Application of Oil and Gas Subsurface Evaluation Methodology to Geothermal: The Value of Data

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Distinguished Lecturer Program
www.spe.org/dl

Source: The Scotsman

Source: North Edinburgh News

We're the Society of **PETROLEUM** Engineers

WHY SHOULD WE CARE ABOUT GEOTHERMAL?

The Future of Energy?

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UNITED NATIONS
PARIS CLIMATE AGREEMENT
SIGNING CEREMONY
22 APRIL 2016

- 195 countries ratified the Paris agreement
- Restrict global temperature increase to below 2 °C
- Will require significant reduction in carbon production, reduction in hydrocarbon use
- Will require significant increase in renewables use

- Wind
- Solar
- Hydro
- Biomass
- **Geothermal**

What is Geothermal Energy?

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Geothermal energy is heat within the earth. The word geothermal comes from the Greek words geo (earth) and therme (heat). Geothermal energy is a renewable energy source because heat is continuously produced inside the earth. People use geothermal heat for bathing, to heat buildings, and to generate electricity

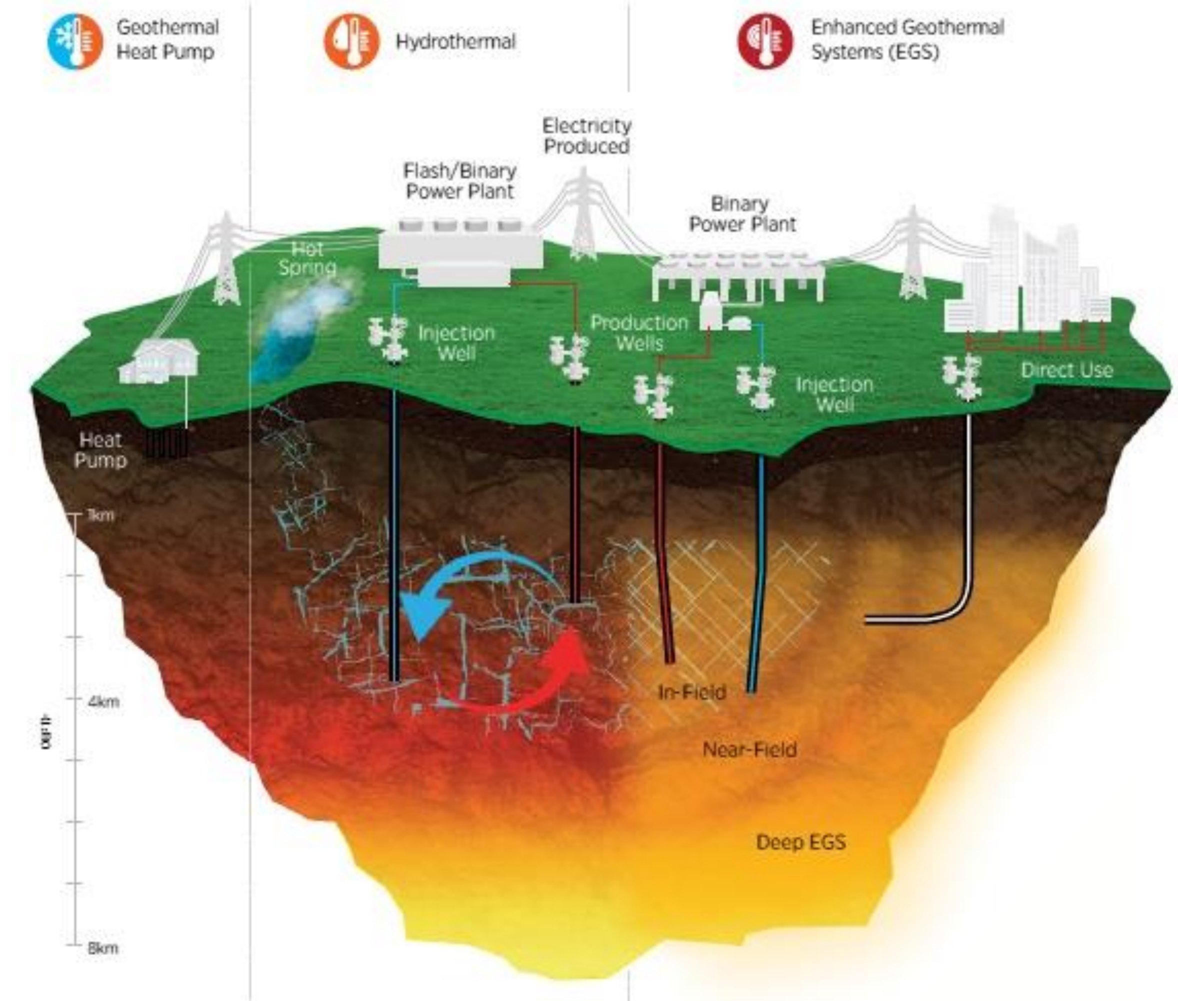
(from https://www.eia.gov/energyexplained/geothermal/)

