GEOTHERMAL ENERGY: Global Reach, Local Impact

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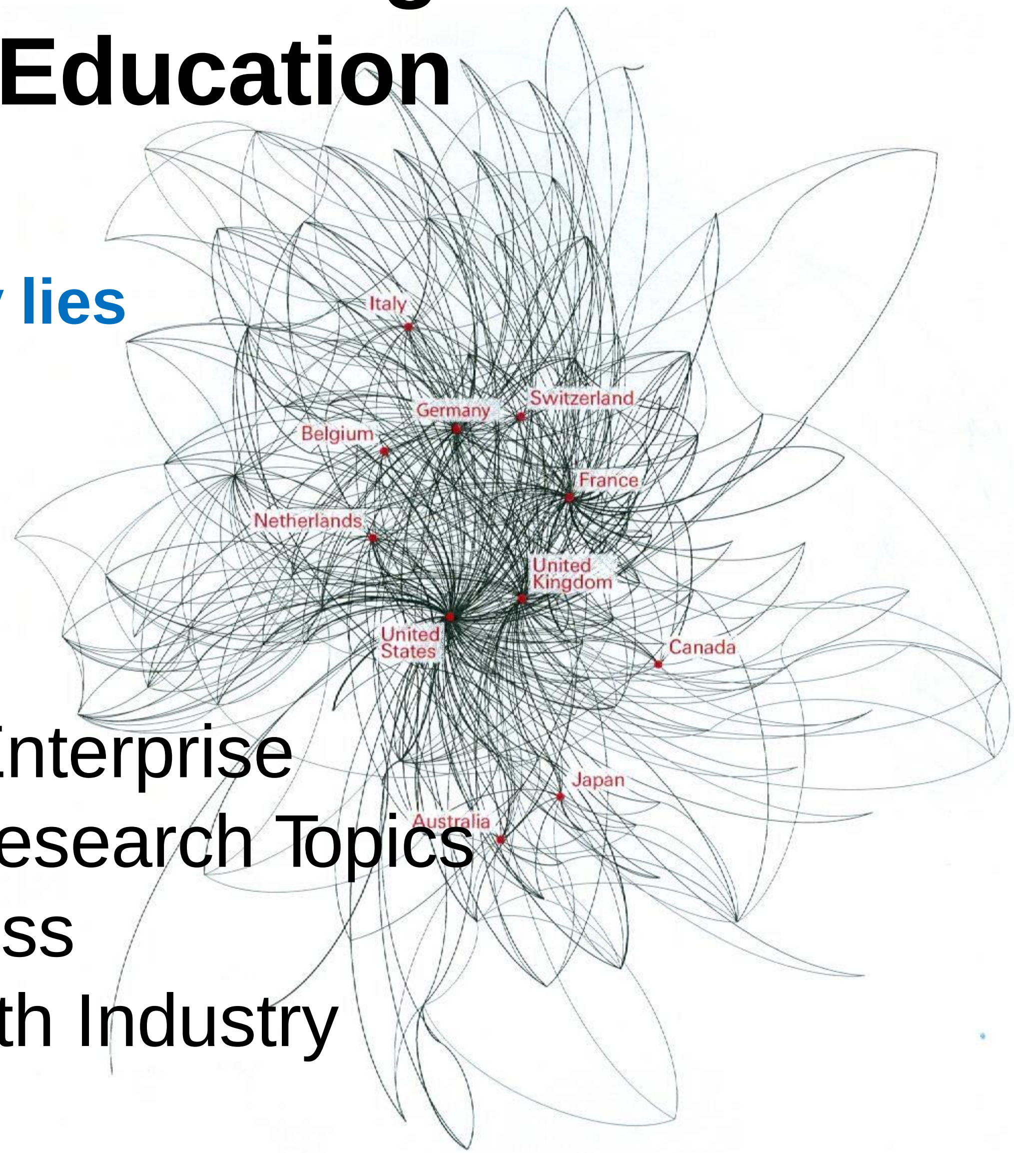
Colorado collaboration for **Su**bsurface Research in **G**eothermal **E**nergy (SURGE)

Opportunities and Challenges for Research and Education

"In the middle of difficulty lies opportunity"

Albert Einstein (1879 - 1955)
Physicist & Nobel Laureate



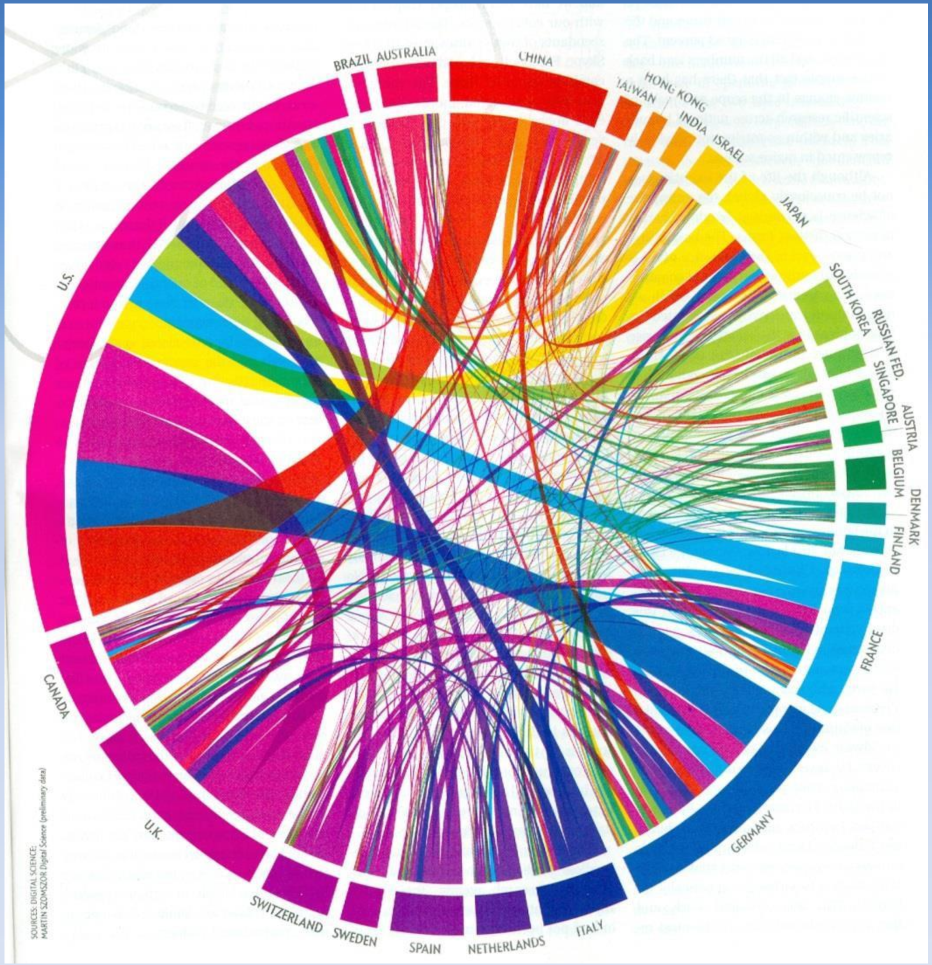
Borderless Knowledge Enterprise
Global Prioritization of Research Topics
Big Data and Open Access
Evolving Relationship with Industry
STEM Workforce Needs

Visualization by the Force Algorithm
Knowledge, Networks and Nations: Global Scientific Collaboration in the 21st Century: The Royal Society (2011)

Borderless Knowledge Enterprise

Global reach of research networks and accelerated pace of innovation monitored through indicators of research activity – published articles, collaborative work, new countries actively engaged in major science.

