HARNESSING VULCAN'S MIGHT

An Overview of Geothermal Energy

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YALE ALUMNI IN ENERGY CONFERENCE

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New Haven, Connecticut

PRESENTATION OUTLINE

The Geothermal Resource
Global Scale
Geology
Hot Rocks
Inside look at a Project
Comparable Economics

Nesjavellir Geothermal Power Plant, Iceland
Photo by Gretar Ivarsson

GEOTHERMAL = HOT ROCKS

PACIFIC “RING OF FIRE”

@ Tectonic Plate Boundaries

Source: USGS

LARGE HYDROTHERMAL SYSTEMS ABOVE THE YELLOWSTONE MAGMATIC SYSTEM

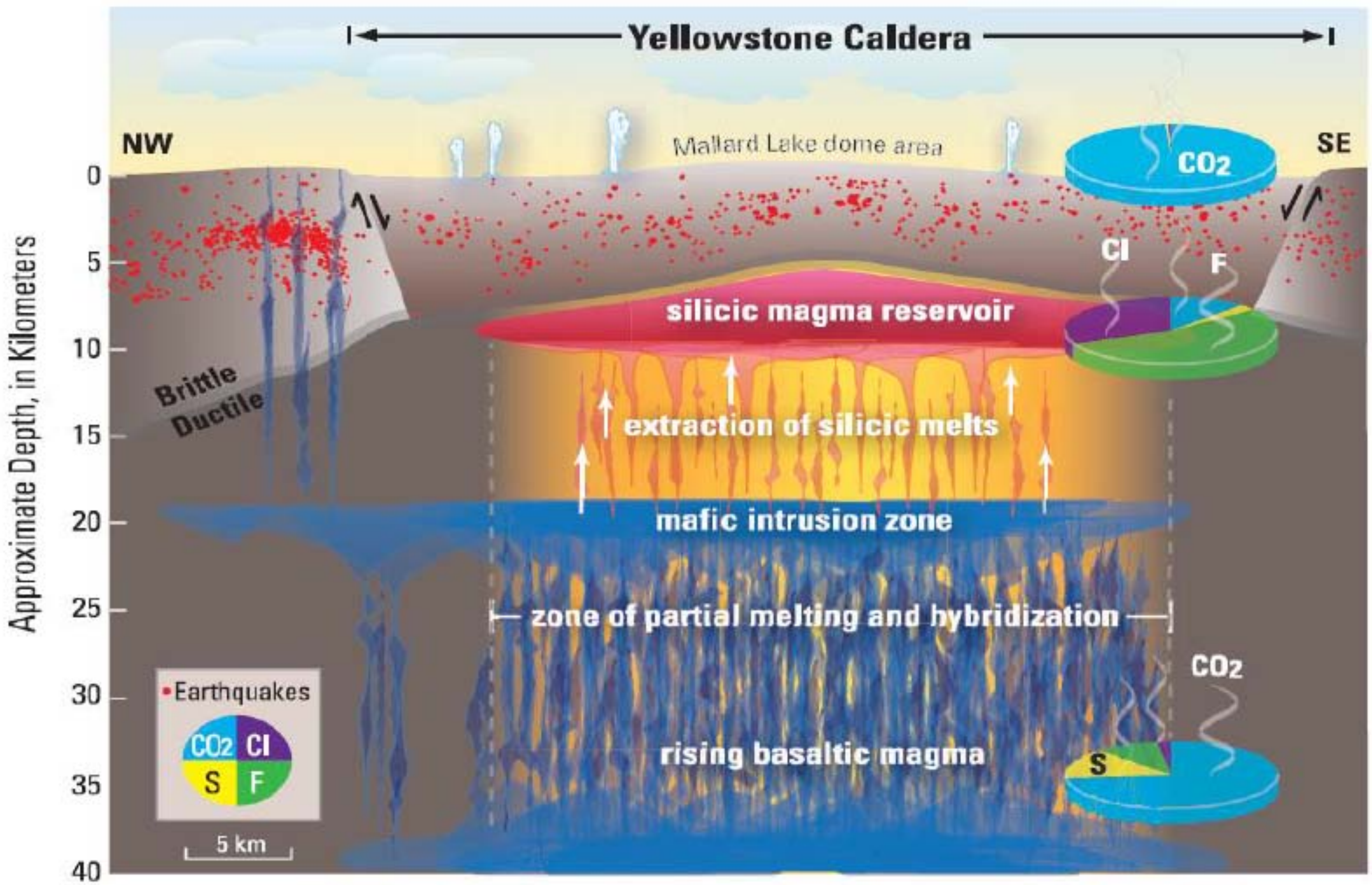
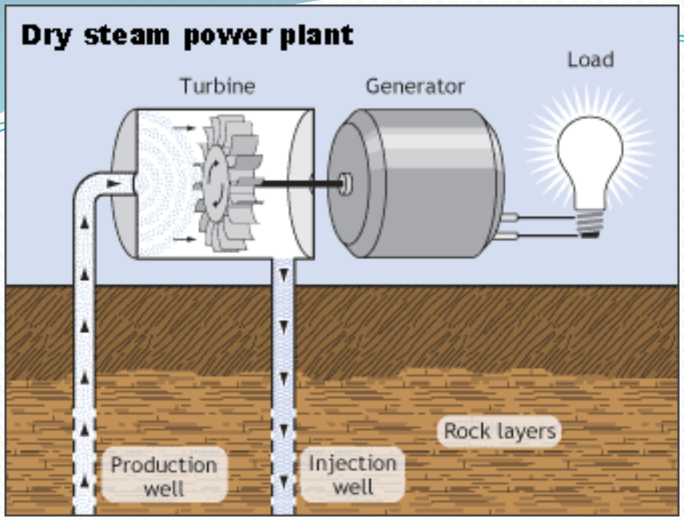
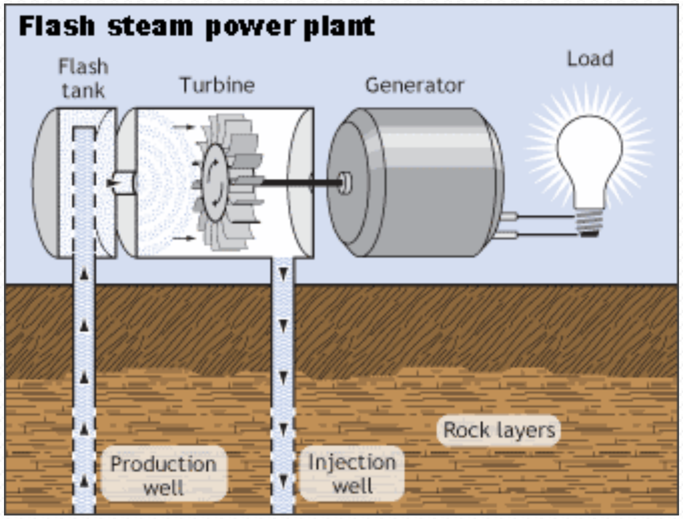


