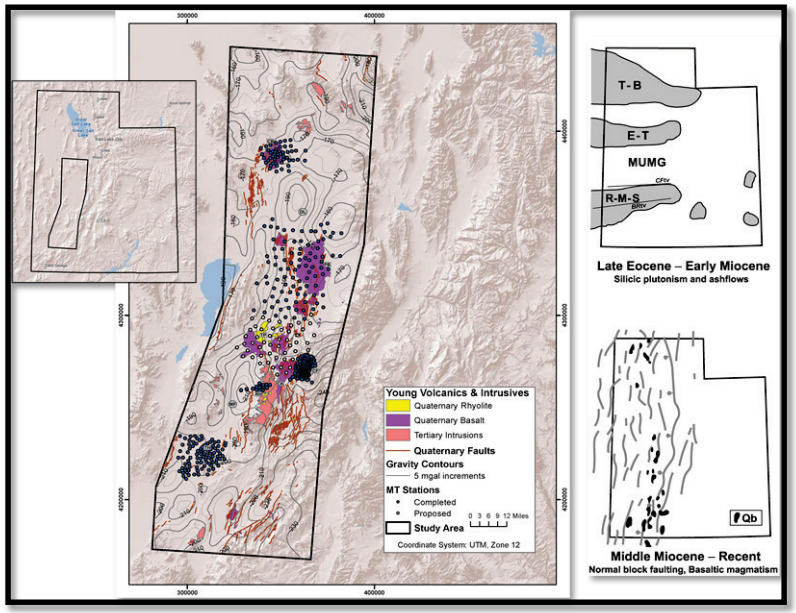




Play Fairway Recent Results

U of Utah, East Great Basin

- Map development
- Goal - confirm that surface indicators can be identified to suggest high temperature upwellings with exploitable fluids/ hot rock



Atlas Geosciences, U of NV Reno, Western Washington State U; Cascades and Aleutians

- Quantifiably rank the geothermal potential of each of the young volcanic centers of the Cascade and Aleutian Arcs

Sponsor: DOE Geothermal Play Fairway Analysis Program Award DE-FOA-0000841

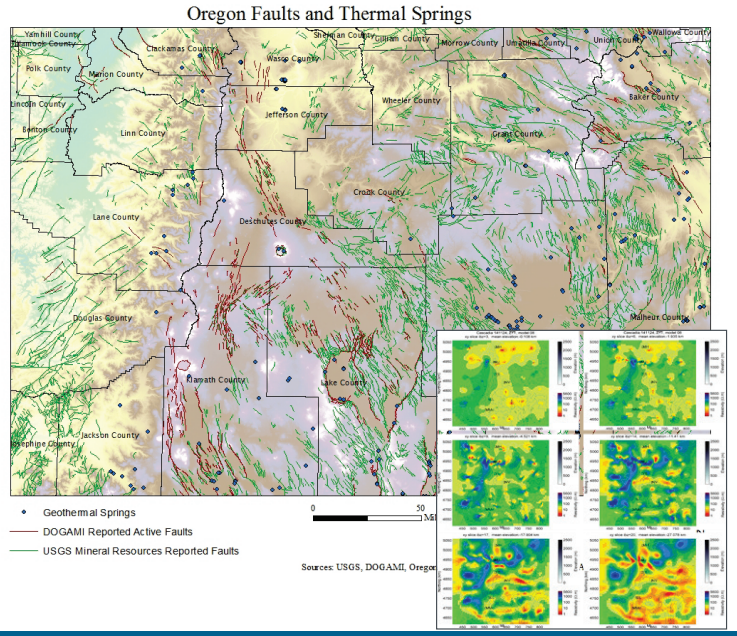
Play Fairway Recent Results

Ruby Mountain, U of Utah: Tularosa Basin

- Couple results with novel reward/failure ratio map and ancillary data to support play ranking
- Geothermal resources and development for Fort Bliss, White Sands Missile Range, Holloman Air Force Base
- Compare data driven hybrid model with knowledge-based model based on petroleum industry standards.

U of Utah, Oregon State, LBNL – Central Cascades

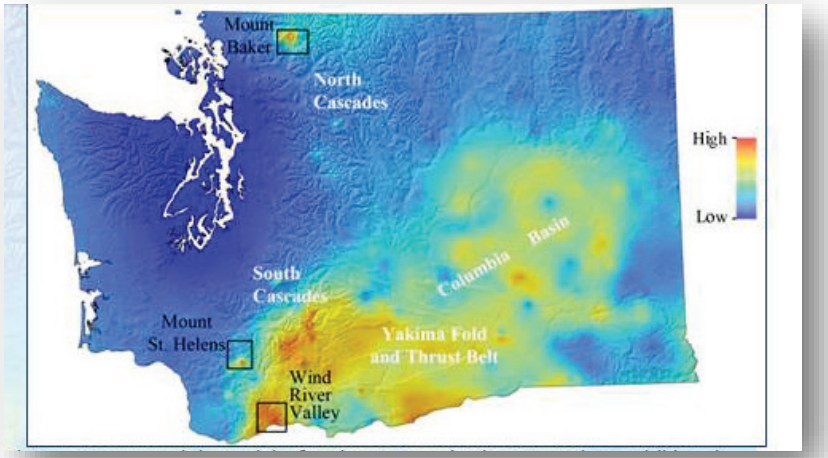
- Map development
- Goal - create conceptual models of volcanic-hosted geothermal resources