Founded in simplicity, speed and ease of communication, and creating an open intellectual ecosystem drawing in more smart people, expanding the pool of talent, with a flow of ideas across the globe.



Graphic: J. Sexton, Scientific American (2012): Collaboration among 25 nations. Source Digital Science

Global Prioritization of Research Topics

A Global prioritization of research topics has emerged which, for any one nation, may be of lesser significance.

Global Challenges require Global Solutions including eradication of poverty; water, food and energy for people; education of women; and sustainable urbanization.

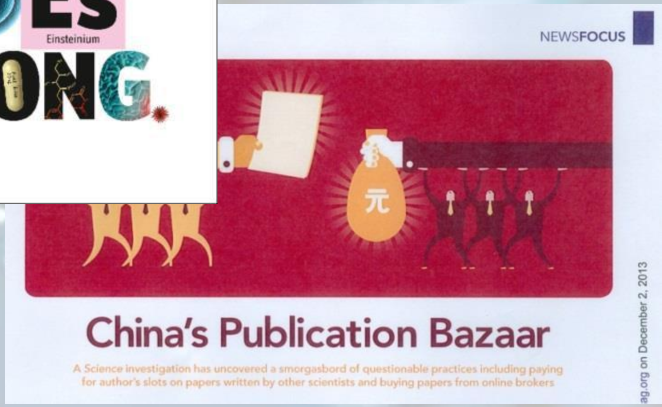
Big international research projects become possible.

Risks include exclusion of those w/o adequate access to internet and advanced education; loss of voices at the margin who challenge orthodoxy; lack of policies, quality control, IP management and confused funding sources.

Big Data and Open Access

A New Era of Cyberinfrastructure touches everything in STEM research and education: capacity to observe at scales that range from the universe to the subatomic; to record, store, and manipulate vast data sets; to share through the Open Data Access mandate; and to enable access to education for vast numbers of people brings new challenges including:

- ***Who has ownership, access, pays, benefits, curates, decides, and assures quality.***



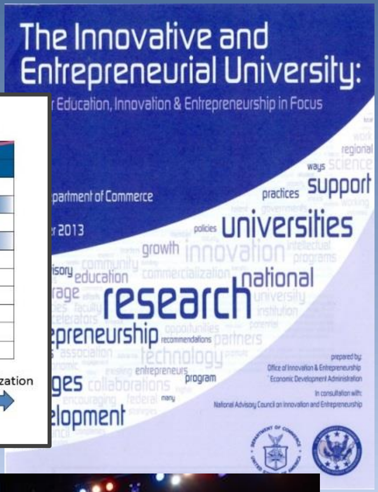
Evolving Relationship with Industry

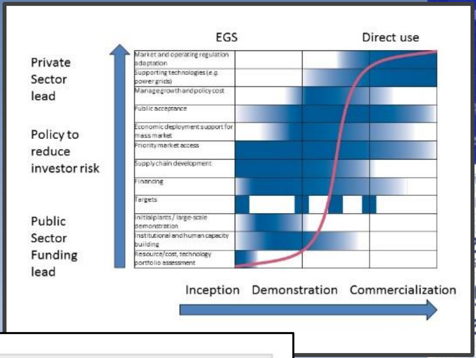
Storied history of global transformation led by America's research universities.

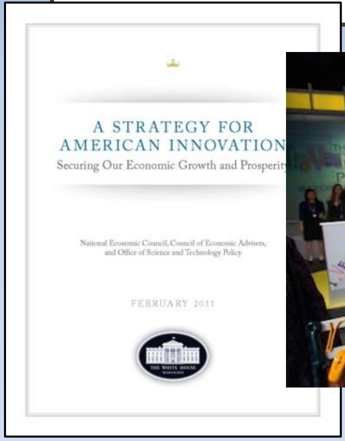
As corporate R&D facilities are dismantled the role these served has been transferred to a combination of research universities and the national laboratory system.

A national emphasis on innovation offers significant rationale to define new expectations of the university-national laboratory-industry partnership.

NSF 2015: $25M for iCORPS program







THE InVENTURE PRIZE™

2014 Georgia Tech Winners designed an inexpensive, mobile toilet bringing relief to refugees in the developing world

STEM Workforce Needs

Innovation and the global knowledge enterprise demand a workforce that goes beyond the professional scientists, engineers and mathematicians.

"STEM Competencies" the set of cognitive knowledge, skills, abilities in ever increasing demand.

- STEM occupations will grow from 6.8 million to 8 million total jobs by 2018
- STEM occupations will provide 2.4 million job openings through 2018, including 1.1 million net new jobs and 1.3 million replacement jobs due to retirement
- 92% of STEM jobs will be for those with at least some postsecondary education and training.

Georgetown University Center on Education and the Workforce, 2011.

UNITED NATIONS DECADE OF SUSTAINABLE ENERGY FOR ALL 2014-2024

“Energy is the golden thread that connects economic growth, increased social equity, and an environment that allows the world to thrive.” UN Secretary-General Ban Ki-moon*

- Achieve universal access for modern energy services
- Double global rate of improvement in energy efficiency
- Double the share of renewable energy in the global energy mix

Investing in renewable energy creates jobs, fosters economic growth, and improves energy security for countries that lack domestic fossil fuel resources

*www.sustainableenergyforall.org

Sustainable Energy Development: "Time to Get Real"

WORLD ENERGY COUNCIL

Three conflicting goals:

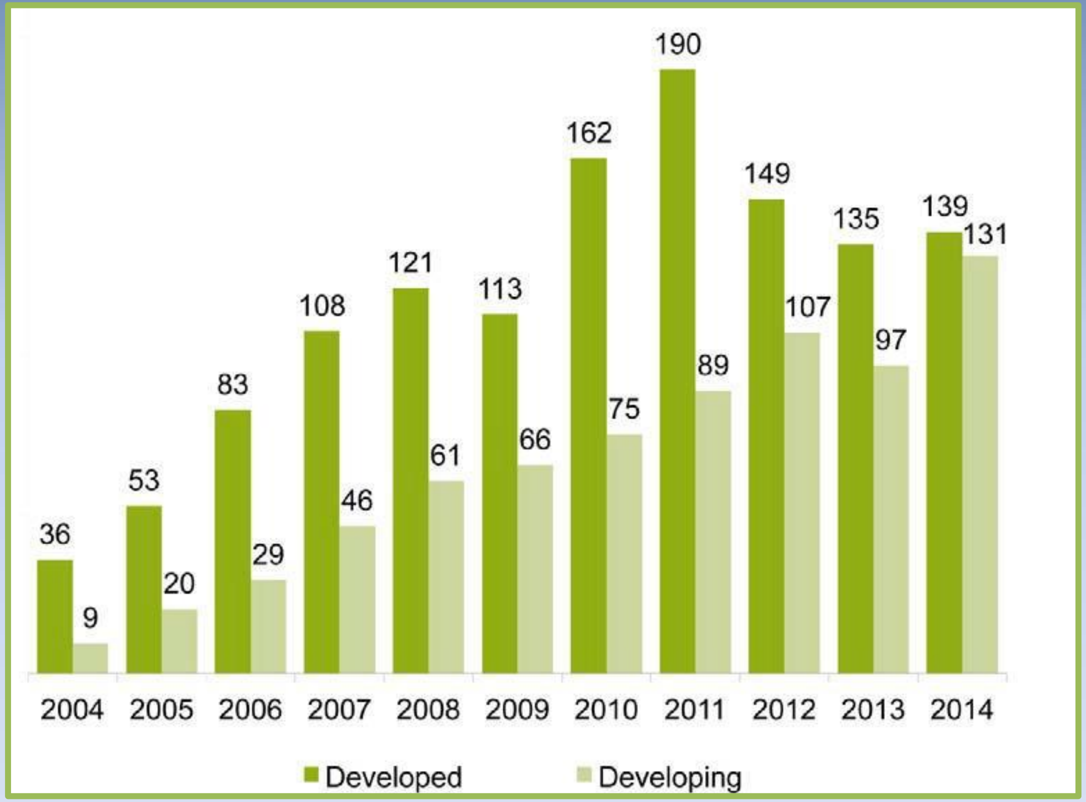
- Energy Security
- Energy Equity
- Environmental Sustainability

Actions:

- Encourage technological advances
- Share knowledge, technical expertise and experience
- Communicate in a common language for business, policy, technology
- Develop proactive energy policies
- Align investment risk and policy

Global Solutions for Global Challenges:
Assist developing countries with charting new energy course

- 17% without access to electricity
- 41% lacks access to clean water
- Experience, knowledge, and skills should be proactively transferred

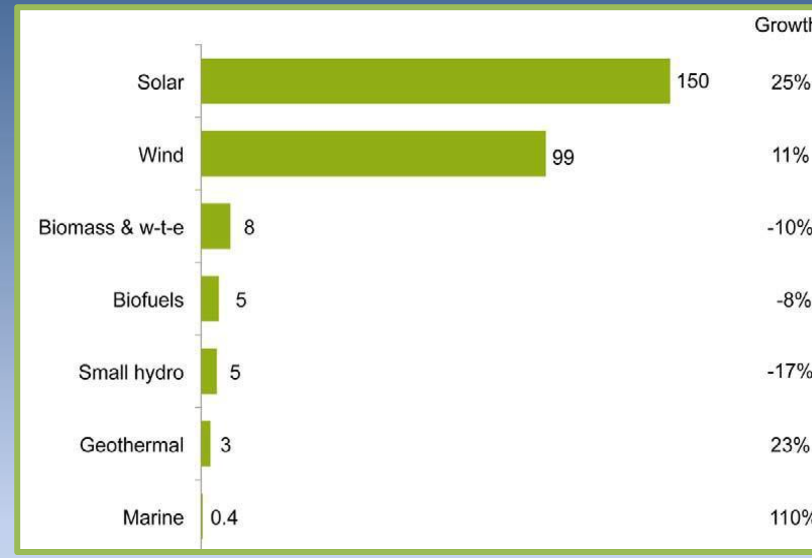


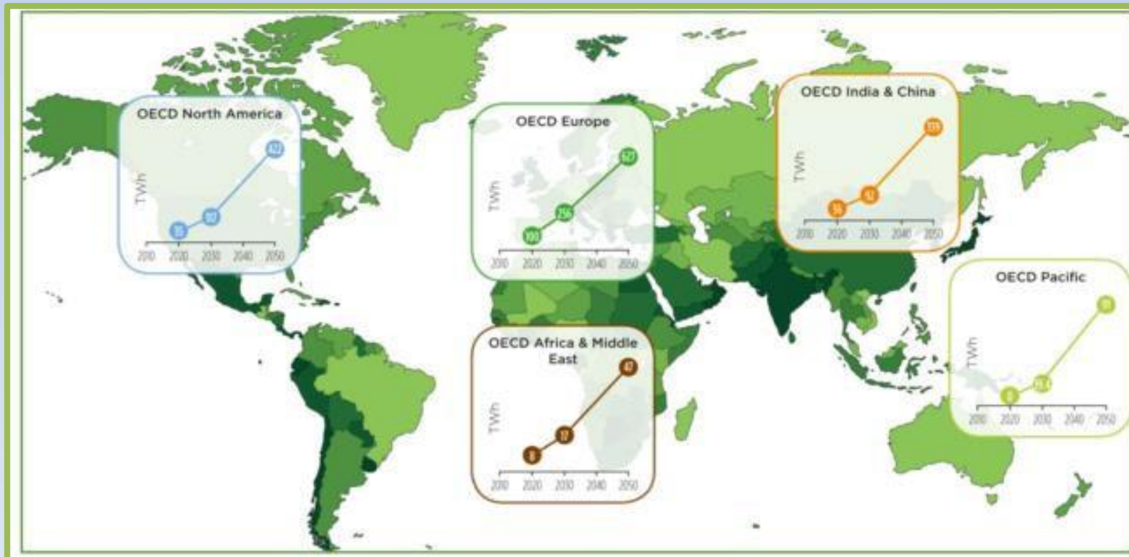
Global new investment in renewable energy: developed vs developing countries, 2004-2014, $Bn

Source: UNEP, Bloomberg New Energy Finance, 2015

Geothermal Energy

Proven technology enabling a sustainable energy portfolio for the world





Geothermal heat and power roadmap, International Energy Association

Global new investment in renewable energy by sector, 2014, and growth on 2013, $Bn

Source: UNEP, Bloomberg New Energy Finance 2015

Global Solutions for Global Challenges:
Assist developing countries with clean water

"Overcoming the crisis in water and sanitation is one of the greatest human development challenges of the early 21st century"

#1: A new method for desalination: scalable, low cost, and using renewable energy.

Sources: United Nations Development Programme; LIGTT, 2014; NAE Grand Challenges

Water is a National issue, too

Drought Impacts California's Energy; Governor Brown's Response Plan (Executive Order B-29-15) April 25, 2015

…shall implement a Water Energy Technology program …accelerating use of cutting-edge technologies such as renewable energy-powered desalination…..

with energy implications….

Carlsbad, CA's Desalination Plant (Poseiden Water, MA)

"And to remove the salt, the plant will use an enormous amount of energy -- about 38 megawatts, enough to power 28,500 homes -- to force 100 million gallons of seawater a day through a series of filters."