Geothermal Energy Applications

Increasing Depth

Type	Approx. Depth	Temperature	Applications	Examples
Heat Pump	< 150m	< 40 °C	Small scale (domestic) heating and cooling	Worldwide
Low Temperature	< 2500m	40-100 °C	District Heating, Agriculture (greenhouse heating)	Netherlands, France, Germany
Mid Temperature	< 4000m	100-150 °C	Industrial uses (Food processing, industrial drying)	East Africa, New Zealand
High temperature	> 4000m	> 150 °C	Power Generation	Iceland, California, Turkey

Geothermal Systems



Source: US DOE Geovision Report

Direct use – direct use of hot water produced from formation

Hydrothermal and enhanced - uses a 'doublet'

- Cold water injected into formations by injection well, heated and produced from producer well
- Commonly passed through heat exchanger to heat working fluid

Closed loop system

- Separates formation fluids from surface equipment

Comparing to Other Renewables

Pros
Potentially available everywhere
Can provide constant baseload
Practically zero emissions
Little reliance on variable environmental factors (sun, wind)
Small footprint when installed
Potential long project life (30+ years)

Comparing to Other Renewables

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Pros	Cons
Potentially available everywhere	Currently capital intensive – sometimes challenging economics
Can provide constant baseload	Lack of public understanding, Social acceptance
Practically zero emissions	Potential environmental effects - seismicity
Little reliance on variable environmental factors (sun, wind)	Lack of required infrastructure (e.g. heat grids), or challenges to integrate with existing infrastructure
Small footprint when installed	"Young" compared to other renewables (e.g. wind, solar, hydro) – less expertise to realise projects, still much to research
Potential long project life (30+ years)	