Play Fairway Recent Results

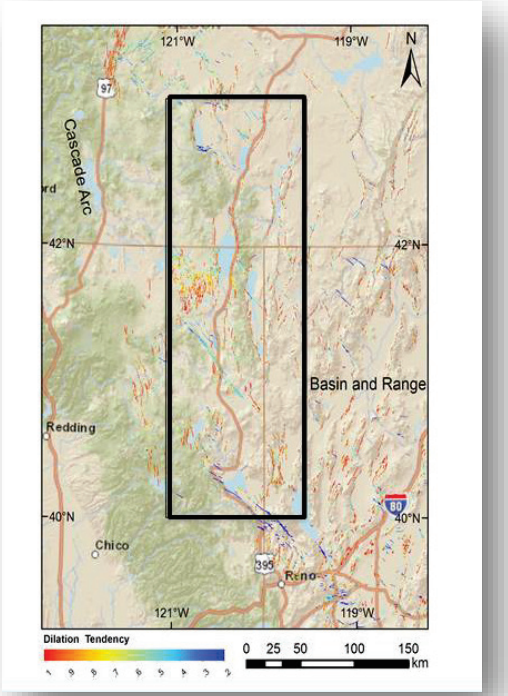
Washington State U, AltaRock, Temple U, BOS Technologies

- Detailed resource modeling first of its kind in Washington
- Three target areas
- Techniques to overcome high vegetative cover



U of Ca Davis, LBNL: MODAC Plateau

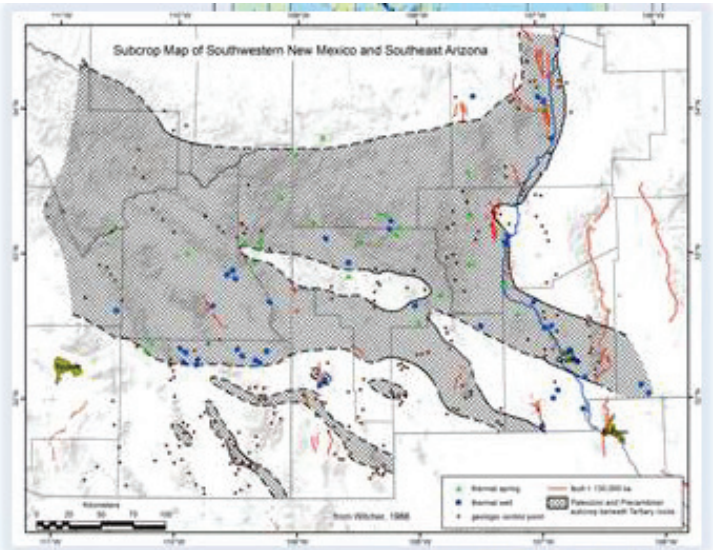
- Hundreds of thousands of data points
- Statistically tested and cleaned for validity



Play Fairway Recent Results

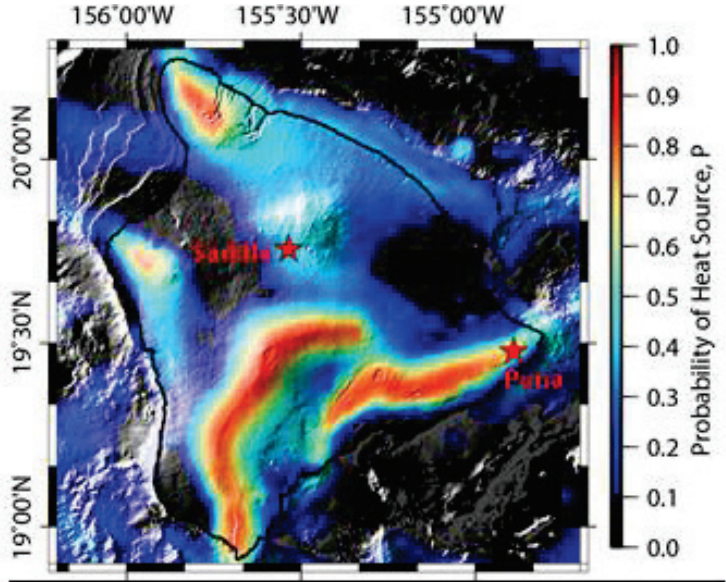
Los Alamos National Laboratory, SMU, Ohio State, New Mexico Inst.