Source: Paul Rogers, San Jose Mercury News

Geothermal Energy in the US

- Embrace the sustainable energy portfolio
- Research and development status is mature
- Focus on technology transfer, process optimization and industry engagement
- In detail, different applications need technological advances, demonstration, and commercial consolidation
- The policy journey enables offset of risk

It’s just one Earth!

- Opportunities arise from multiple interests in subsurface
- Leverage experience, knowledge and investment of others
- The Grand Challenge of interdisciplinary, multi-scalar approaches to characterize and interpret the Earth transcends resource

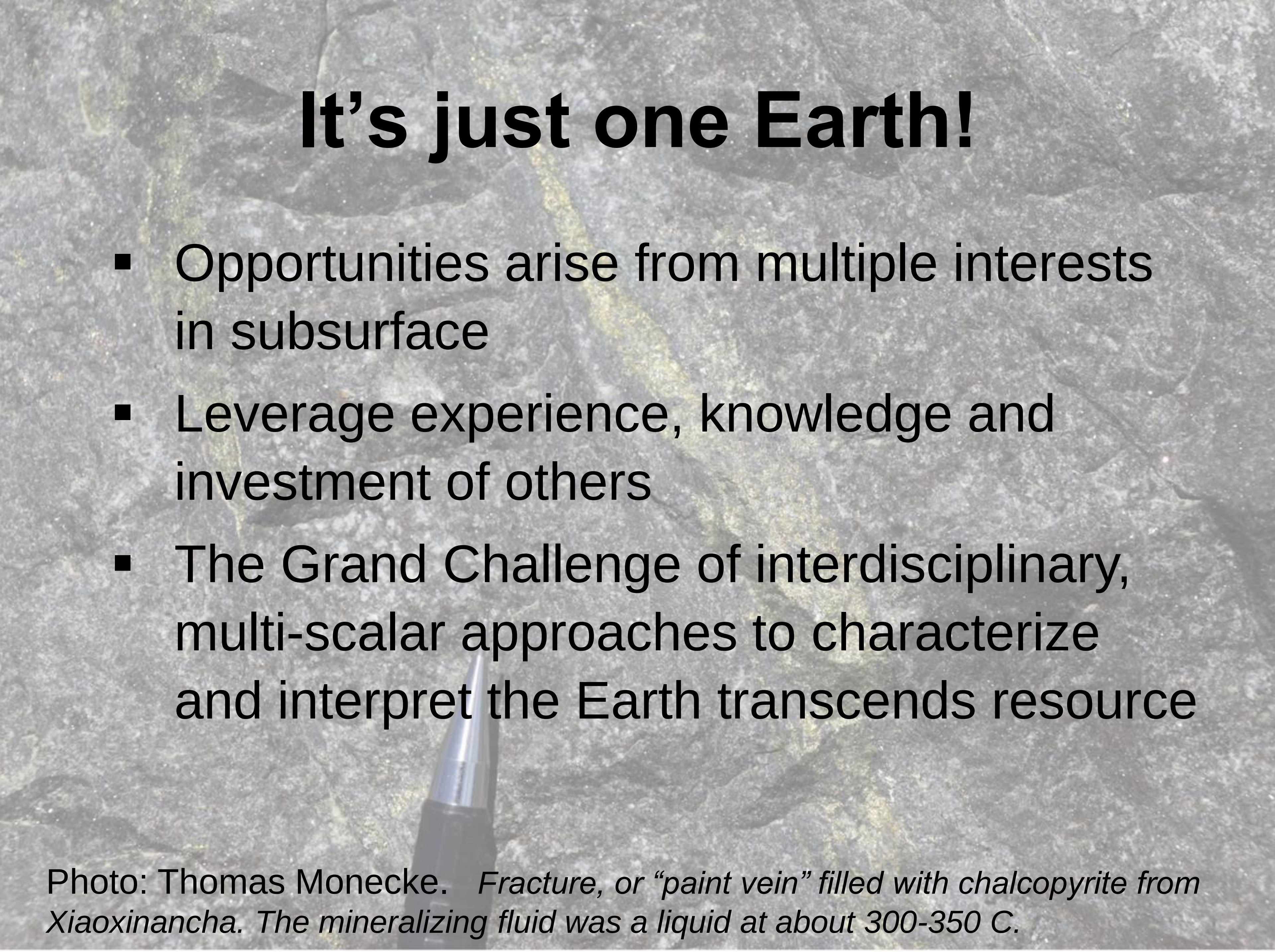
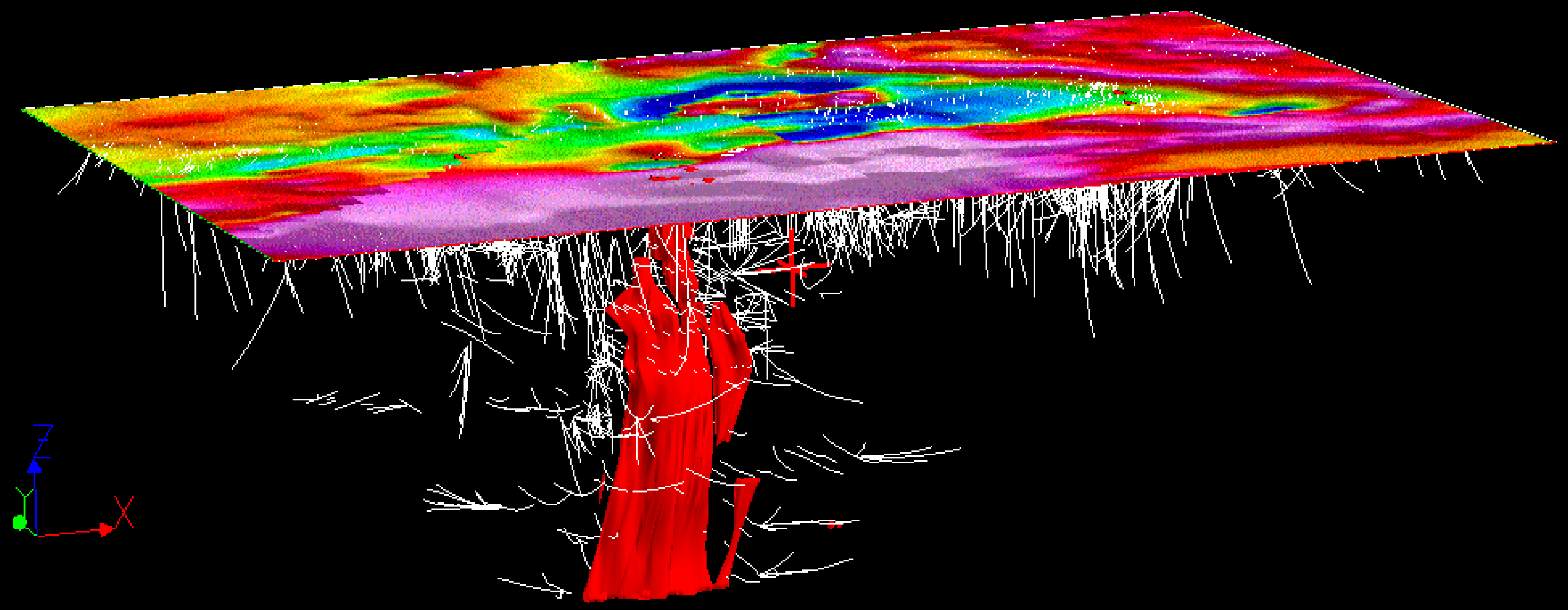