Global Installed Renewables Capacity

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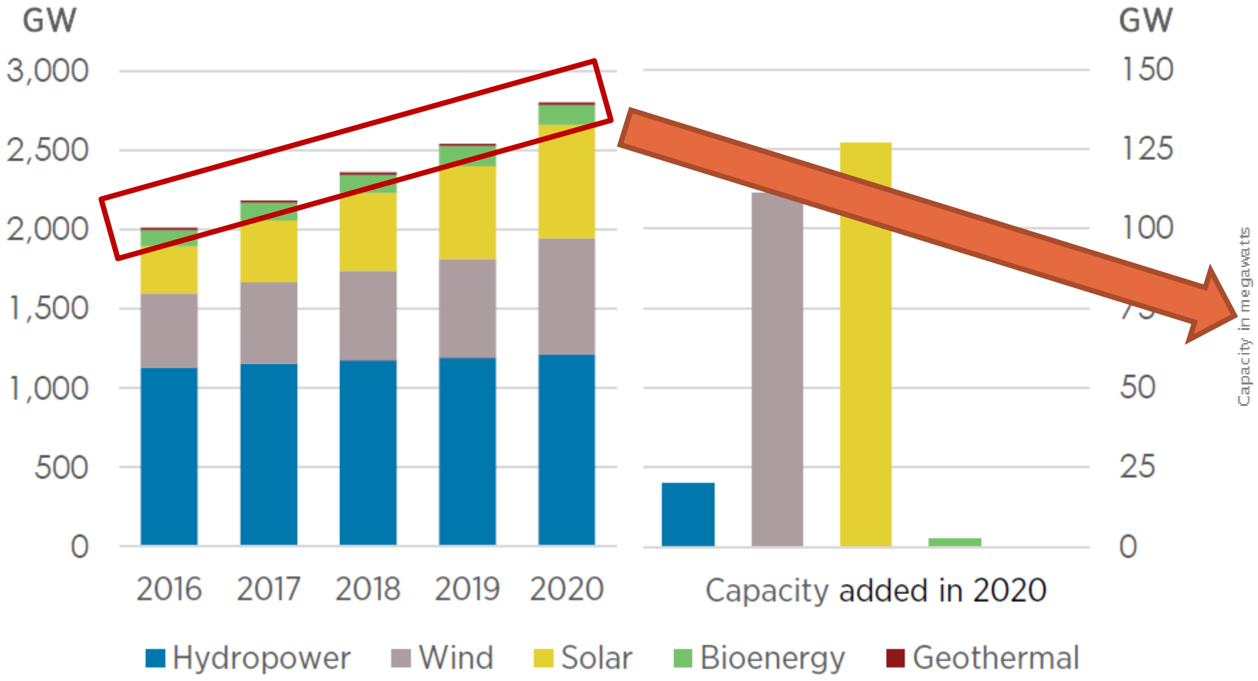
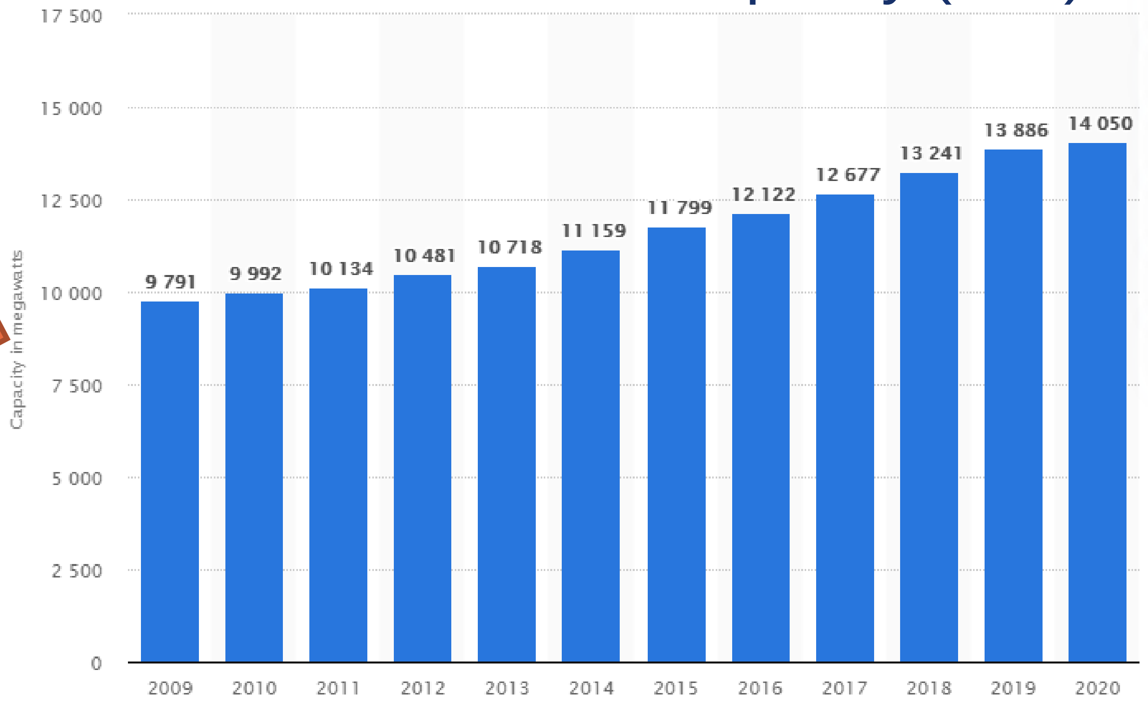
Installed Renewables Capacity (GW)