- PF maps of Rio Grande Grand Rift and southern basin and range in NM and AZ



U of Hawaii, UNR

- 90% of energy is fossil fuel
- Current development at Puna with high risk



Above image illustrates geothermal resource probability (high in warm colors) from layering of independent gravity and rift zone mapping data. Stars mark locations of: ***Puna*** (where operational plant exists) and ***Saddle*** (where hot water was encountered during a 2013 drill project in an "unexpected" area as it is off the rift zone).

Utah State University – Snake River Plain

UtahStateUniversity · BOISE STATE UNIVERSITY · BERKELEY LAB · DOSECC Exploration Services · USGS science for a changing world · NREL NATIONAL RENEWABLE ENERGY LABORATORY · leidos

GEOLOGIC SETTING

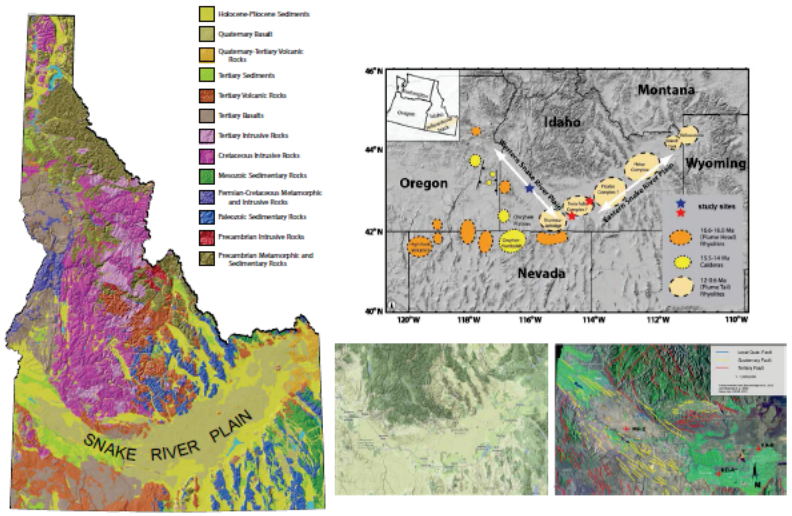


Figure 1. Location, geology, and physiography of the Snake River Plain, Idaho study area. The location of the Mountain Home discovery drill hole and surrounding faults are shown (lower right). Digital topographic map of southern Idaho and surrounding area in the US Pacific Northwest (upper right) showing location of eruptive centers related to the track of the Yellowstone Hotspot (revised from Shervais and Hannan, 2008). The Kimberly and Kimama sites (red stars) are located on the perimeter of the Twin Falls eruptive complex. The Mountain Home site (blue star) is located on the eastern margin of the western Snake River Plain graben.

POTENTIAL FIELD DATA

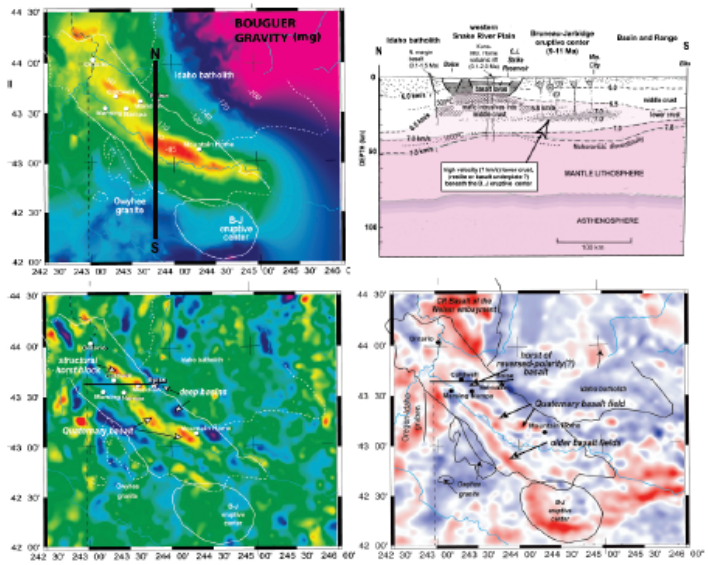


Figure 4. WSRP gravity (upper left), filtered gravity (lower left), crustal refraction model (upper right) and upward continued total magnetic field (lower right) highlighting upper crustal structures related to the WSRP. Gravity data highlight dense volcanic rocks beneath the WSRP. Sub-parallel, basin depocenters (blue) are highlighted along the margins of the WSRP and sub-parallel en-echelon horst blocks (red) that appear along the basin's axis. Magnetic data highlight magmatic intrusions along the southern WSRP margin (red) that do not appear along the northern margin. Key volcanic features are highlighted. Refraction data and models are from Hill and Pakiser (1967) and Prodehl (1979).