Photo: Thomas Monecke. *Fracture, or “paint vein” filled with chalcopyrite from Xiaoxinancha. The mineralizing fluid was a liquid at about 300-350 C.*

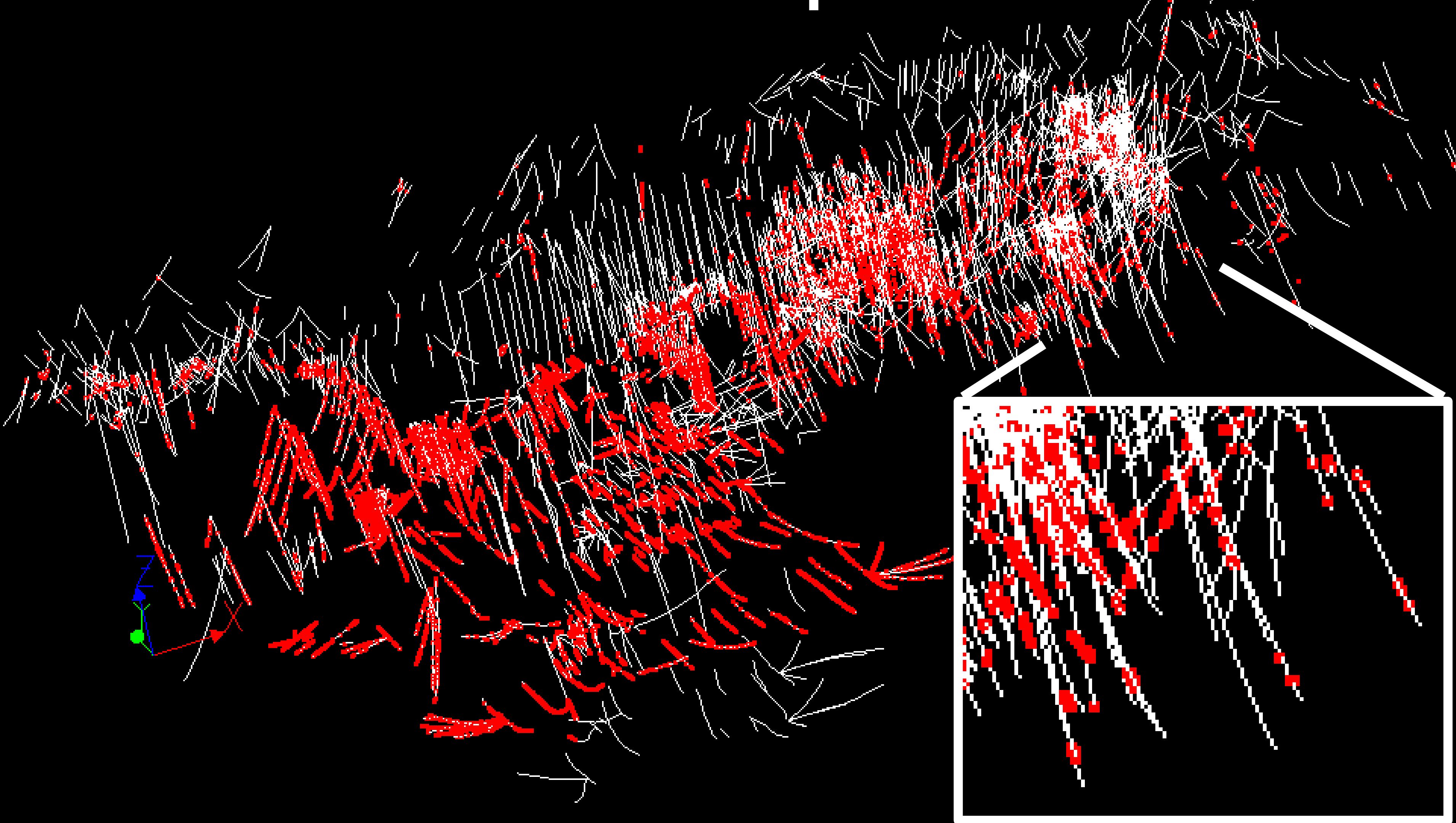
From Kilometers to Micrometers



Regional model (7 km across) of the giant Horne, Quebec volcanic-hosted massive sulfide deposit. The deposit shows up as the red body going towards depth. Strata are vertically dipping. The white lines show drill holes from surface. The surface is a projection of the ground magnetic signature. Modeled in Gocad.