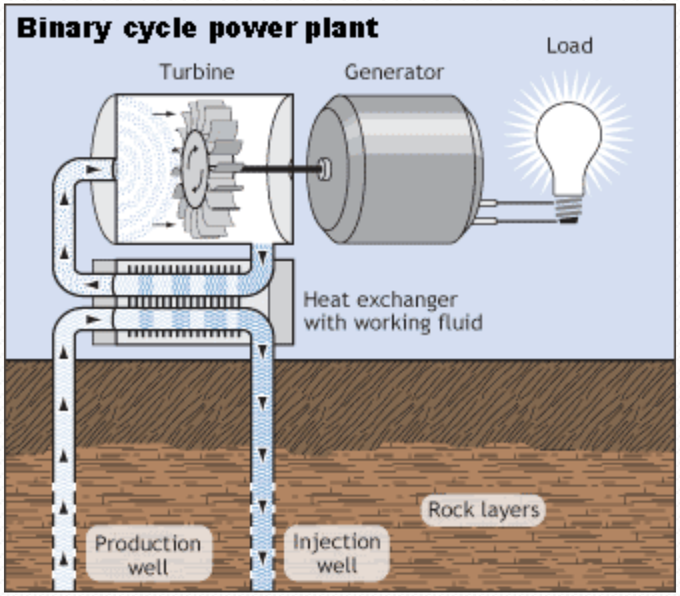
Figure from Lowenstern and Hurwitz 2008

Yellowstone Park Hot Spot
Surface Expression

GWH Oct 2016







Reservoir Fluid @ 260-700 º F

GEOTHERMAL =

Ideal base load renewable resource

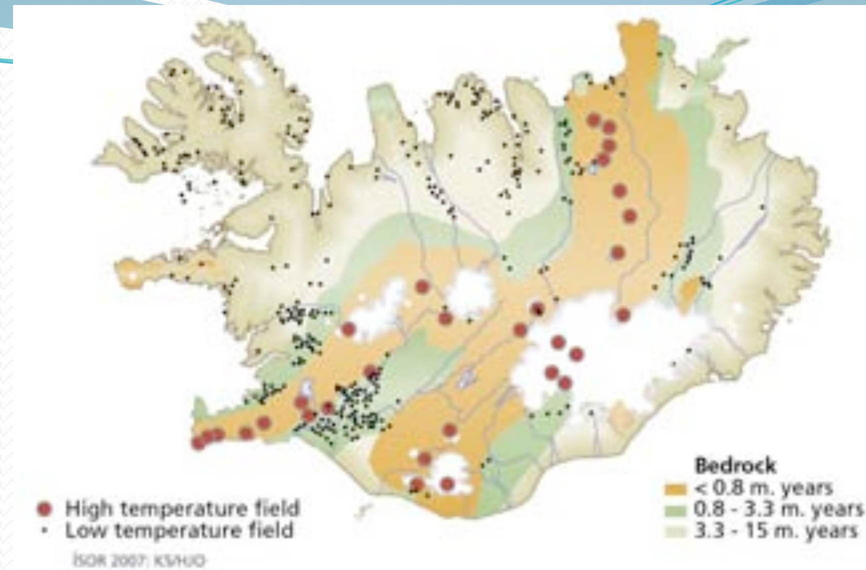
No emissions

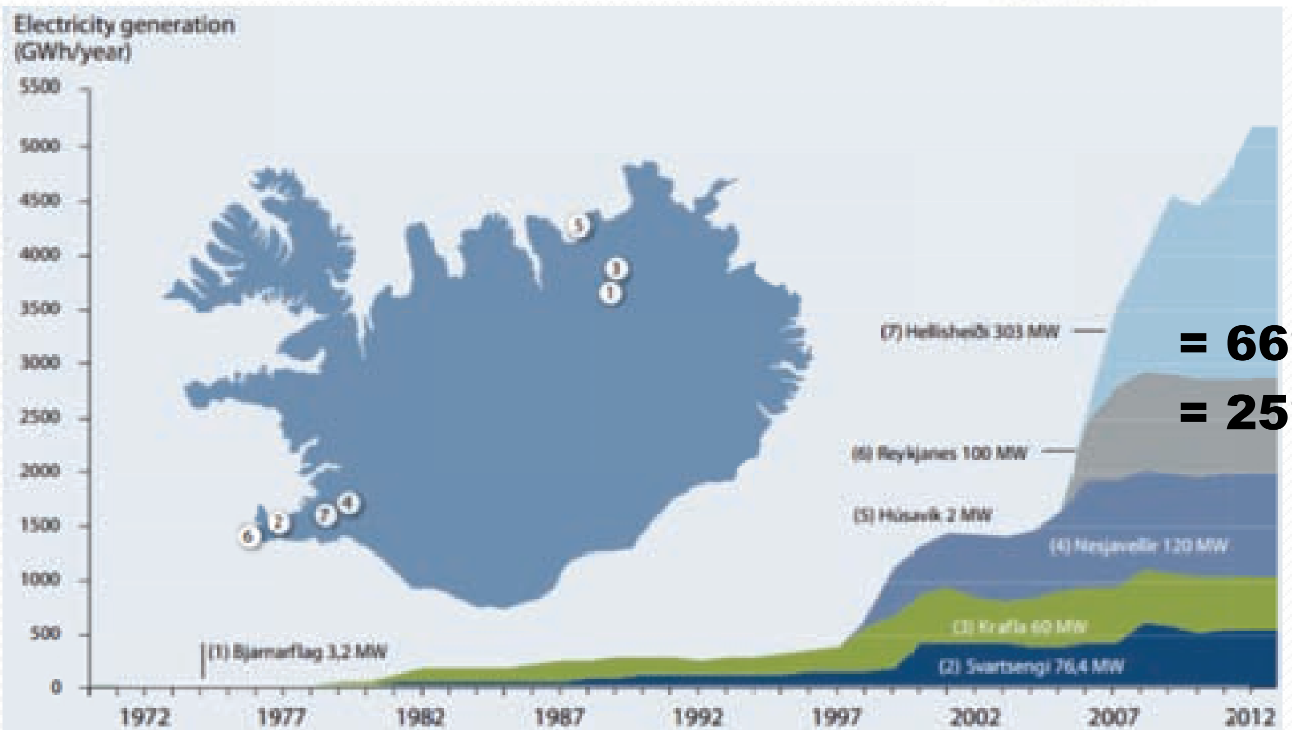
24/7 reliable

flexible

Source: EIA

ICELAND





ICELAND GEOTHERMAL

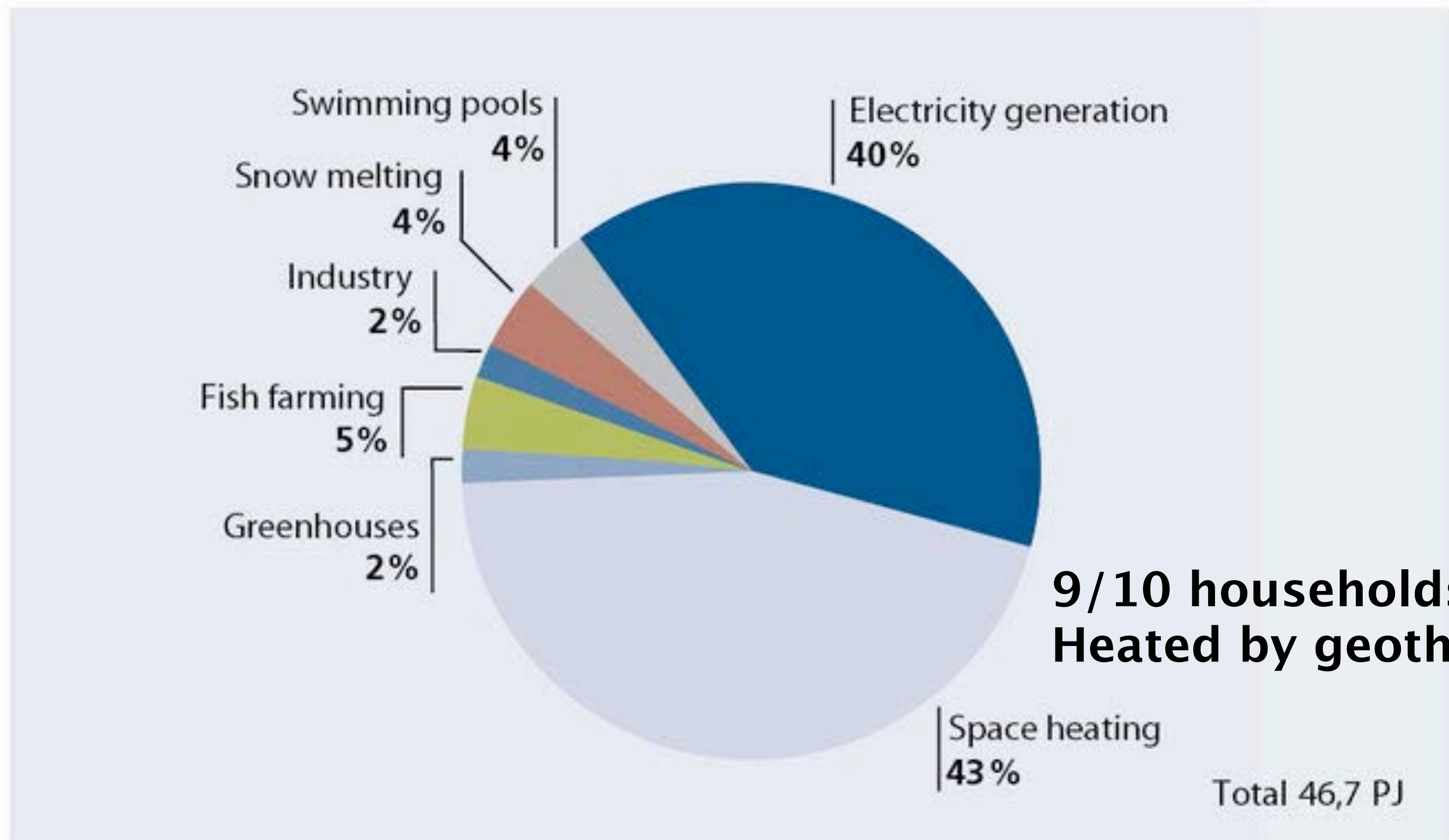
= 66% of Primary Energy

= 25% Electric Power

@ 665 MWe

Source: Iceland National Energy Authority

Utilisation of geothermal energy 2013

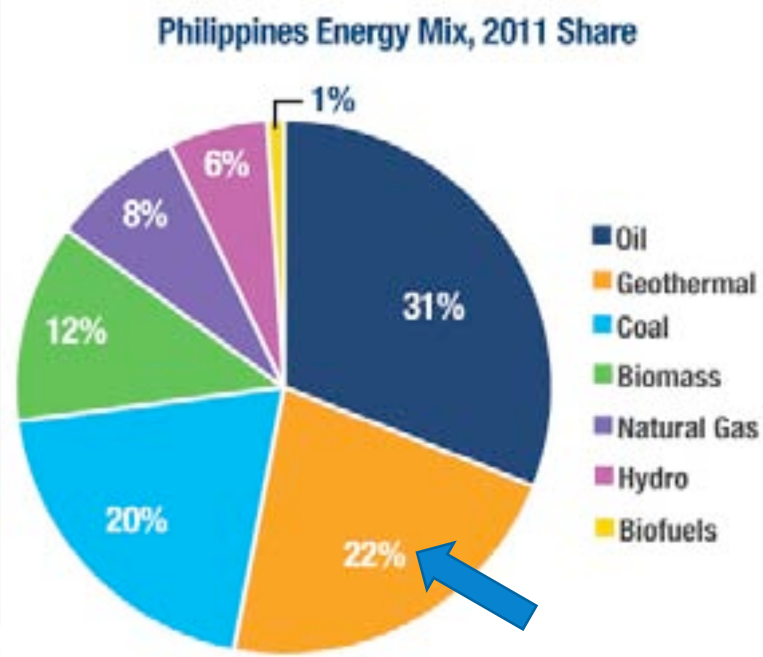


9/10 households Heated by geothermal

ICELAND

Source: Iceland National Energy Authority

PHILIPPINES GEOTHERMAL



Geothermal

@22% of Philippines Electric Power with 1848 MW installed capacity from 7 fields

Geysers Geothermal Power Plants California

GEYSERS GEOTHERMAL FIELD

@ 30 Mi^2 (= largest in world)
Dry super-heated steam
Avg. depth @ 8,500'
Avg. temp @ 359ºF

Initial operation in 1921 @ 250 KW for hot spring resort
1960's at 11 MW by PG&E

2,000's – Calpine Corp with 13 operating plants
327 steam wells and 56 injection wells
inst
Avg

USA INSTALLED GEOTHERMAL CAPACITY (MW) AS OF 2013

State	Capacity (MW)	Share of U.S total
California	2,732.2	80.7%
Nevada	517.5	15.3%
Utah	48.1	1.4%
Hawaii	38.0	1.1%
Oregon	33.3	1.0%
Idaho	15.8	0.5%
New Mexico[14]	4.0	0.1%
Alaska	0.7	<0.1%
Wyoming	0.3	<0.1%
Total	3,389.9	100%

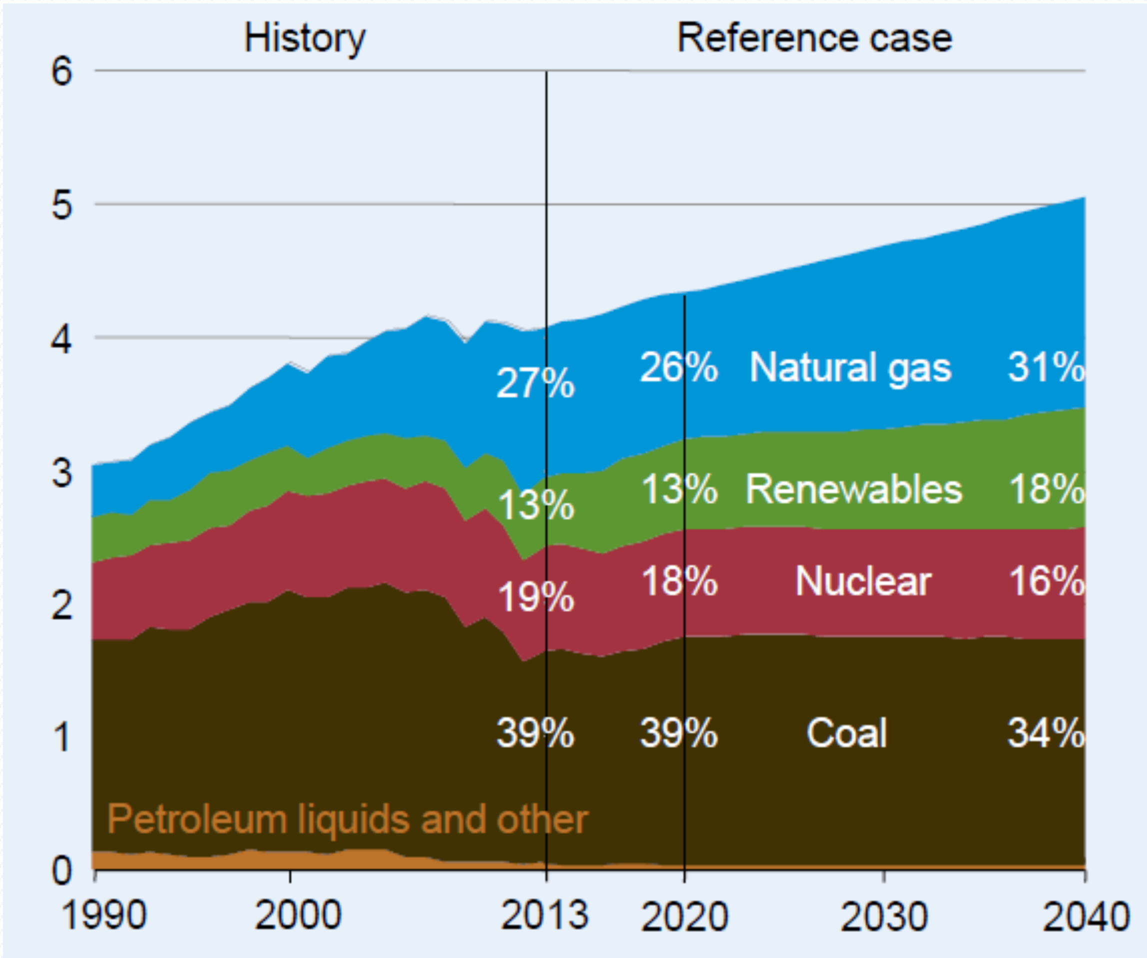
Source: Geothermal Energy Association , EIA