Minerals Recovery Rationale

- Potentially add to US production of REE and limited, high value and strategic/critical minerals
  - Rare earth elements (REE)
  - Critical & strategic minerals e.g. tellurium, lithium, manganese, zinc
  - High Value minerals e.g. precious metals
- Added Value Stream
  - Recover critical materials and REE could improve income stream for:
    - Low temperature (<150 deg C) geothermal operations
    - Higher temperature geothermal power plants, oil and gas operations, mining
- Primary Value Stream
  - Potential high mineral concentrations e.g. Salton Sea fluids

Critical Materials Projects

Assessment Projects

- University of CA at Davis
- Planned Results: Data about REE, strategic and critical materials occurrence in US geothermal and produced fluids, and a sampling methodology
- Idaho National Lab – analytical support, standardized brines

Applied R&D Projects

- Carnegie Mellon University, LBNL, PNNL, Southern Research Institute, SRI International, Tusaar
- Planned Results: Assess a variety of extraction approaches for material extraction, recovery, media regeneration and estimated economic success.

Critical Materials Applied R&D Projects

AWARDEE	PROJECT
Carnegie Mellon University	Chelating Resins for Selective Separation and Recovery of Rare Earth Elements
Lawrence Berkeley National Laboratory (LBNL)	Engineering Thermophilic Microorganisms To Selectively Extract Strategic Metals
Southern Research Institute	Geothermal Thermoelectric Generation (G-TEG) with Integrated Temperature Driven Membrane Distillation and Novel Manganese Oxide for Lithium Extraction
SRI International	Engineered Resins for REE recovery
Pacific Northwest National Laboratory	Magnetic Partitioning Nanofluid for Rare Earth Extraction
Pacific Northwest National Laboratory	Advanced Sorbants to Recover Rare Earths, Precious Metals and other Critical Materials
Tusaar Corp.	Environmentally Friendly Economical Sequestration Of Rare Earth Metals

RESOURCE ASSESSMENT: University of CA - Davis

PROBLEM: MINIMAL DATA

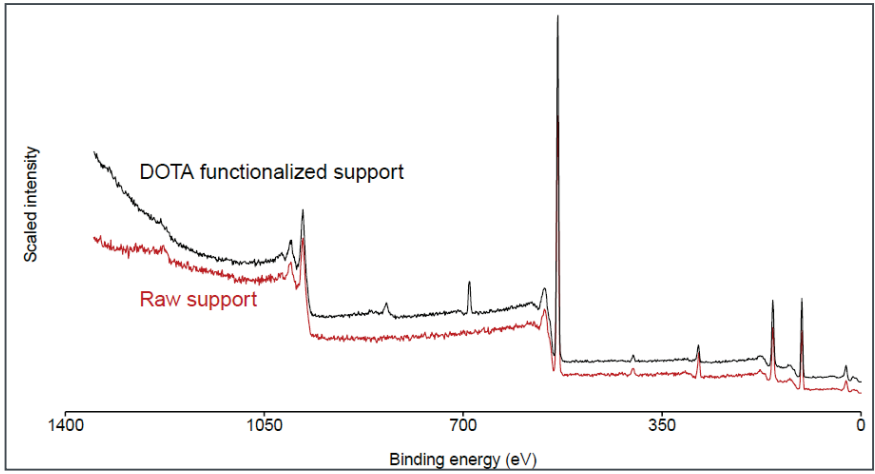
- APPROACH: geothermal fields
  - Quantify partitioning
- REE in US geothermal fluids
  - Specialized equipment to capture down-hole samples
- Model and identify minerals in geothermal systems
  - fluid data, resident alteration minerals

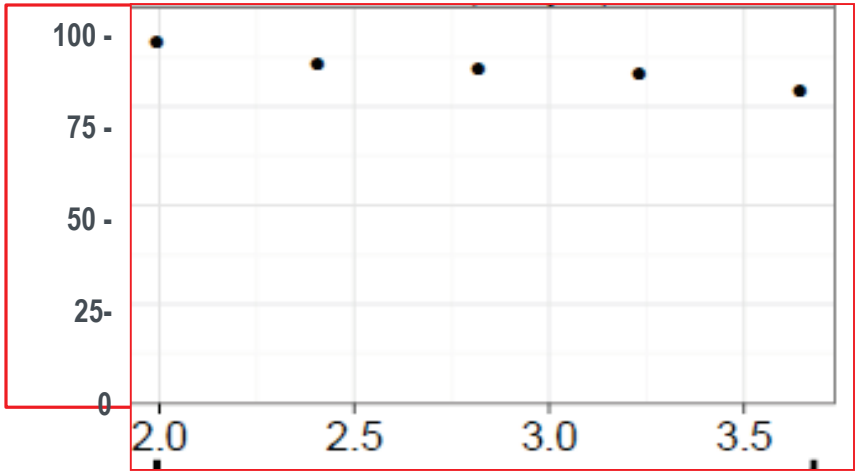
PLANNED RESULTS:

- Establish ability to estimate fluid compositions from mineral analysis;
- Identify promising geothermal systems for optimal REE recovery