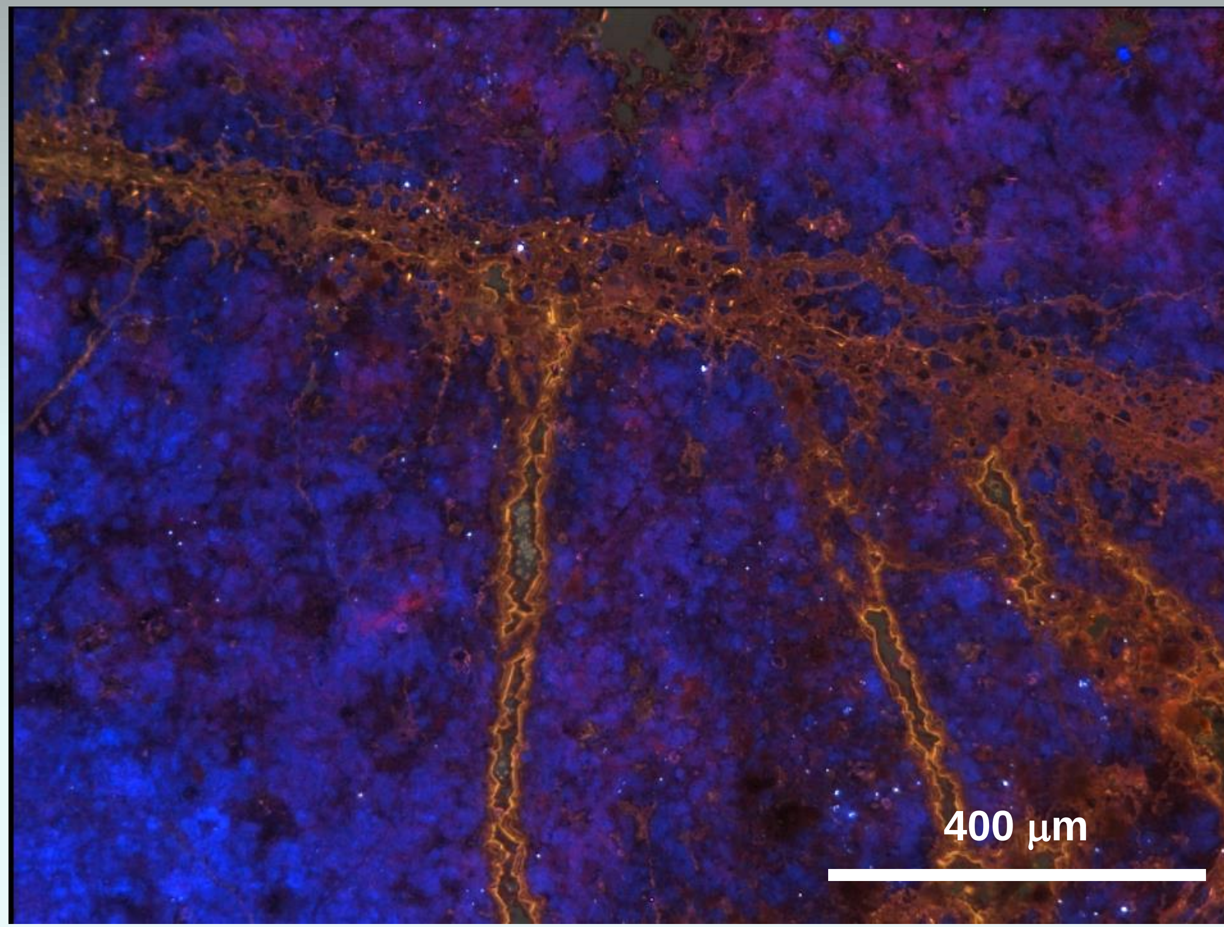
Source: T. Monecke

Data Resolution and Spatial Distribution



Same model as previous slide; white lines are the drill holes and red points are locations for which elemental data are available (up to 100 variables per 1 m interval)

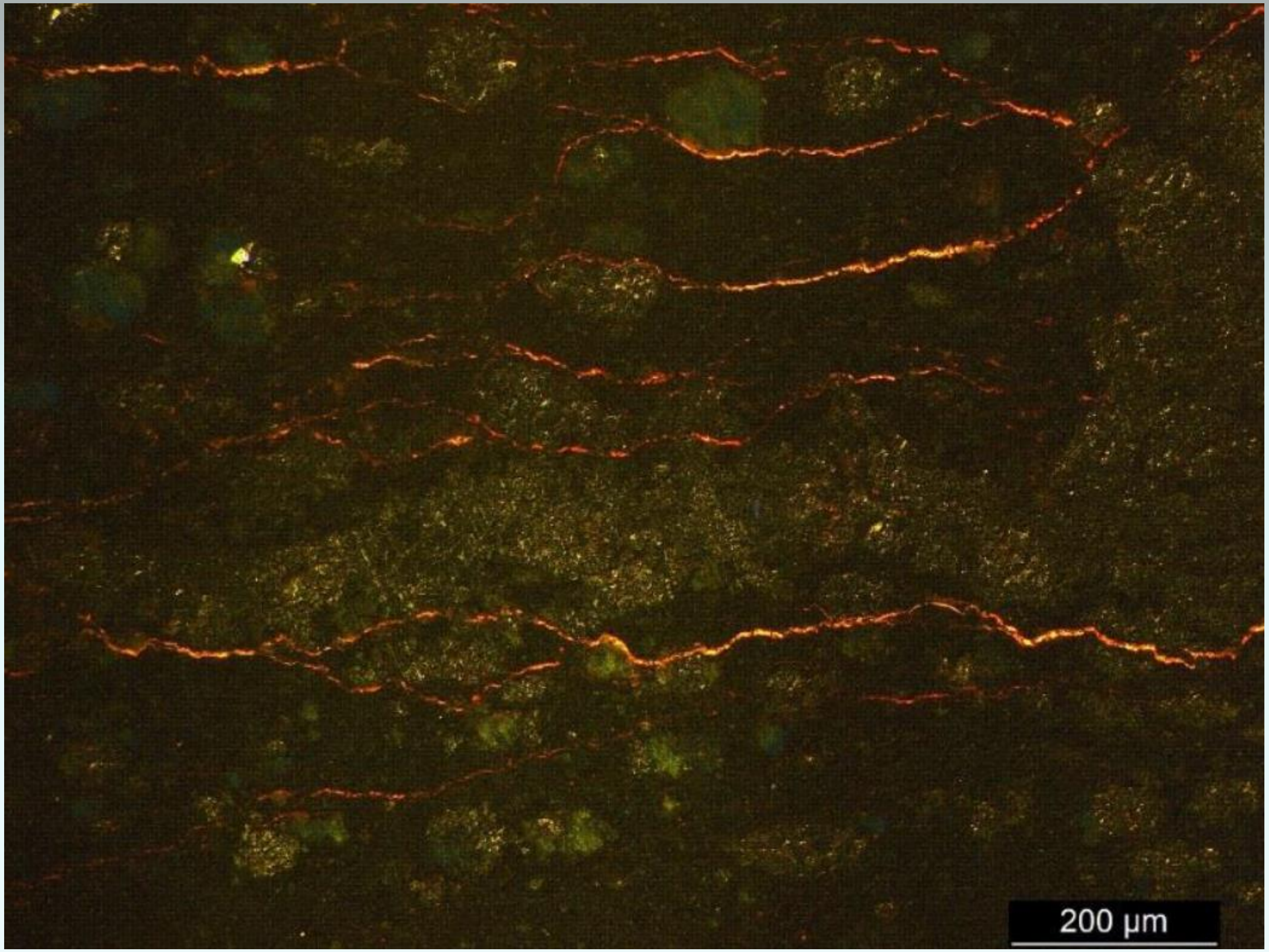
Understanding heat and mass transfer in fractured rock is a timeless challenge



Two generations of quartz: blue, >500C vapor deposit and yellow-brown <250C hydrothermal quartz. Veladero deposit in Argentina (13-11 Ma), is host to 11 million ounces of gold.