@ 3.6 GW capacity In 2015

Individual plants are small, typically 15 – 45 MW

= 0.39% total USA Electric Generating Capacity

USA ELECTRICITY GENERATION BY PRIMARY SOURCE



Note: Renewables includes Hydro, biomass, wind, solar And geothermal; but geothermal is tiny %.

Note: This is not all Energy (i.e. excludes transportation)

Source: EIA 2016

Global Geothermal Installed Capacity @ 13.8 GW

(84% Steam and 16% Binary)

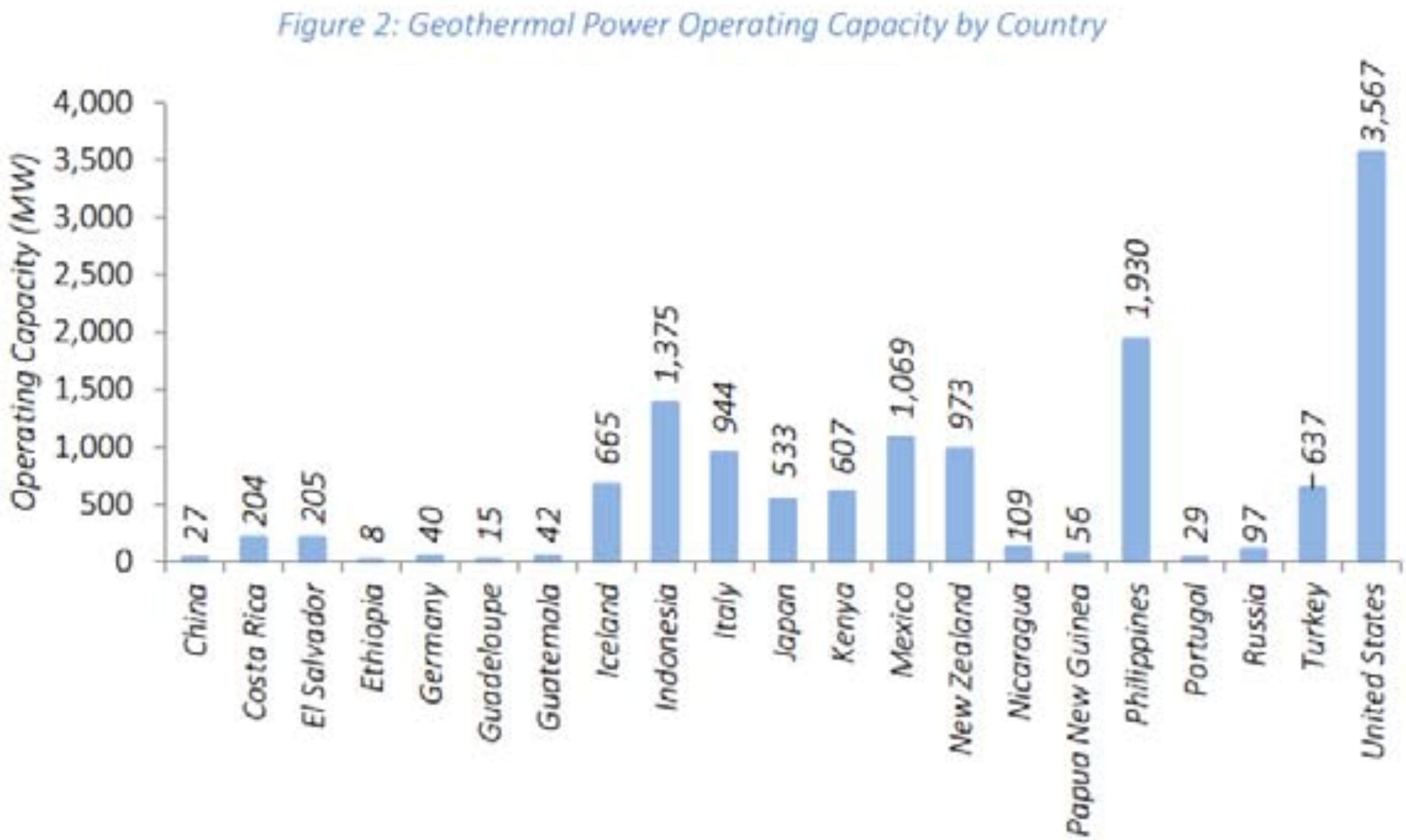
Potential Growth = 10x Current Capacity

Source: Hydrothermal Geothermal Resources Potential, EMERGING ENERGY RESEARCH, LLC. Global "Geothermal Markets and Strategies: 2009–2020", May 2009. "Geothermal Power Generation in the World 2005–2010 Update Report" Ruggero Bertani Enel Green Power, via Dalmazia 15 – 00198 Roma (Italy) April 2010. 2015 Annual U.S. & Global Geothermal Power Production Report GEA Feb 2016,2016 International Development - Interim Report, GEA Report Oct, 2016.

ORMAT

Source: Ormat. Reproduced with permission

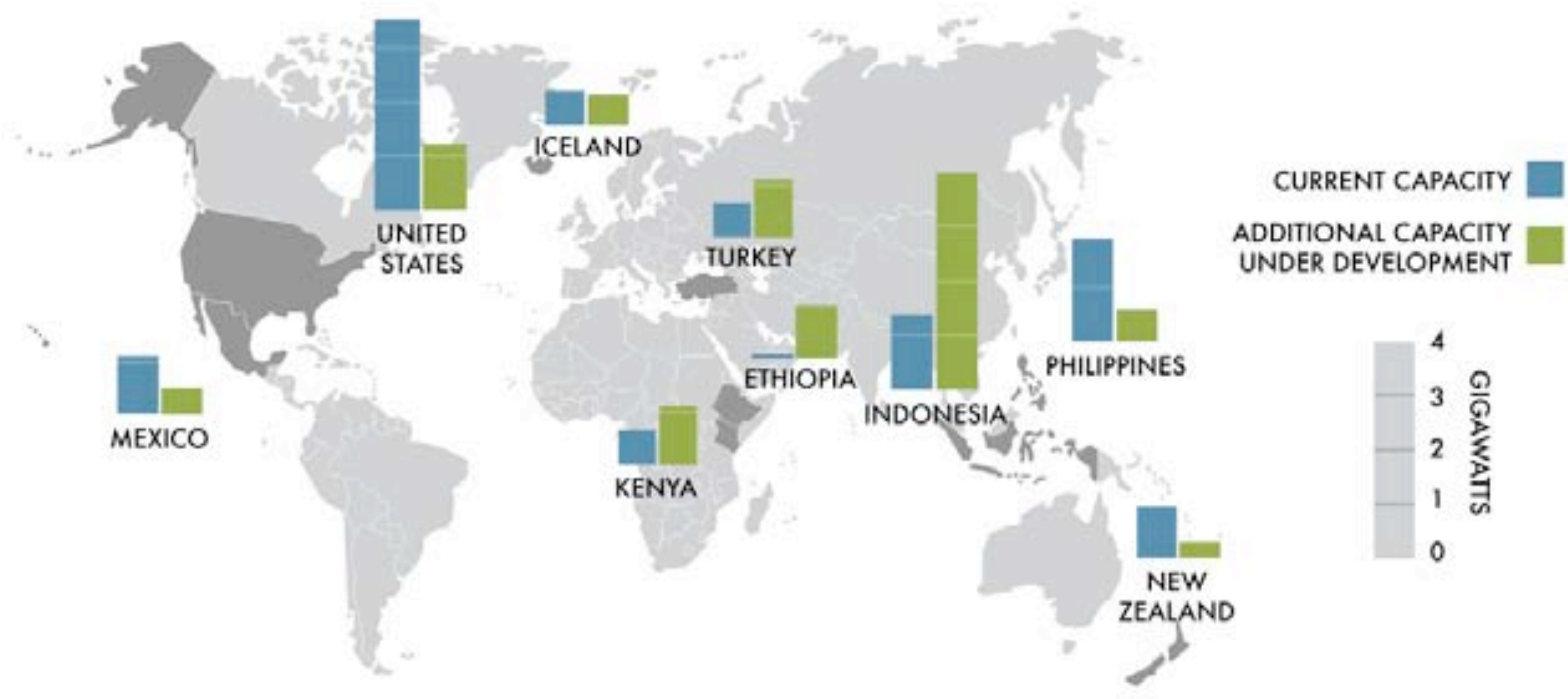
GLOBAL GEOTHERMAL CAPACITY (MW) 2015
@ 13.8 GW