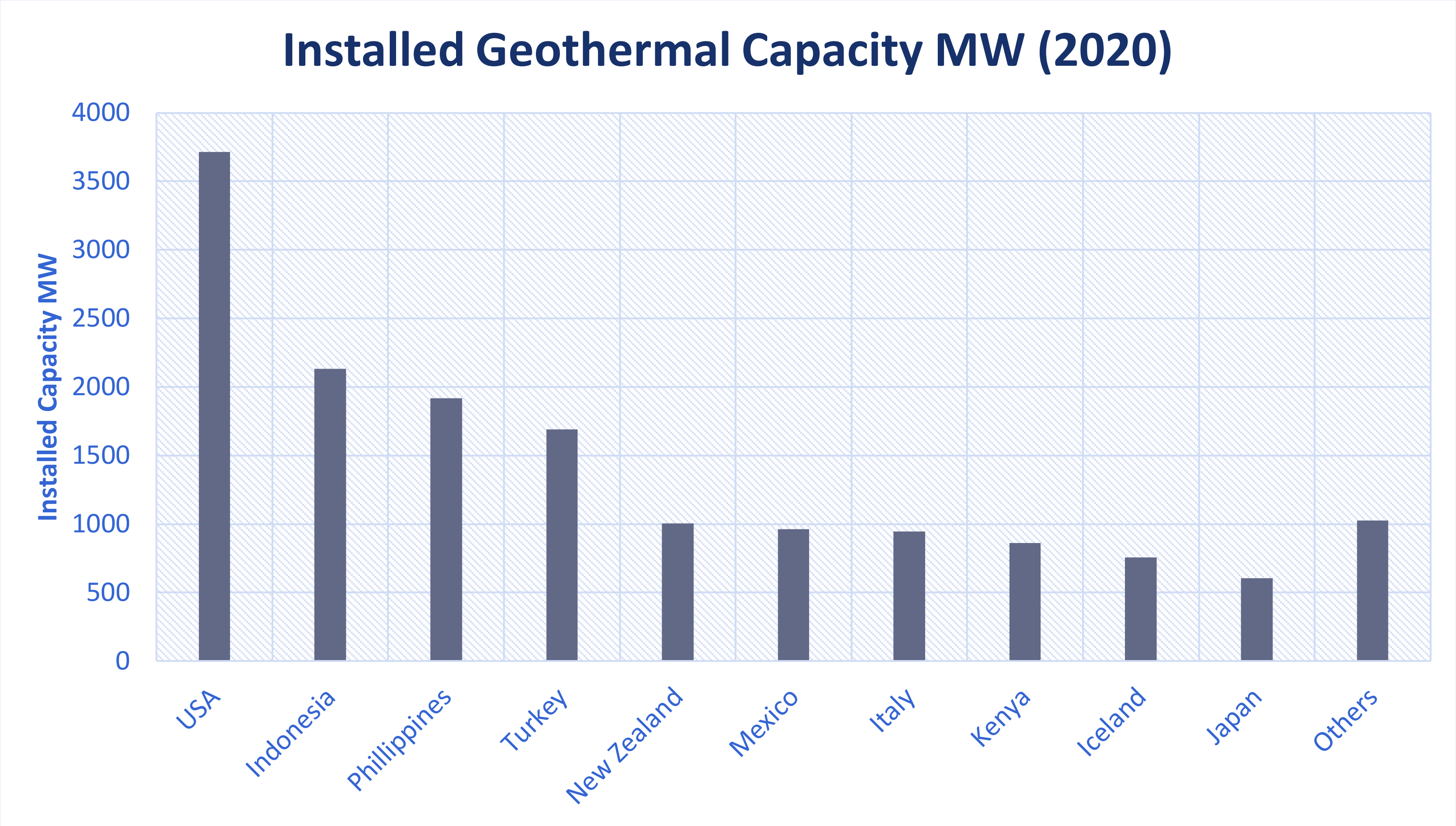
Installed Geothermal Capacity (GW)



Geothermal, though currently small compared to other renewables, is growing rapidly

Source: https://www.statista.com/statistics/267233/renewable-energy-capacity-worldwide-by-country/

Installed Geothermal Capacity by Country



Source: https://www.thinkgeoenergy.com/thinkgeoenergys-top-10-geothermal-countries-2020-installed-power-generation-capacity-mwe/