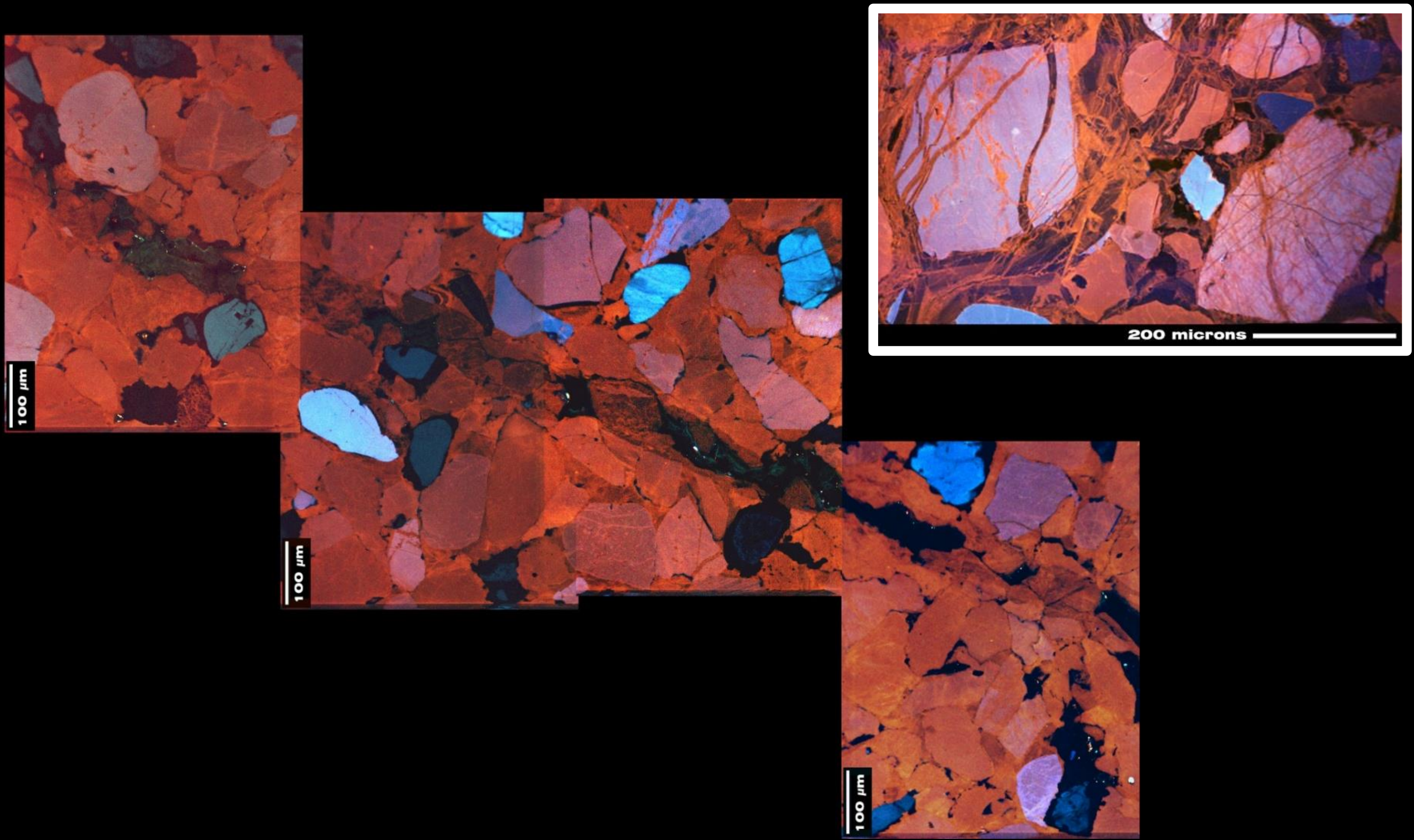
Photo: E. Holley, T. Monecke, J. Reynolds

Fractures in Bakken Shale:
Water? Oil? Gas? Heat?



Source: S. Sonnenberg

Fracture distribution controls movement of hydrocarbons, water, and mineral-bearing fluids



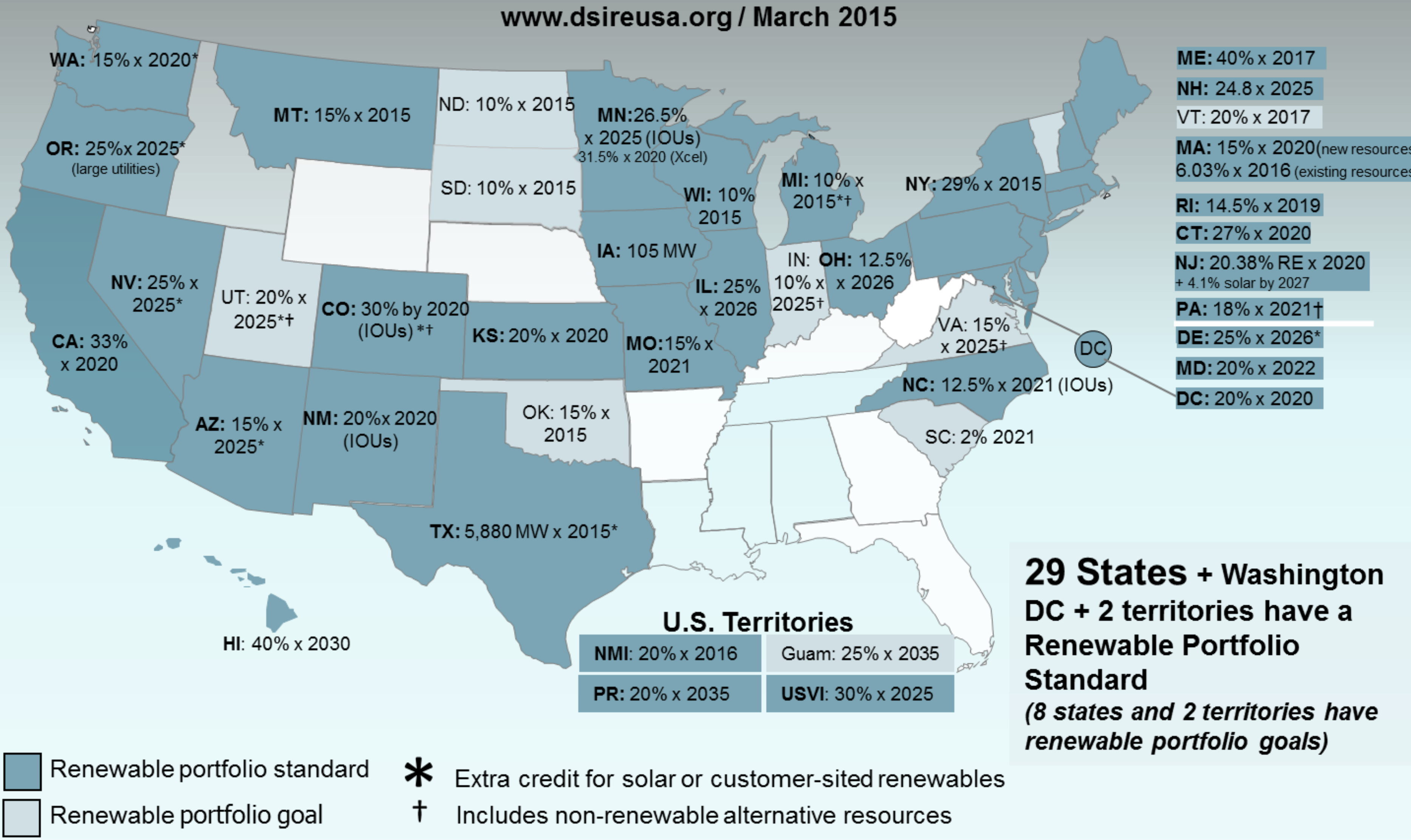
Fall River Formation Wyoming fractured sandstone with oil staining