Source: Geothermal Energy Association

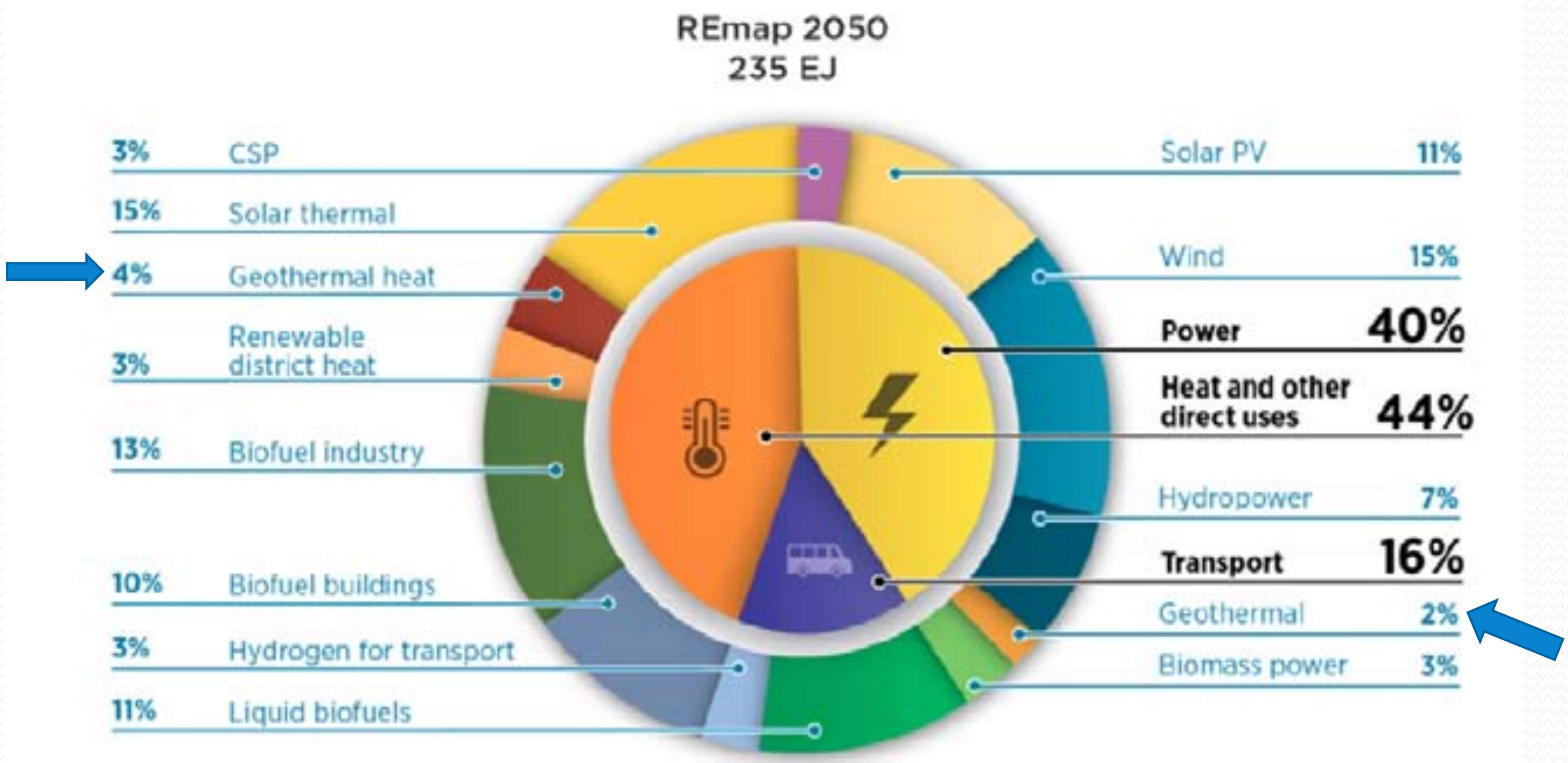
BOOSTING GEOTHERMAL AROUND THE WORLD

Many nations are in the process of ramping up their geothermal electricity generation, so much so that the Geothermal Energy Association has forecast that global geothermal electricity capacity could reach about 18.4 gigawatts by 2021 and 32 GW by the early 2030s, from 13.3 GW in 2015.



Source: 2016 Annual U.S. & Global Geothermal Power Production Report, Geothermal Energy Association

RENEWABLE ENERGY PROJECTIONS 2050

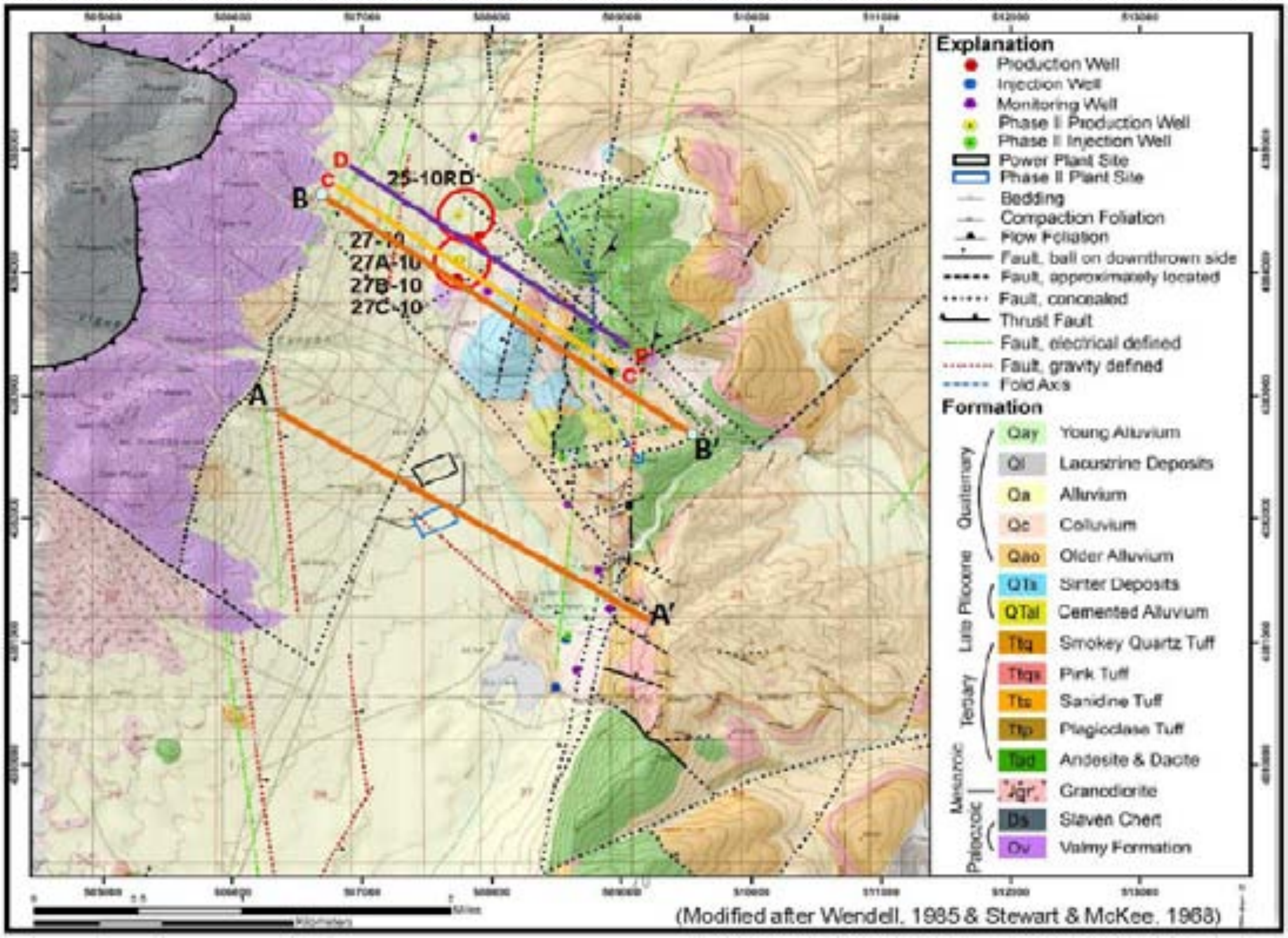


Source: OECD/IEA and IRENA 2017

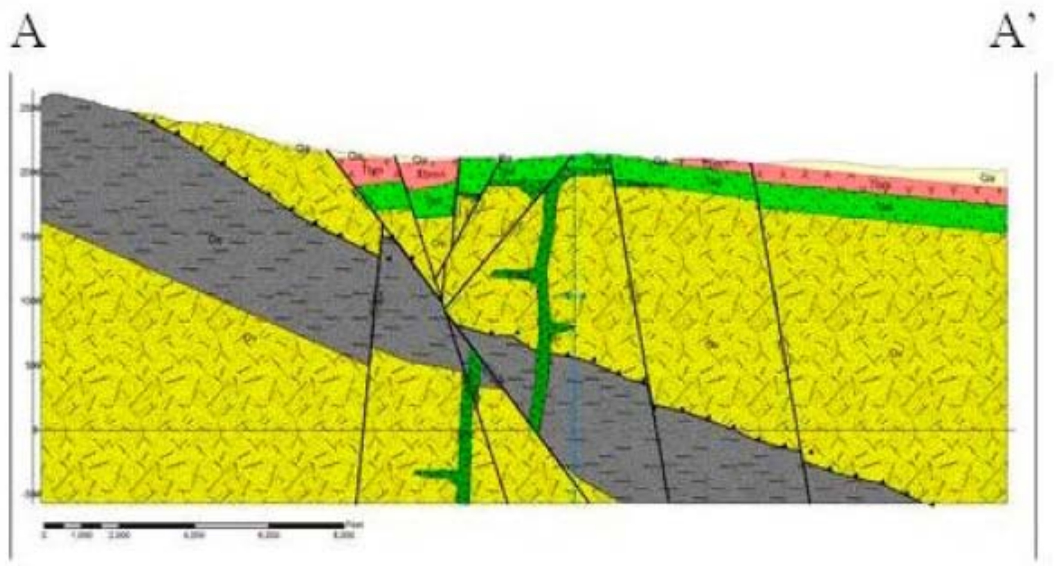
GEOTHERMAL GEOLOGY

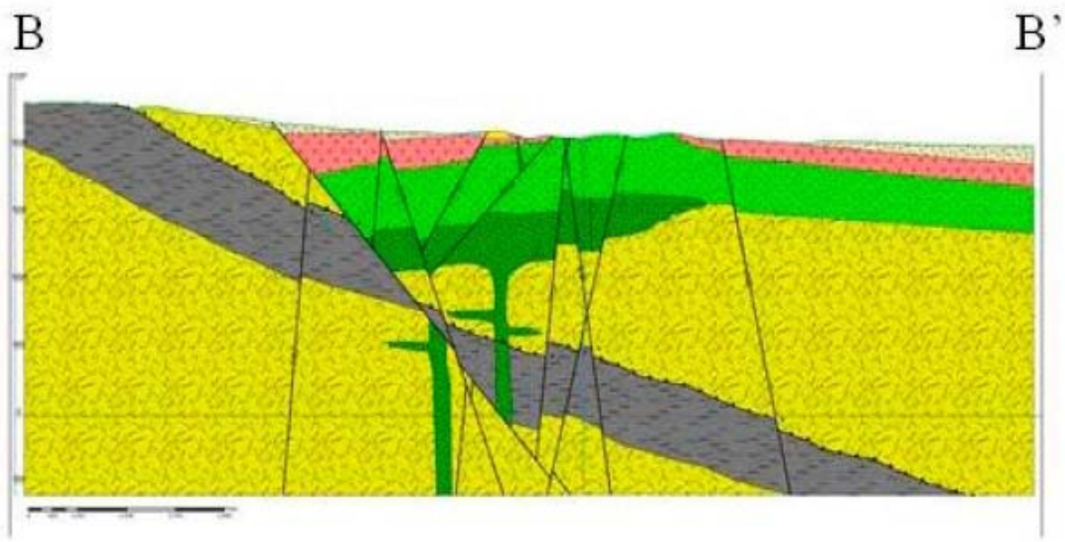
Good technical due diligence matters as projects do fail