THE ECONOMICS OF GEOTHERMAL

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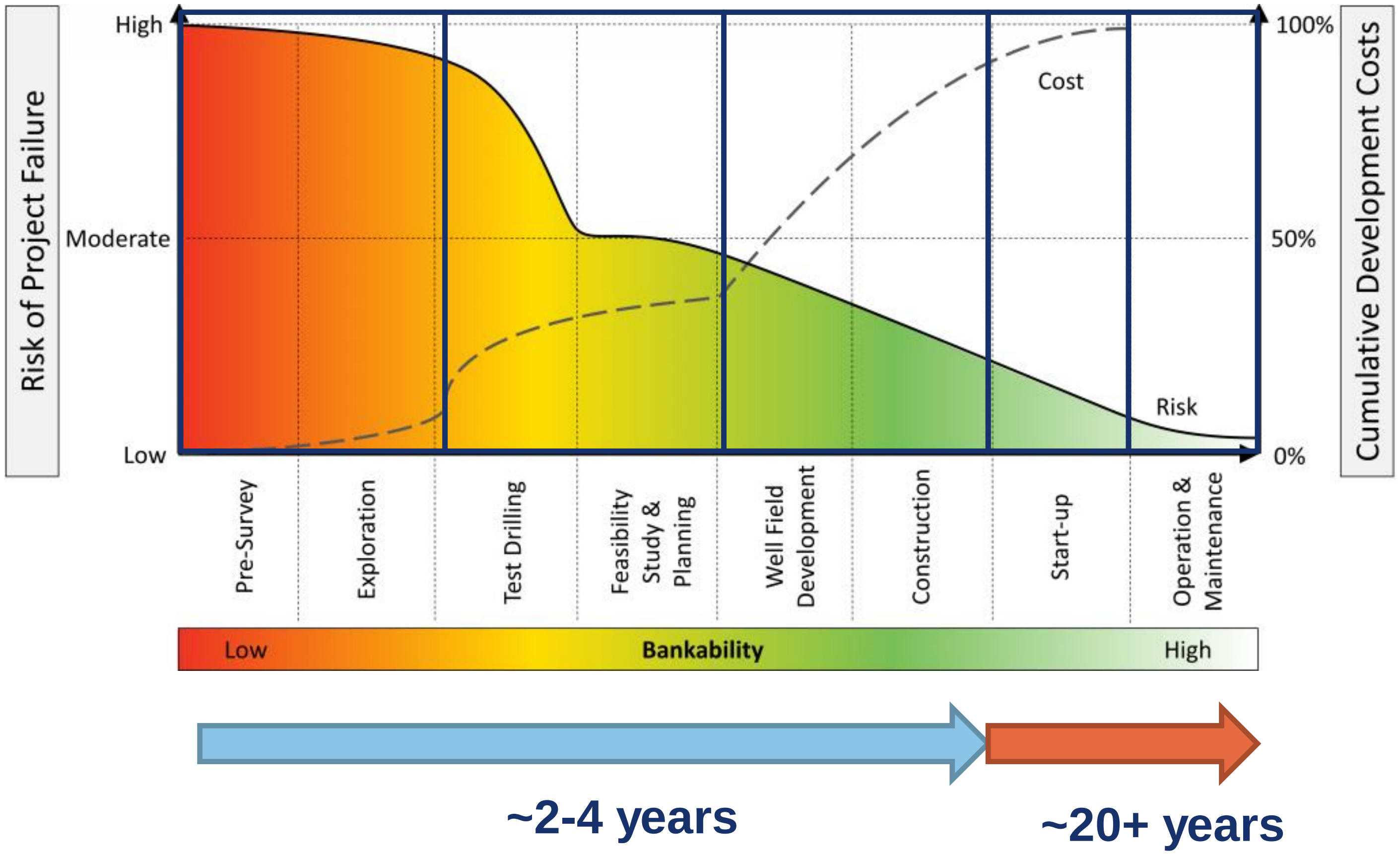
Project Realization Cost/Risk vs Time