APPLIED R&D
Carnegie Mellon University

- High capacity resins
  - Functionalized organic ligands (molecule that binds to a central metal atom)
  - Solid-phase extraction
- Results to date:
  - Robust coupling to a range of solutions
  - Successful uptake of Gd
- End of Phase 1 Plan:
  - Bench-scale verification - effective, economic resin
  - Extract/recover REE
  - Reusable



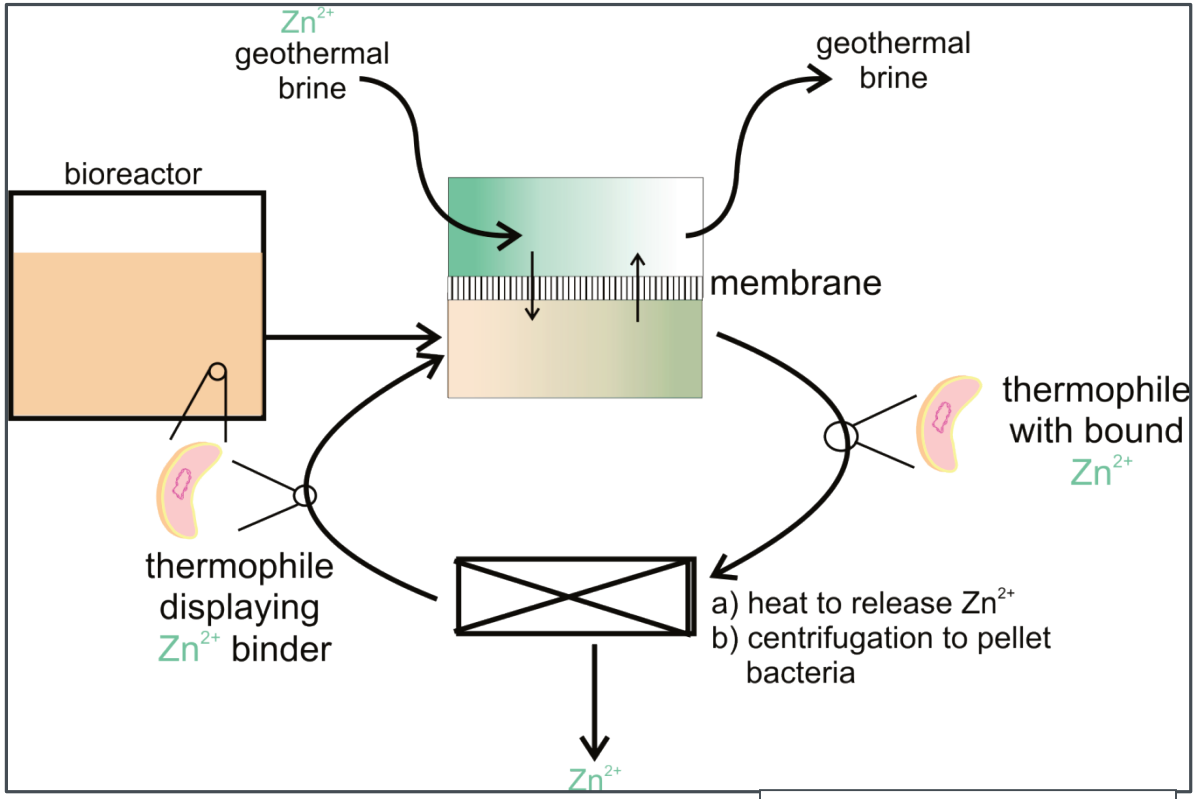


APPROACH

- Combine synthetic biology with materials science
- Evaluate thermophilic microbes
- Selectively absorb target minerals (such as zinc)
- Establish release and regeneration

PLANNED RESULTS:

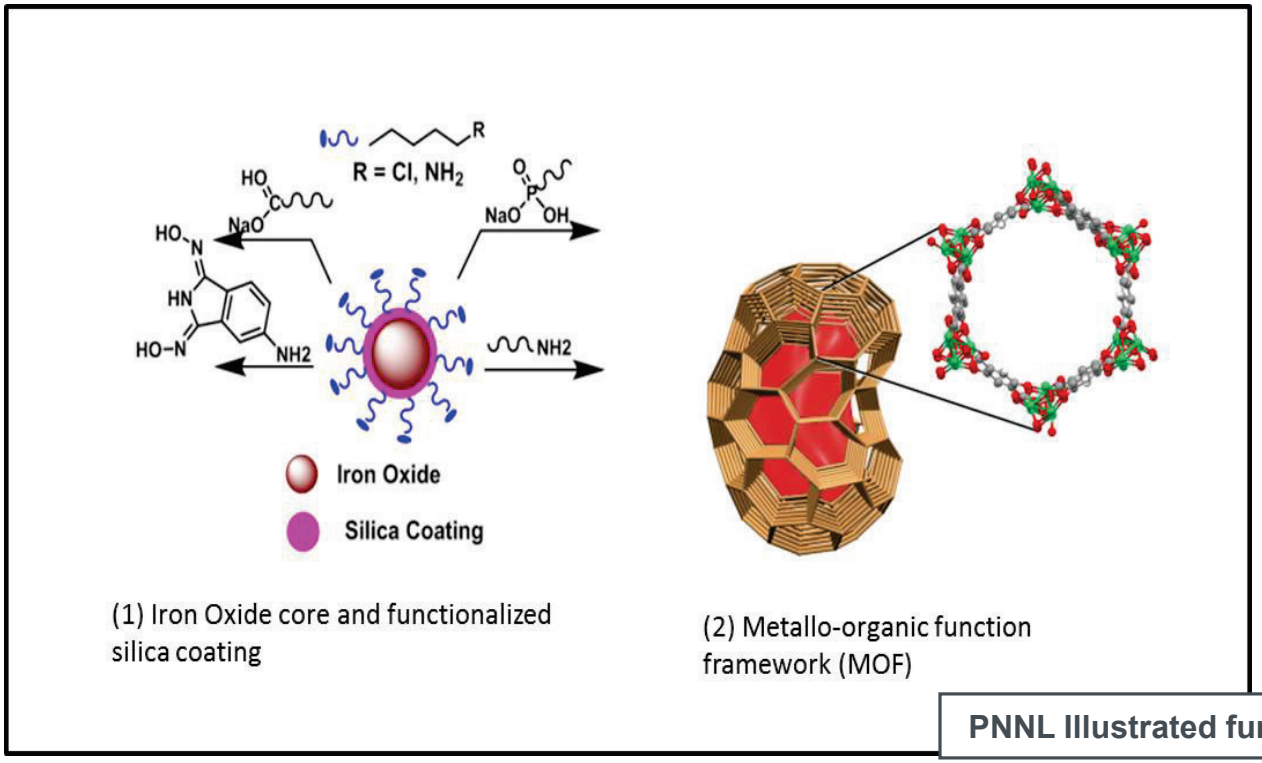
- Successfully and economically harvest metal from waste brines
- Possible wide applications in other industries



LBNL Process Schematic

APPROACH:

- Nanometallic iron core with functionalized coating
- Preliminary adsorption test are 90% efficient



PNNL Illustrated functionality

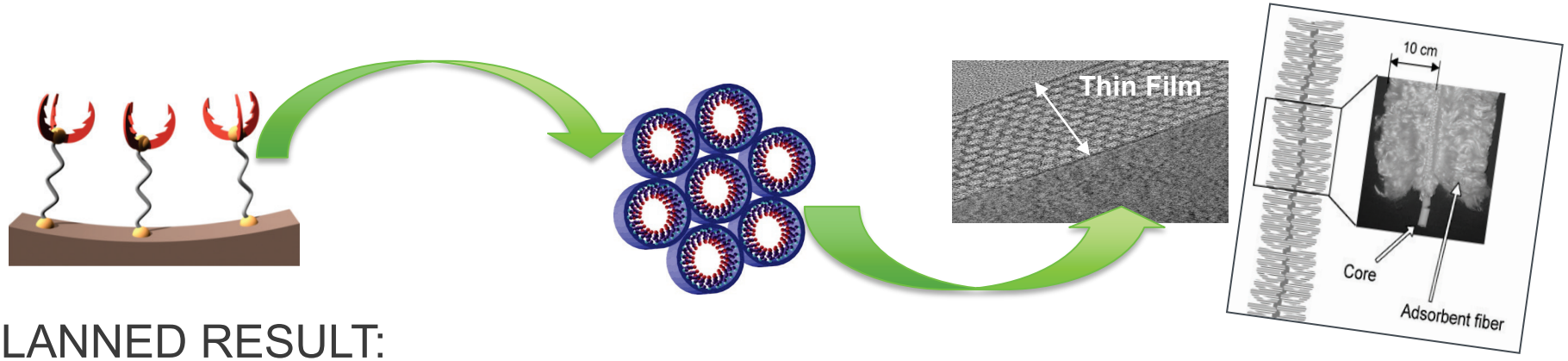
PLANNED RESULT: Bench-scale demonstration selective extraction and preliminary economic analysis.

APPLIED R&D: Pacific Northwest National Laboratory

Extraction Methodologies Compared				
Element Tested	**Advanced Composite Sorbant**	Ion Exchange Resins	Chelating Resin	Activated Carbon
REE	**~ 4,300**	2 to 40	3	12
Gallium	**530**	20 to 90	7	6
Ruthenium	**1200**	20 to 40	49	38
Silver	**230**	15 to 80	16	8
Uranium	**3,500**	50 to 70	44	130

Process design parameters:

- scalable,
- flexible design,
- clean operations,
- solid phase technology

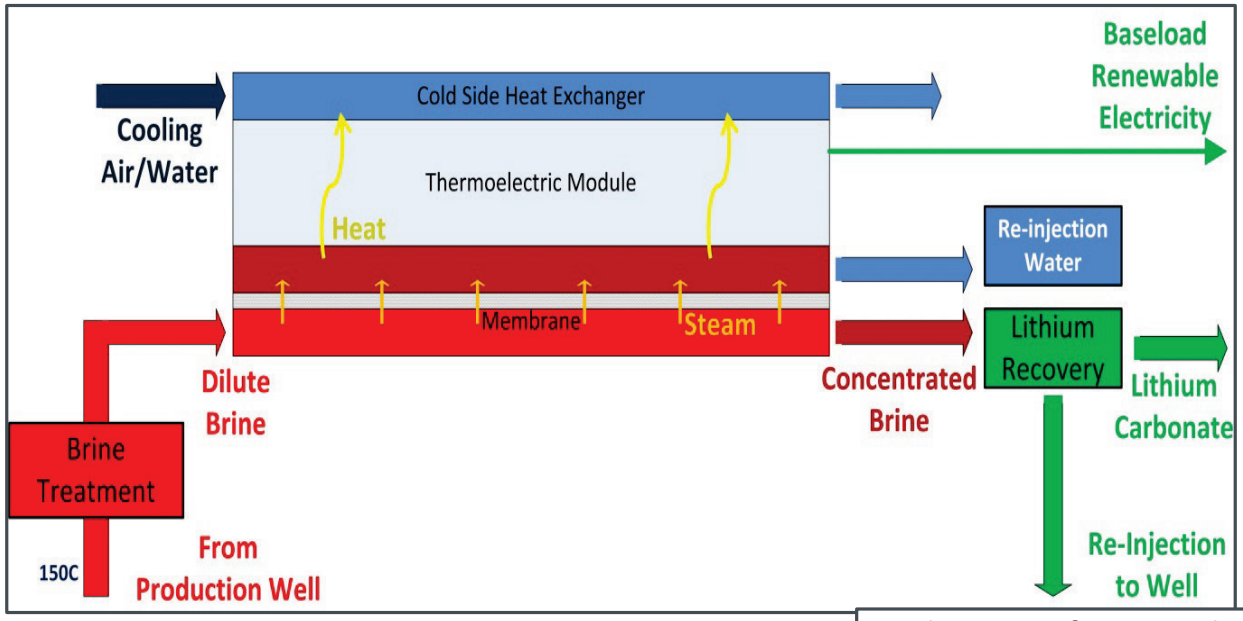


PLANNED RESULT:

Demonstrate effective extraction, suitable for a wide range of applications.

APPROACH

- Combined power generation and mineral recovery
  - Model components and systems, conduct bench tests, techno-economic analysis



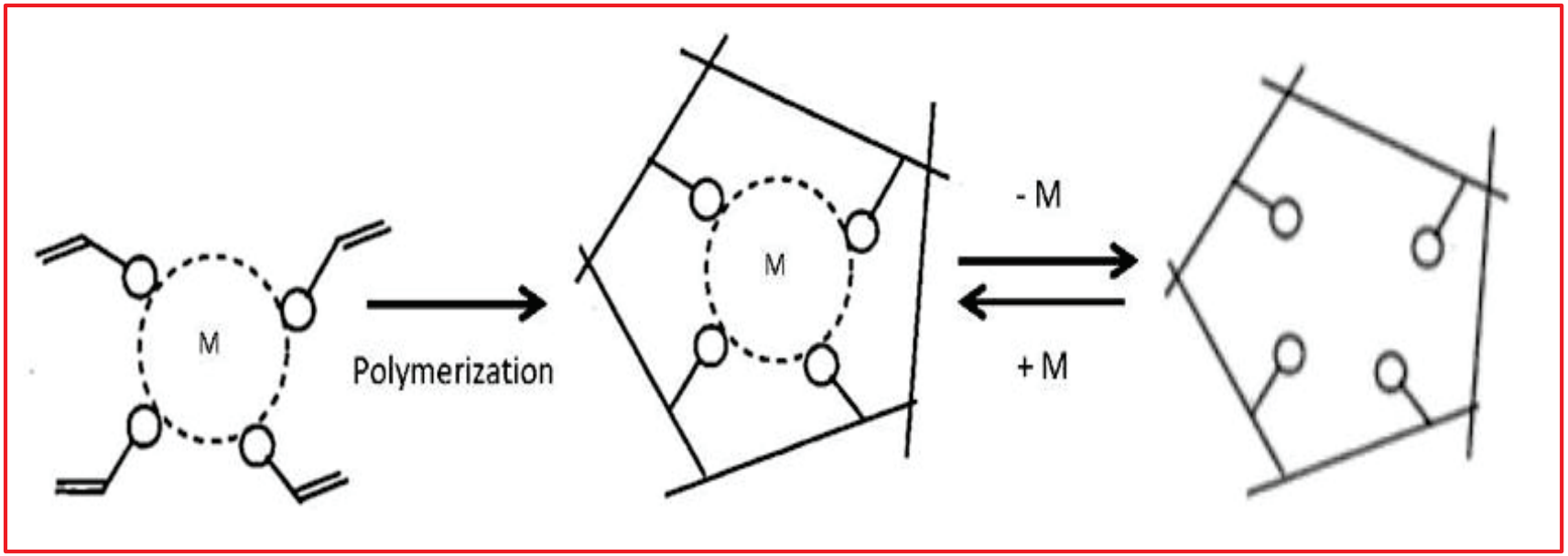
Schematic of proposed Southern's process

PLANNED RESULT: Demonstrated performance of a 'Geothermal Thermoelectric Generation' system combined with effective mineral extraction from the geothermal fluids.