UNDERSTANDING THE GEOLOGY



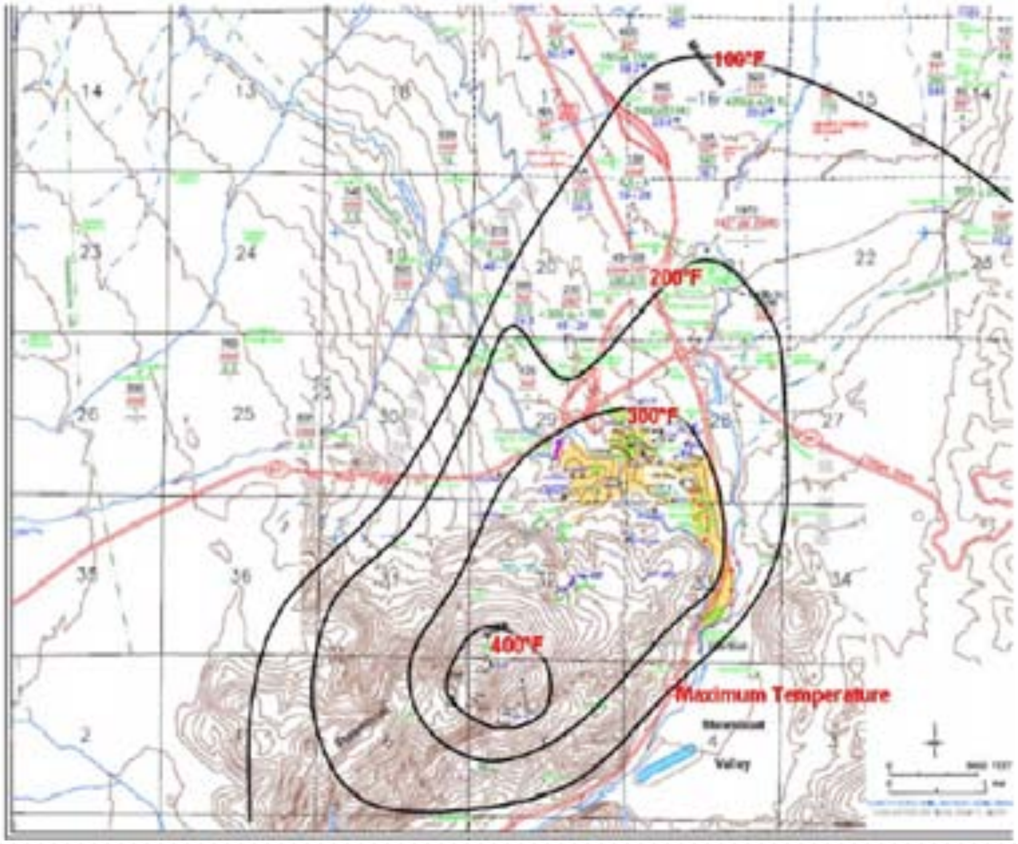
Geological x-sections

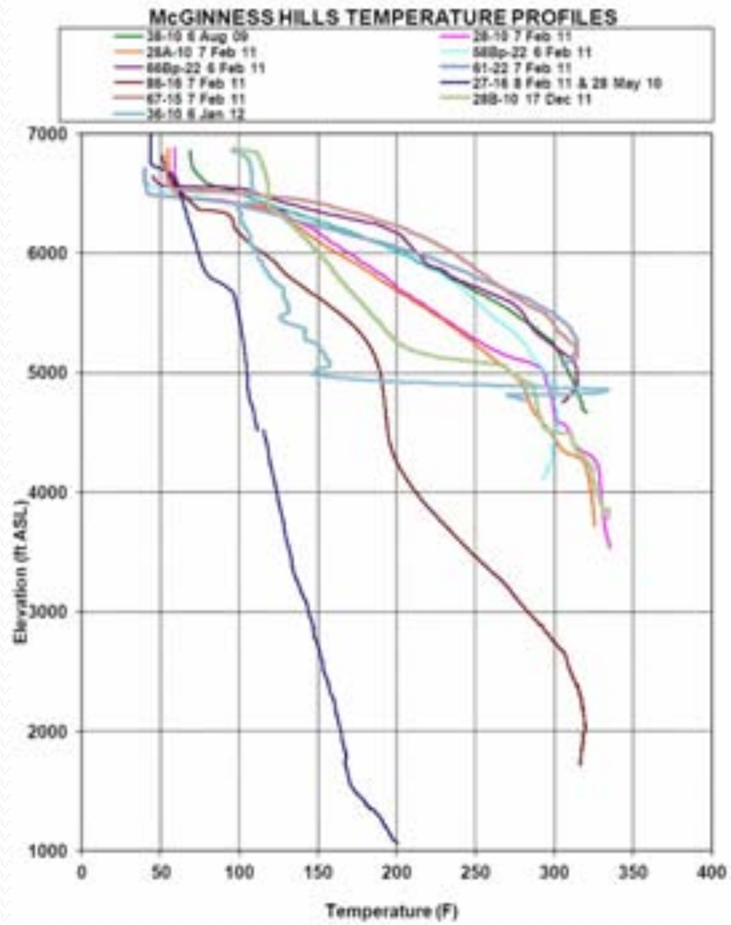




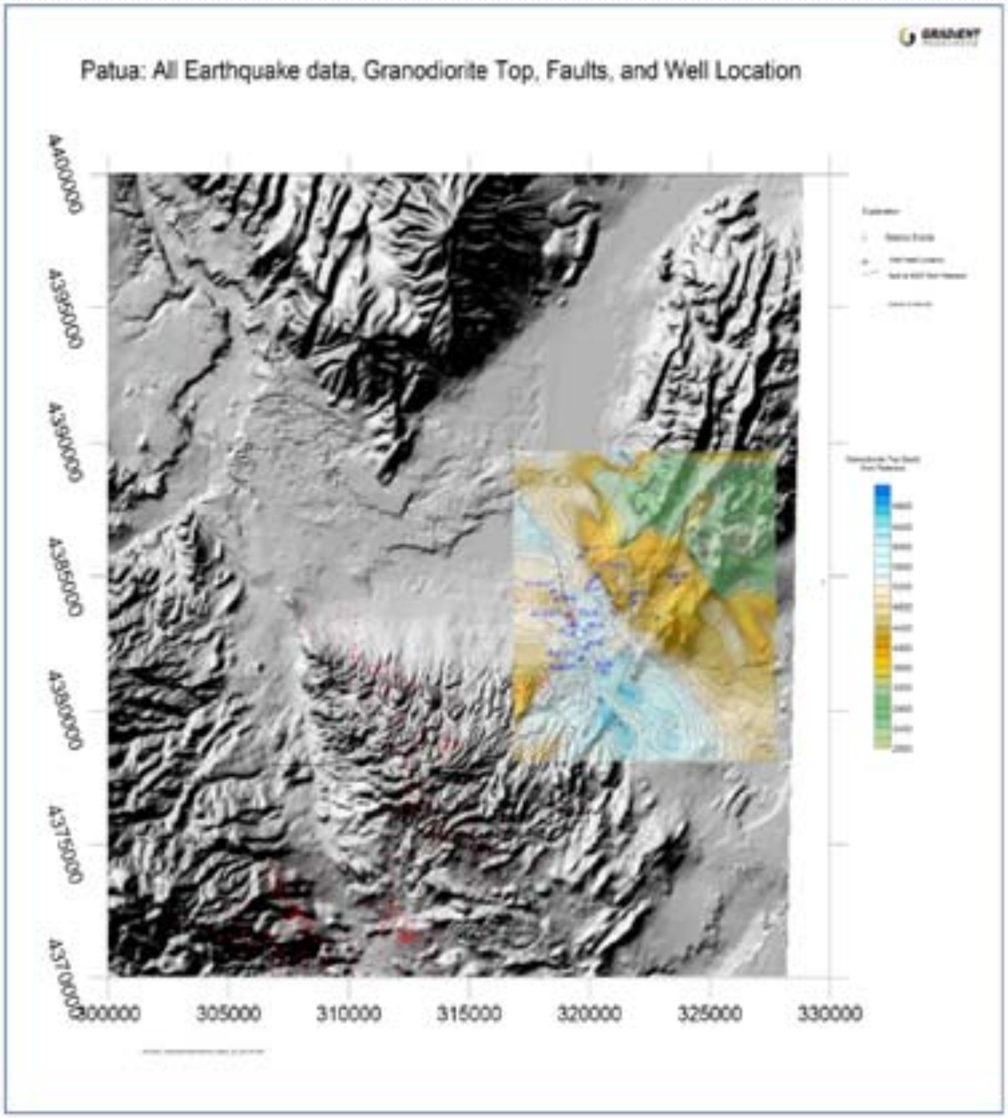
Source: Nordquist and Delwiche, 2013

Understanding Temperature Distribution





Source: Nordquist and Delwiche, 2013



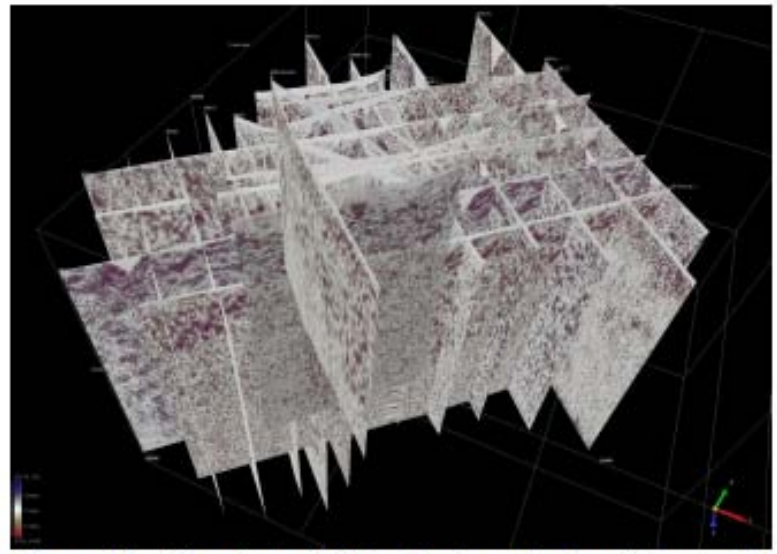
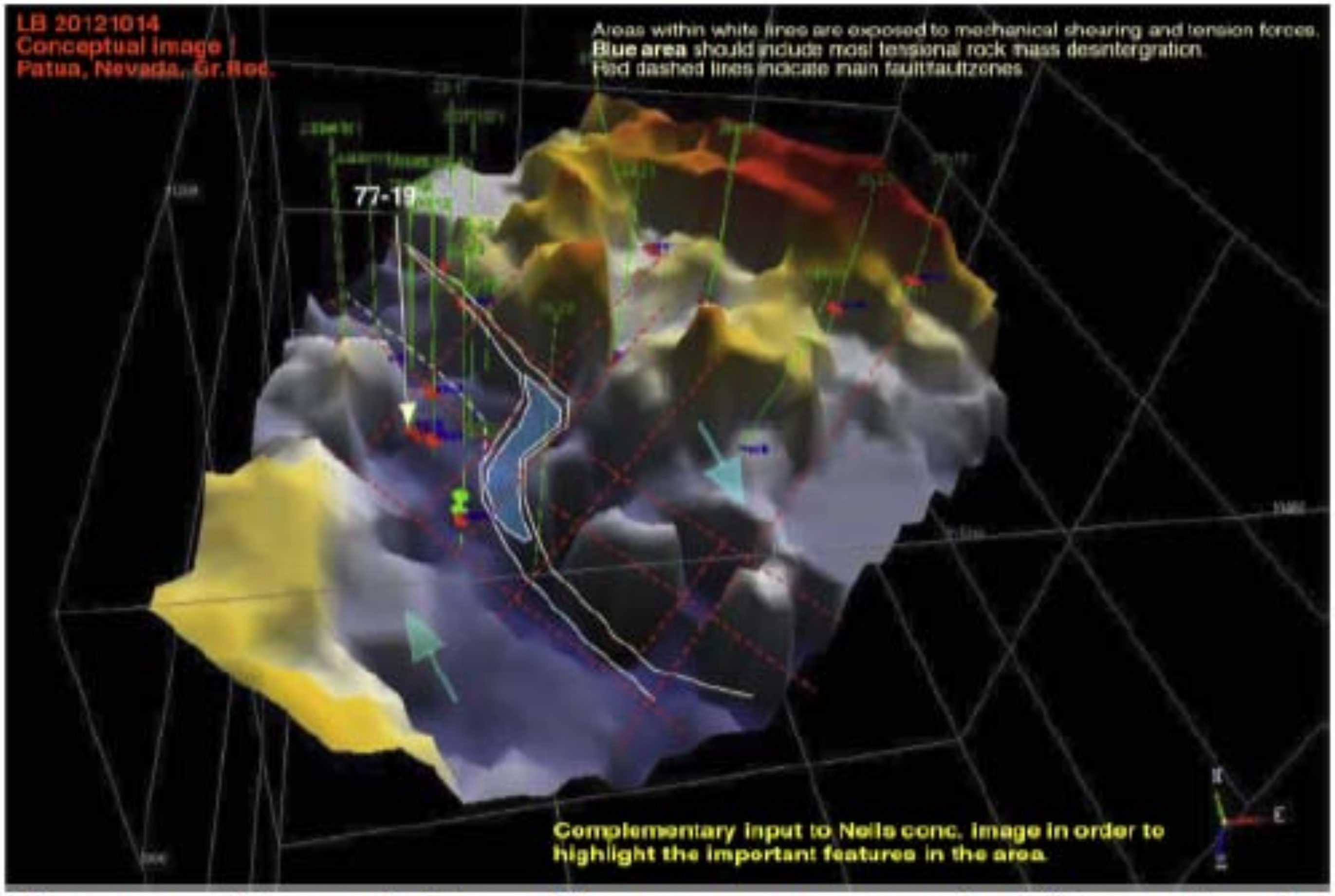
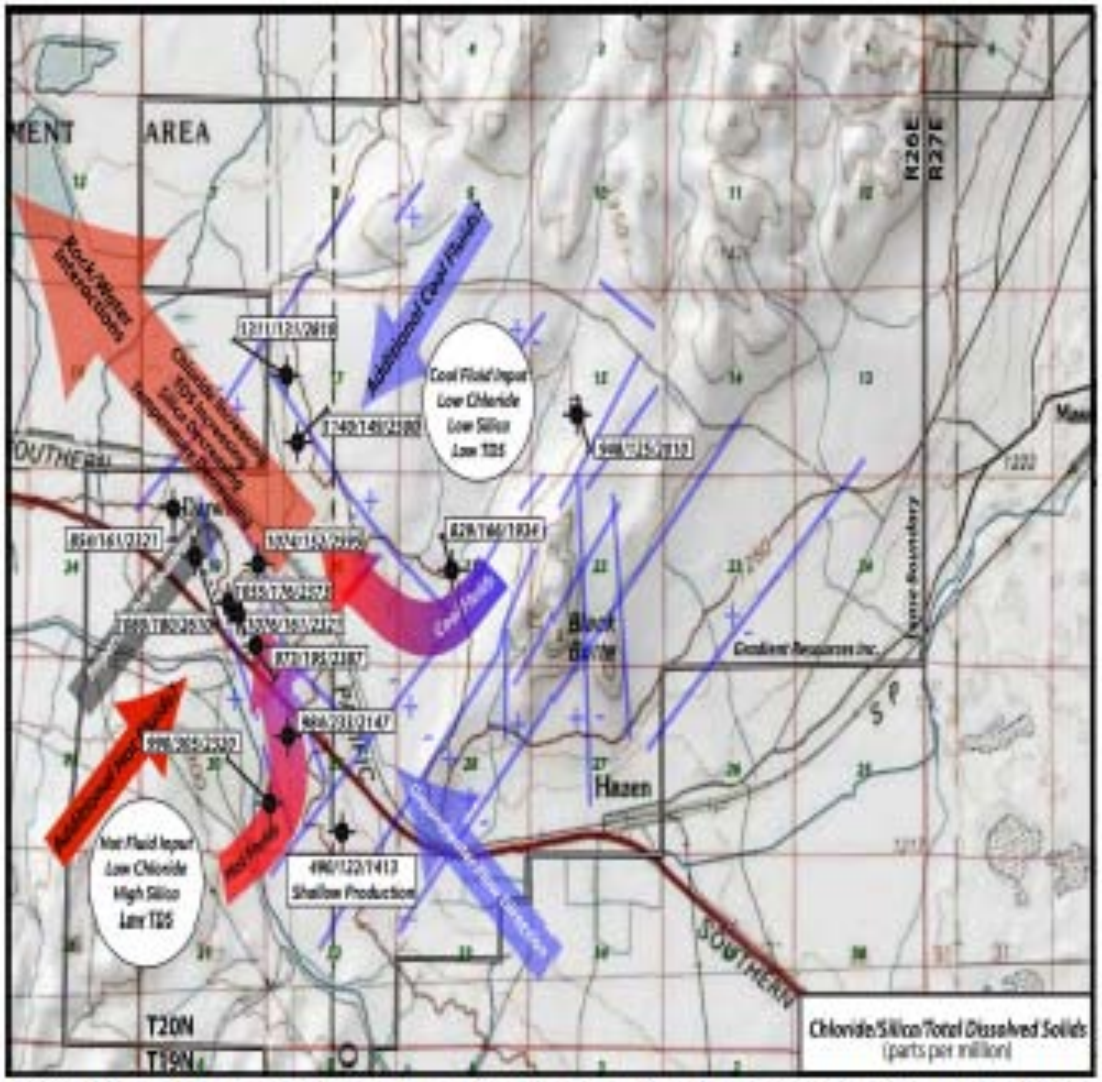


Figure11. Snapshot of 2D seismic reflection lines in the Patua project area. The grid consists of more than 42 miles of 2D seismic reflection profiles.