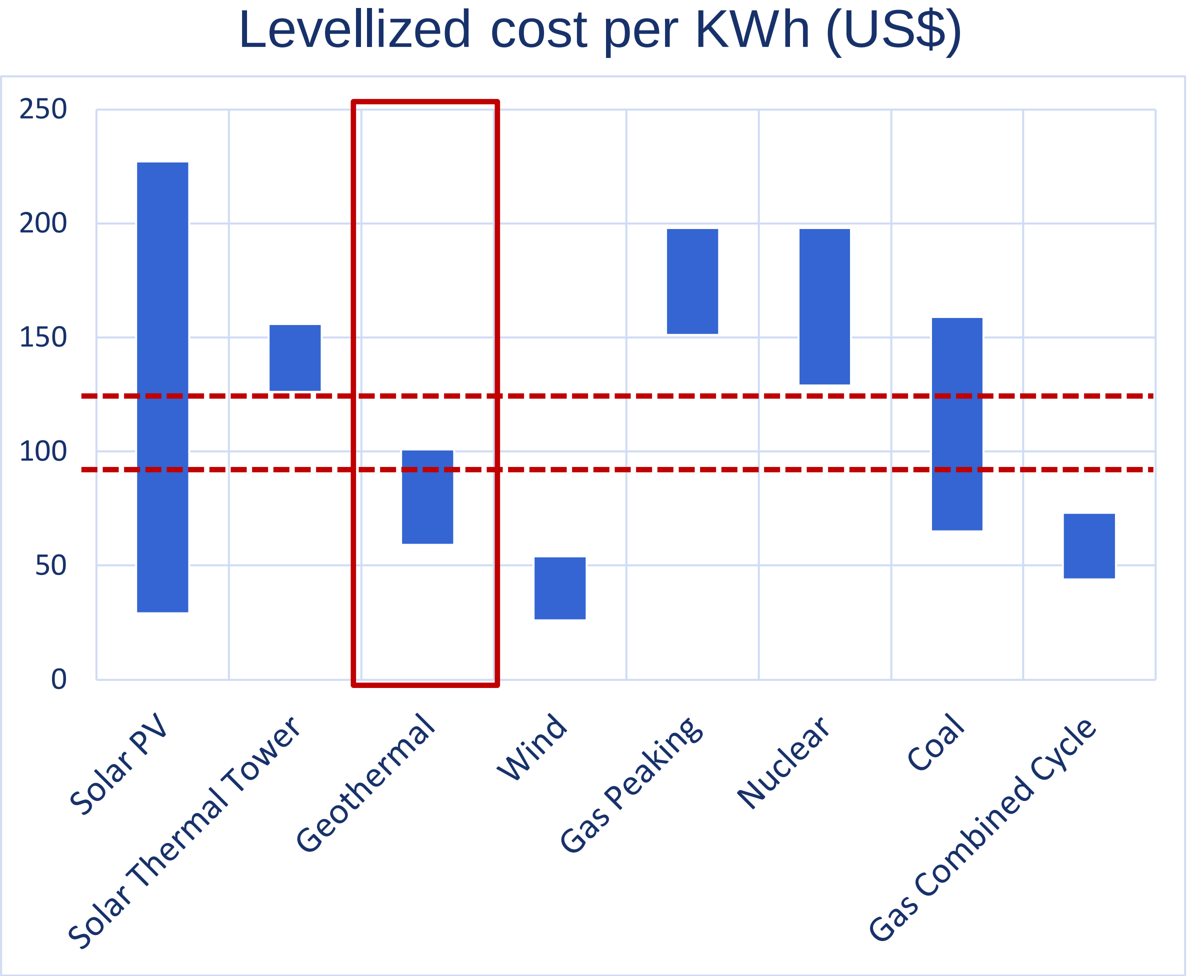
Source: https://www.esmap.org/sites/esmap.org/files/DocumentLibrary/FINAL_Geothermal%20Handbook_TR002-12_Reduced.pdf

Projects have similar risk/cost/return vs. time to hydrocarbon exploration

- Initial relatively low cost but high risk exploration stage
- Appraisal stage with increasing costs
- Development and construction stage with rapidly increasing costs
- Project start up with reducing costs and returns finally beginning
- Long operating phase, with low costs and steady returns

How can we reduce risk, cost and realisation time?

Unsubsidized Levellized cost per KWh



Once installed, geothermal energy is competitive with other energy sources

- However risks in geothermal development are greater than other renewables
- Return on investment can be longer

How can we reduce these risks and improve returns?

Source: https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2020/

How Do Oil and Gas and Geothermal Compare?

Similar Objectives to Oil and Gas?

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The safe, economic extraction of a subsurface energy source with the minimum of adverse effects on the environment

Comparing the Two Industries

Oil and Gas
Established extensive worldwide industry
Mix of major operators and independents, well established supporting industries
Over 150 years of knowledge
Well established methodologies, best practices, regulation, procedures for safely and economically utilising resources

Comparing the Two Industries

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Oil and Gas	Geothermal
Established extensive worldwide industry	Long established, global footprint, significant growth in last few years, but still small compared to oil and gas
Mix of major operators and independents, well established supporting industries	Relatively small industry, few major operators, little experienced supporting industry
Over 150 years of knowledge	Knowledge base growing, but still gaps (subsurface, operational, HSE etc)
Well established methodologies, best practices, regulation, procedures for safely and economically utilising resources	Fewer accepted methodologies, best practices, regulation, procedures for safely and economically utilising resources.