APPLIED R&D: SRI International

APPROACH

- Develop and validate selective ion exchange resins
  - Metal ion-imprinted, macroporous bead
  - Evaluate extraction processes, bead regeneration and durability



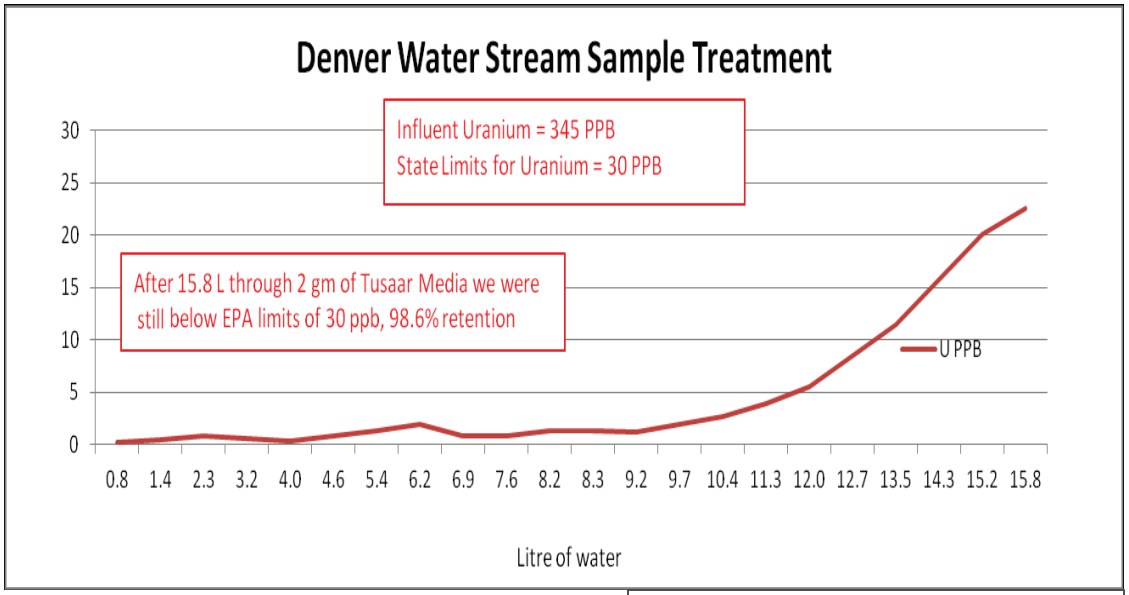
PLANNED RESULT: 90% efficient imprinted polymers over temperatures from 45 to 100 deg C.

APPLIED R&D: Tusaar, Inc.

APPROACH

- Evaluate Tusaar media to extract REE and other critical materials
  - Ability to extract target minerals, recovery capabilities
  - Media regeneration and cycles for reuse
- Assess fluid quality impacts (e.g. hardness, pH, TDS, flow rates, temperature)

Tusaar Media



Example of Tusaar media effectiveness

PROPOSED RESULT: Demonstrated effectiveness and estimate of technical effectiveness and economic recovery

Geothermal Concepts and Approaches to Validate Mineral Recovery

REQUEST: Input on ideas in 3 categories to encourage increased development of geothermal resources through recovery of dissolved critical materials.

CATEGORY 1: Explore extensive engineering validation testing of feasible technologies or processes that can efficiently and cost-effectively capture, concentrate, and/or purify high-value materials

CATEGORY 2: Concepts and approaches that can be combined drilling technologies, rock stimulation technologies and mineral extraction technologies (for example solution mining) to combine geothermal/heat mining with mineral extraction from deep rock systems.

CATEGORY 3: Existence and concentration of high-value materials in U.S. geothermal fluids or low-temperature process streams or assessing U.S. resources as a whole.

Responses no later than 5:00 pm (ET) Monday, June 8, 2015

Risk and Uncertainty Management in Geothermal Exploration

Seeking information on risk quantification and management in geothermal exploration:
- especially as it pertains to decision making in late stage exploration activities such as drilling and advanced geophysical surveys.

GTO is specifically interested in information on current opportunities to develop, test, and validate risk and uncertainty models for prospects that have already been identified by industry.

QUESTIONS?

CONTACT INFORMATION

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