3D Visualization



Figurey. 3D rendering of basement topography illustrating the direction of slip and the net effect of tensional forces generated along theBBRFZ. (Figure by Bjelm, 2012)

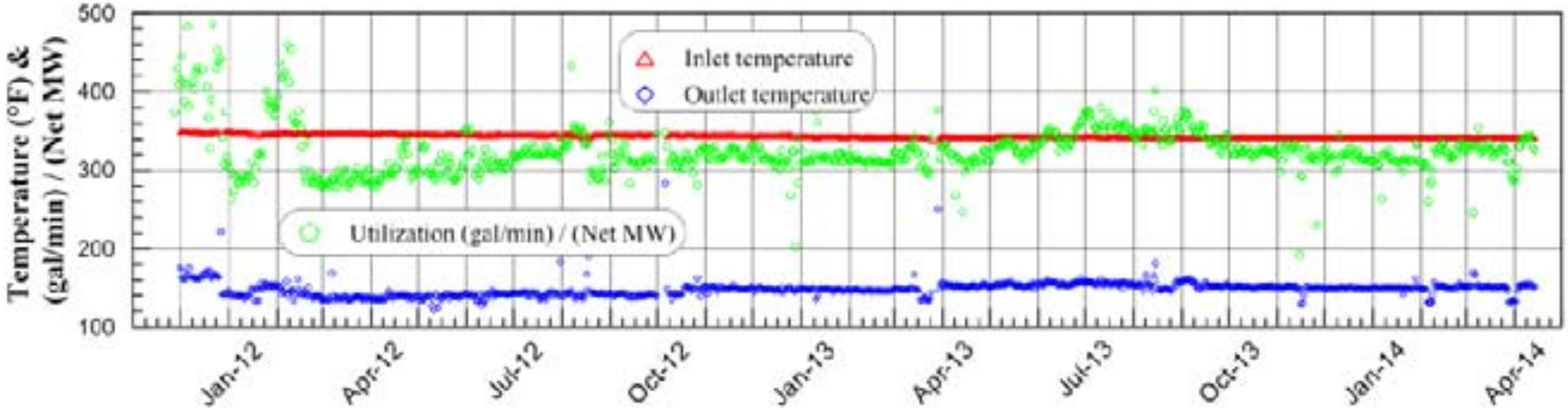


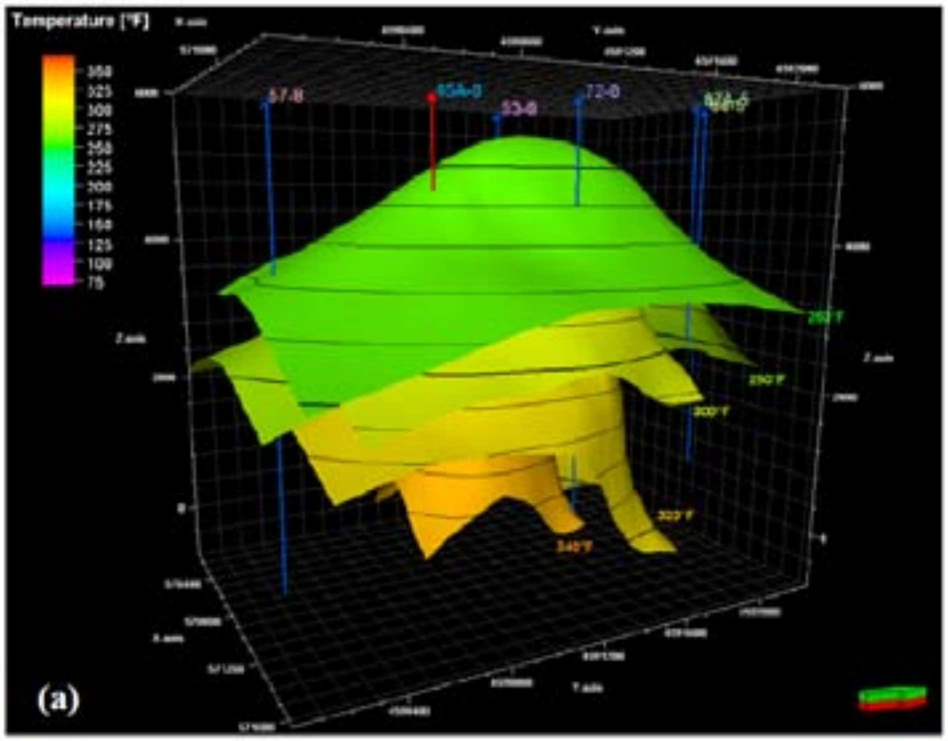
Figre16. Plot of groundwater movement from C. Goranson. Flow directions derived from chemical analyses and pressure data measured in deep monitoring wells. Depiction shows upwelling around the BBRFZ and outflowing to the northwest.