Source. http://www.geo.utexas.edu/faculty/mosher/RobReed/sandstone.html

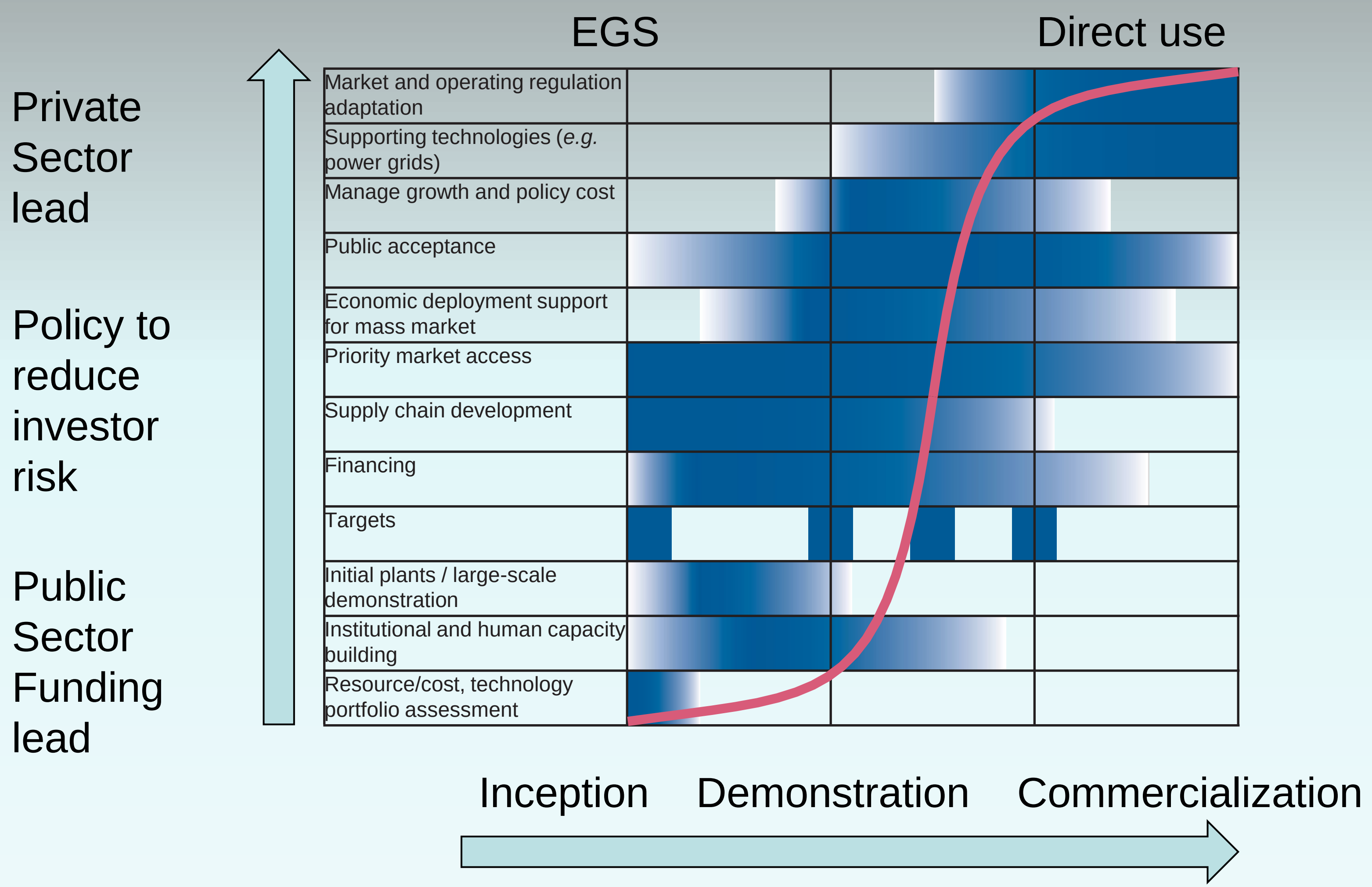
Distribution of Energy Resources: Science underpins policy

Source: Tinker, 2015

Renewable Portfolio Standard Policies



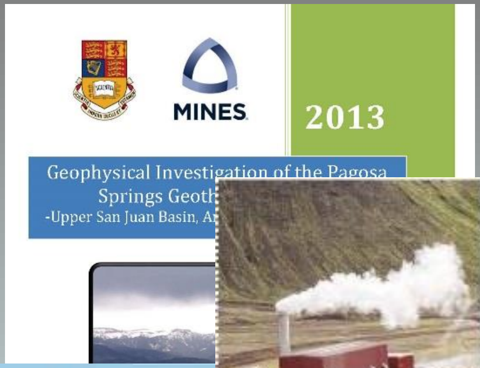
Policy Priorities Change as Deployment Advances

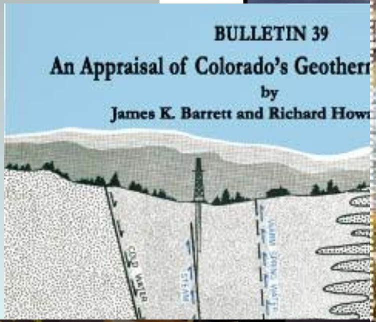


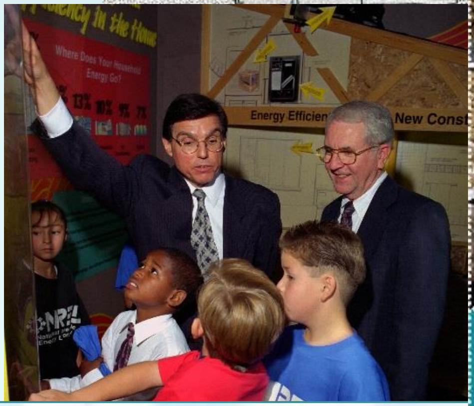
Cell shading reflects the relative significance of individual issue along the deployment path. Dark shading indicates high significance of the respective intervention. Light shading suggests that intervention is required but lower priority. Source: OECD/IEA 2011

Education and Outreach

- Rural vs urban
- Regional infrastructure vs local direct use
- Off-grid
- Citizen engagement and support
- Policy and commercialization have different roles and scales
- Provides developing nation relevance







Colorado SURGE

Subsurface Research in Geothermal Energy

Founding Partners:
National Renewable Energy Laboratory
Colorado School of Mines

NREL NATIONAL RENEWABLE ENERGY LABORATORY

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

Outcomes

- Collaboration on geothermal research and development
  - National leadership emerging at frontiers of energy science and technology
  - Joint faculty/staff appointments
  - Joint technical leadership
- Outreach activities connecting oil and gas and geothermal sectors and policy makers
- Graduate and undergraduate student engagement in geothermal energy
  - Workforce development
  - Educational support
  - New geothermal curriculum

Projects

- Desalination using low-enthalpy geothermal energy
- Flow characterization in fractured rock network at Edgar Mine
- Feasibility assessment of geothermal production in sedimentary basins
- Application of petroleum best practices to geothermal drilling and completions
- Innovative completion of horizontal geothermal wells

FY	Funding, $K
2014	$ 800
2015	$1,223
2016	pending

Geothermal Energy has a special future in global solutions for global challenges

- Critical to the Sustainable Energy Portfolio
- The Policy Journey must enable
- Leverage subsurface knowledge base
- Multi-disciplinary, multi-organizational, multi-national