Technical Challenge #1
Mapping source and direction of flow of produce Fluids, and injection path through Fractured reservoir.

Solution: Pressure analysis, Chemical/radioactive Tracer Microseismic; High resolution Seismic tomography

Why Important?
= Mitigate cooling

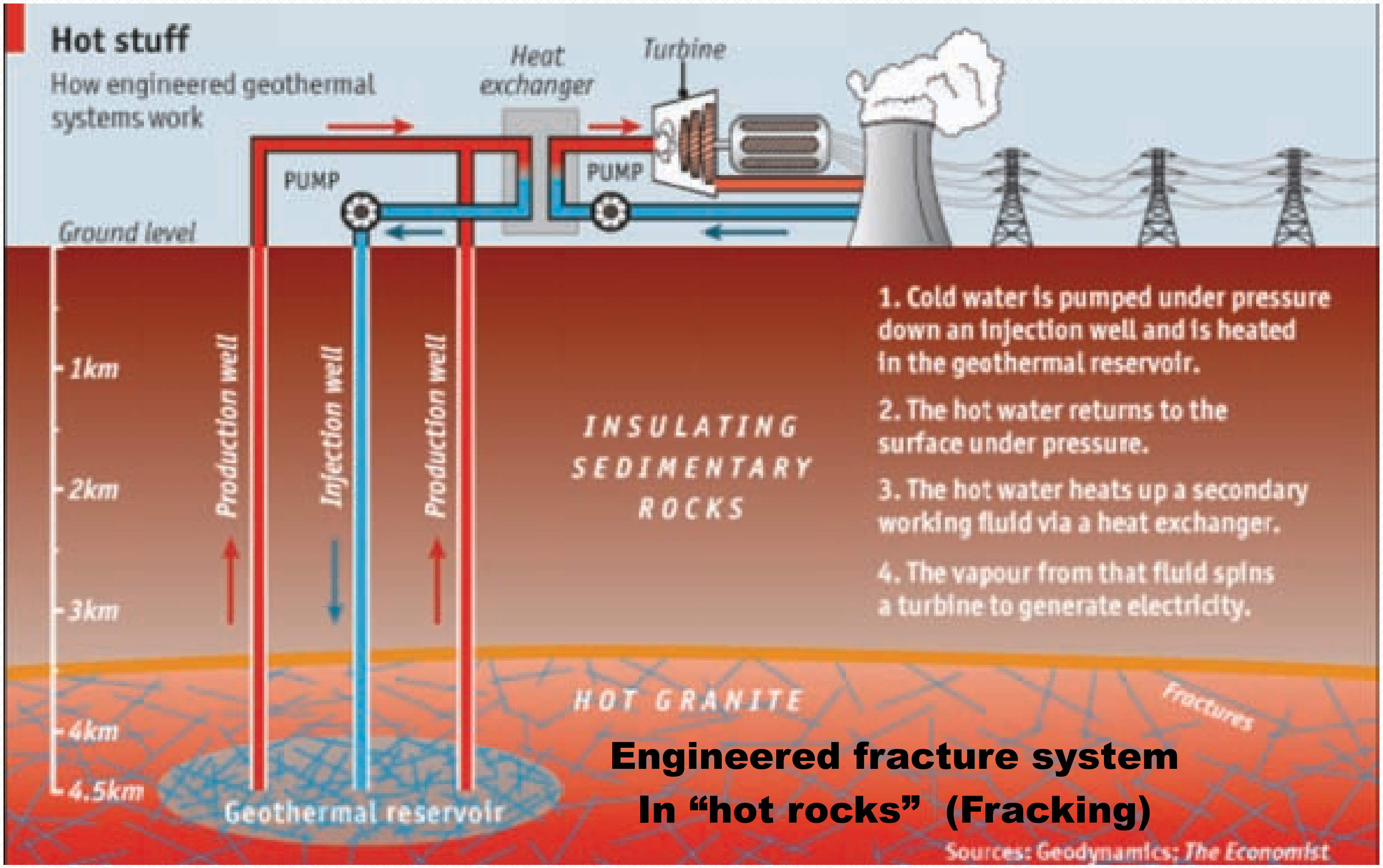




Understanding Production Temperature Trends

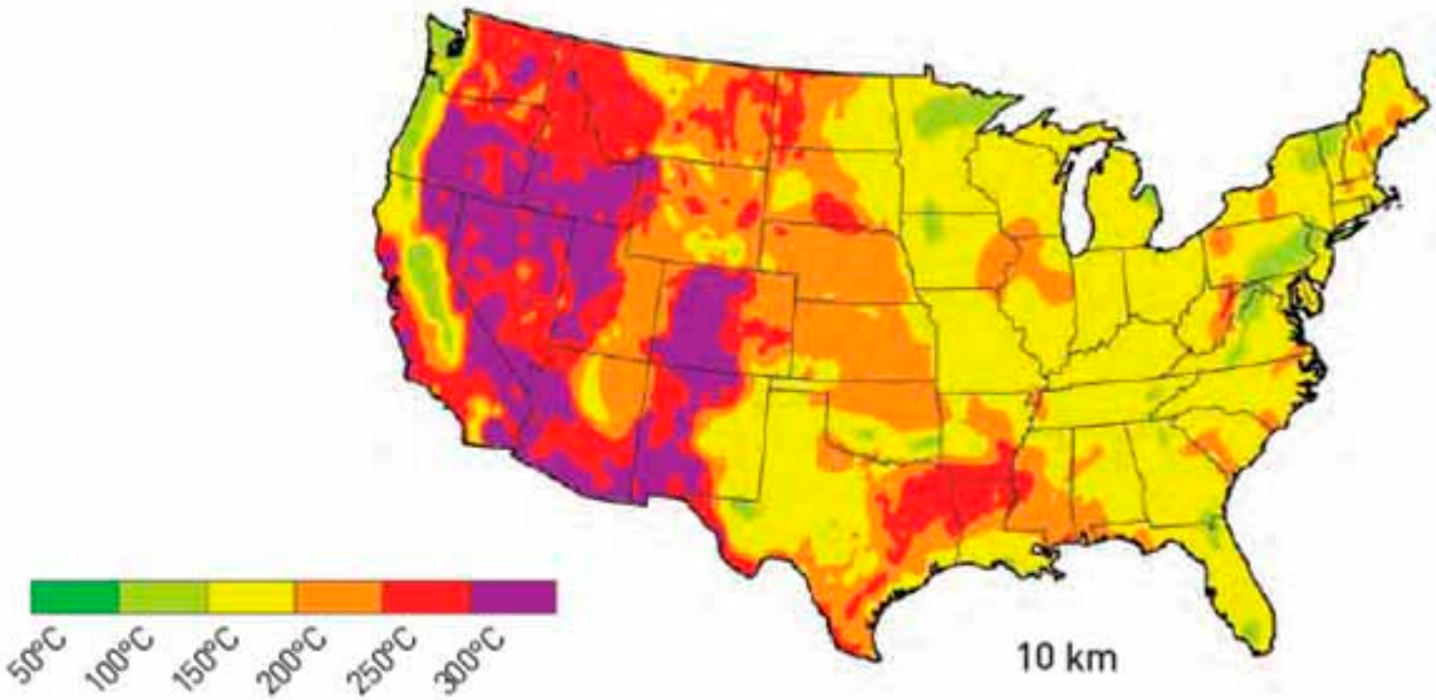
Source: Chabora et al, 2015

ENHANCED GEOTHERMAL SYSTEM (EGS)



Potential 100 GWe economically viable resource per DOE
(@ 10% USA electrical capacity)

EGS Resource at Depth of 10 KM



Permeability and fracture connectivity
Is the challenge to commerciality

Source: Tester, J., et al. 2006. The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century. Massachusetts Institute of Technology.

McGinnis Hills Geothermal Power Project
Ormat Technologies, Inc
Lander County, Nevada

McGinnis Hills Geothermal Project

Lander County, Nevada

103 MW Gross (avg 87.5 MW net) generation capacity
Binary - Ormat Energy Converters
(Organic Rankin Cycle with Pentane)
Avg. pumped flow at 31,000 gpm @ 336ºF

Air cooling (in desert)

Phase I online May 2012 @ 37.5 MW
@30 MW base-load

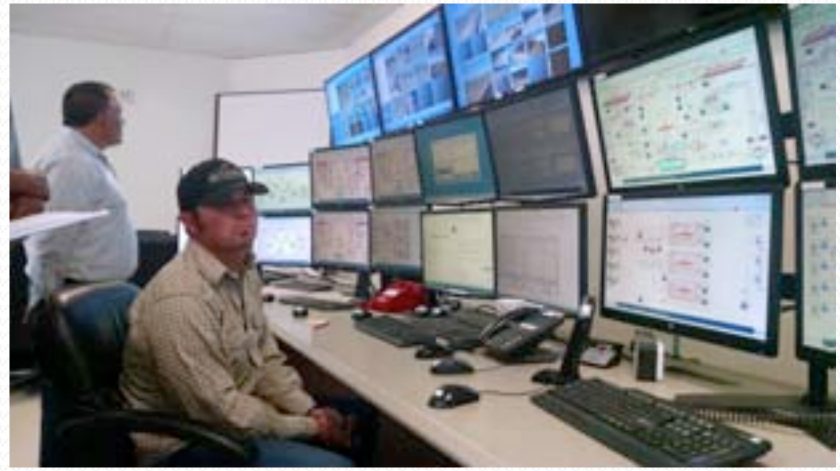
Phase 2 online February 2015 @ 36 MW
(sales to Calif. Public Power Authority @ $81- $85/MWh)

10 production wells pumping @ avg 3100 gpm
@ depths of 3,900 – 2,000 feet (= 8 MW parasitic load)

Injection wells @ 1,500 – 6,000 gpm

Production well @ 3000 GPM

Pumps and cooling
= 5-10 MW parasitic load
Per project



Inside the plant

Geothermal Economics from the Perspective of Ormat Technologies, Inc.

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GREEN ENERGY IS NOW
BIG BUSINESS!
2016 global investment in renewable energy
@ US$ 288 Billion
USA Employment in wind and solar industries@ 475,545
vs coal @ 174,000
Source: Forbes, Bloomberg, EIA

Global Investment In Renewables Is Outpacing Other Energy Sources (Part 2)

Annual Renewable Energy Investment from 2008 – 2015 Nearly Double that in Fossil Fuels (Power Sector)

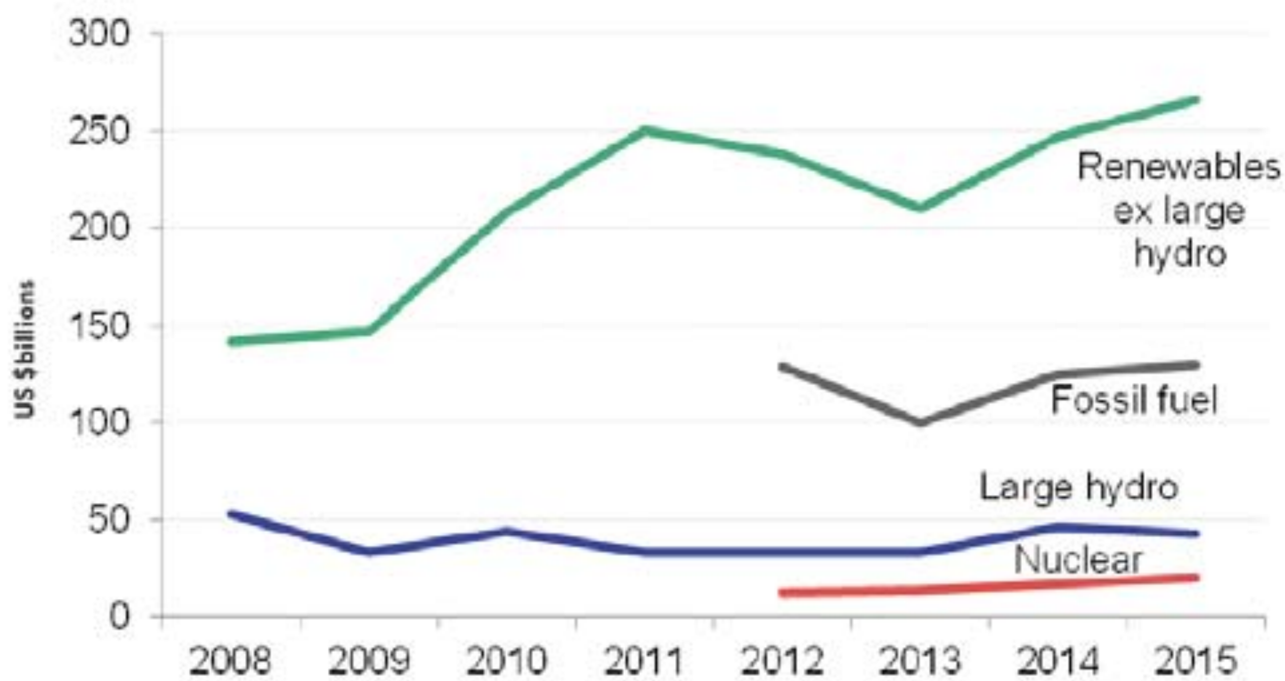
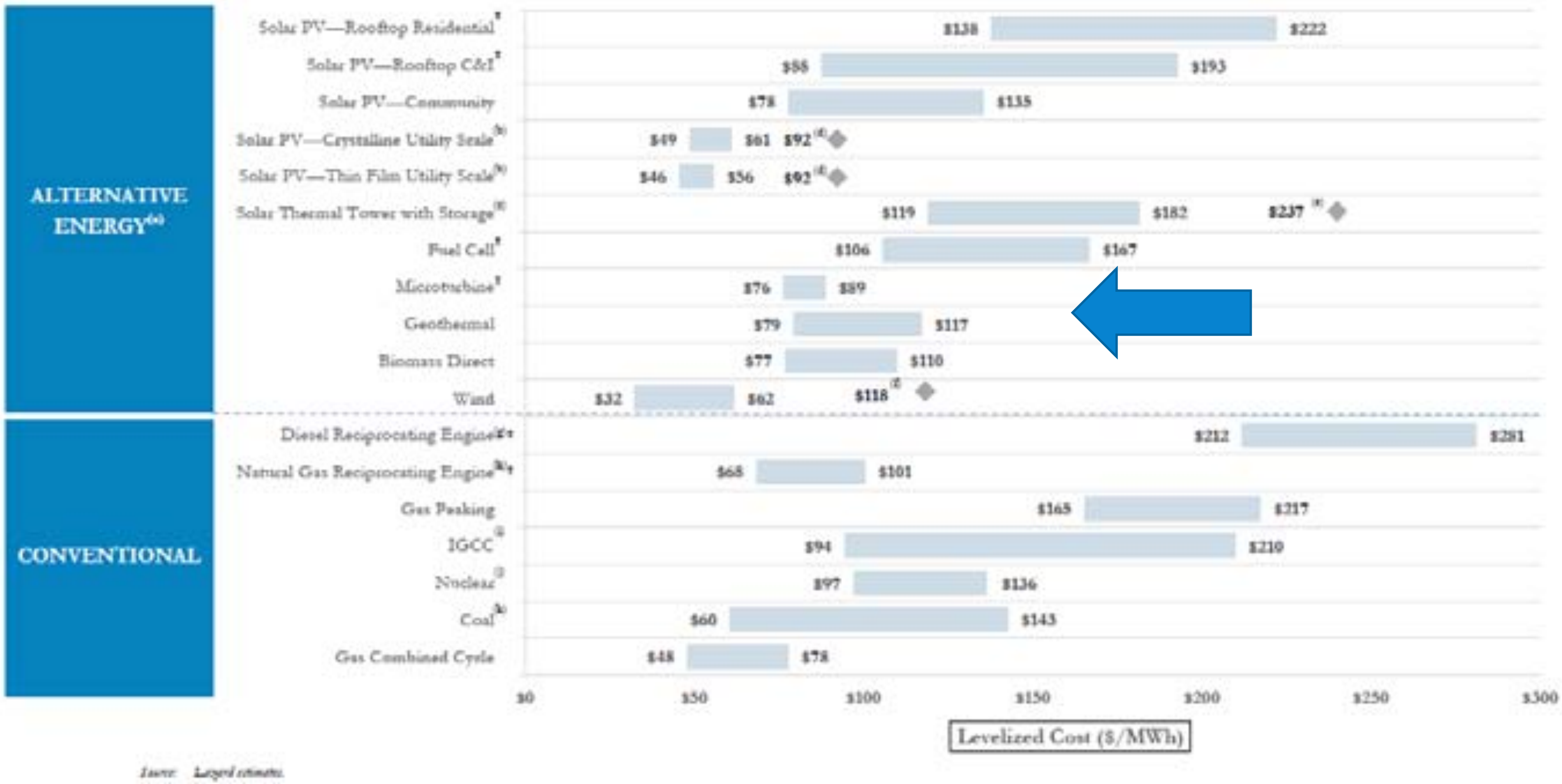


Chart courtesy of BNEF

ACORE
American Council On Renewable Energy

Unsubdized Levelized Cost of Energy Comparison $/MWh



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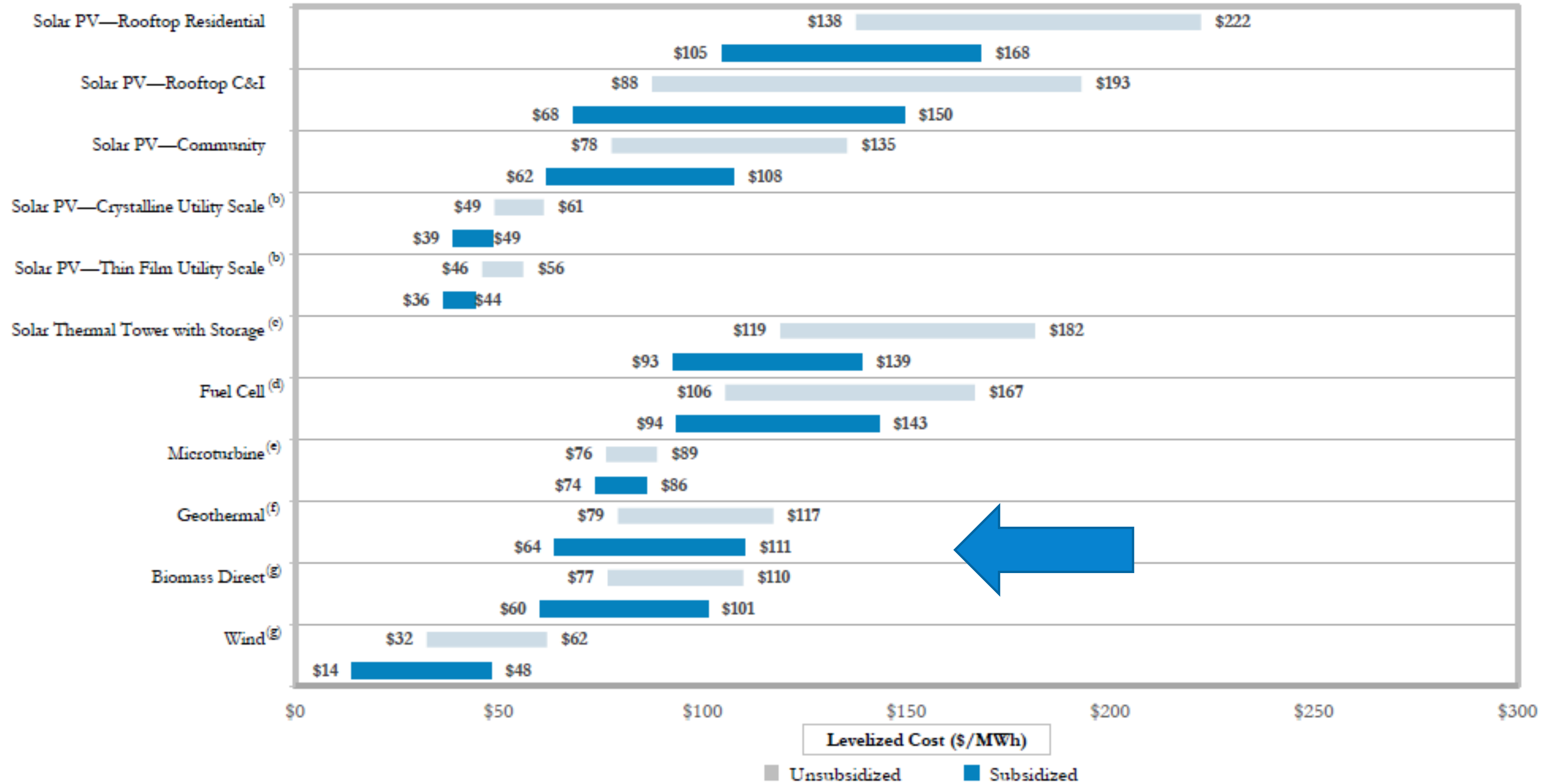
Levelized Cost of Energy $/MWh
Sensitivity to U.S. Federal Tax Subsidies
Geothermal @ $ 23/MW Production Tax Credit



Source: Lazard –Reproduced with permission

Capital Cost Comparison $/kw

Source: Lazard. Reproduced with permission

So Why Is Geothermal So Limited?

= Cost competitive, but……..

Regionally limited resource occurrence

Individual power plants are small

Fossil fuels are cheap

Stay warm with geothermal!

A special thanks to

Ormat Technologies, Inc.
Lazard Freres & Co. LLC
American Council on Renewable Energy