Can Oil and Gas Contribute?

What's Important for Oil and Gas?

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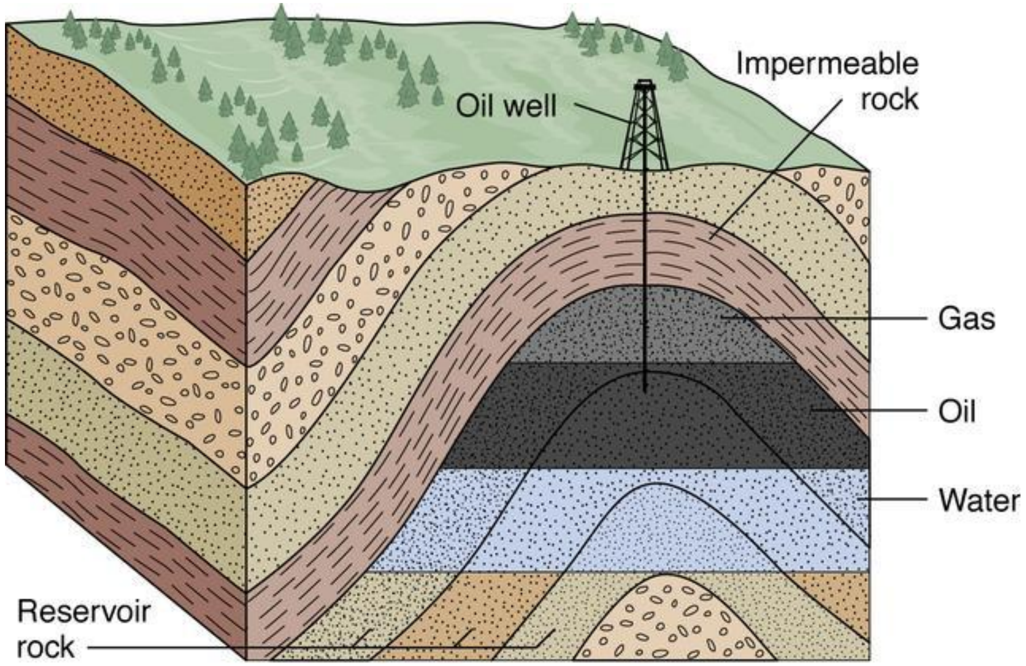
What's Important?
Where are the hydrocarbons
How much is there
Are they producible
What will it cost

What Controls These?
Reservoir structure, thickness and aerial extent
Porosity
Hydrocarbon Saturation
Permeability
Recovery factor



What's Important for Geothermal?

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Property
Temperature
Permeability
Effective porosity
Fractures

What’s Important for Geothermal?

Property	What do we want?
Temperature	Higher is better
Permeability	Higher is better
Effective porosity	Higher is better
Fractures	More open fractures is better

What's Important for Geothermal?

Property	What do we want?	Why?
Temperature	Higher is better	More heat produced
Permeability	Higher is better	Greater flow, more heat production
Effective porosity	Higher is better	More surface area, more heat transfer
Fractures	More open fractures is better	More surface area, better permeability, greater flow, more heat

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Is there anything else?

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Is there anything else?

Property
Lithology and geochemistry
Formation water
Formation and reservoir structure
Geomechanical properties

What's Important for Geothermal?

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Is there anything else?

Property	Why?
Lithology and geochemistry	Different lithologies behave differently with injection = scaling potential, pore plugging
Formation water	Dissolved solids, scale (radioactive?) and corrosion
Formation and reservoir structure	Is the well in the optimal position? Better location = better flow = more heat. Is the injected water going where you think it is?
Geomechanical properties	Rock strength, fracture strength. Subsidence and seismicity, wellbore stability

What's Important for Geothermal?

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Is there more?

- **What don't we know?**
- **What must we learn?**

How Well Do We Know The Subsurface for Geothermal?

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What information is commonly recorded in a geothermal well?

Subsurface acquisition – Logging (Wireline/LWD)

- Seen as 'expensive', often limited – Gamma Ray, occasionally resistivity, identify formation tops for stopping
- Porosity, permeability, thermal properties often inferred from other data – not measured

Well Tests

- Bulk measurement of flow
- Doesn't say where flow is coming from

Implications?

- High local uncertainty on formation properties

Information from Public Data

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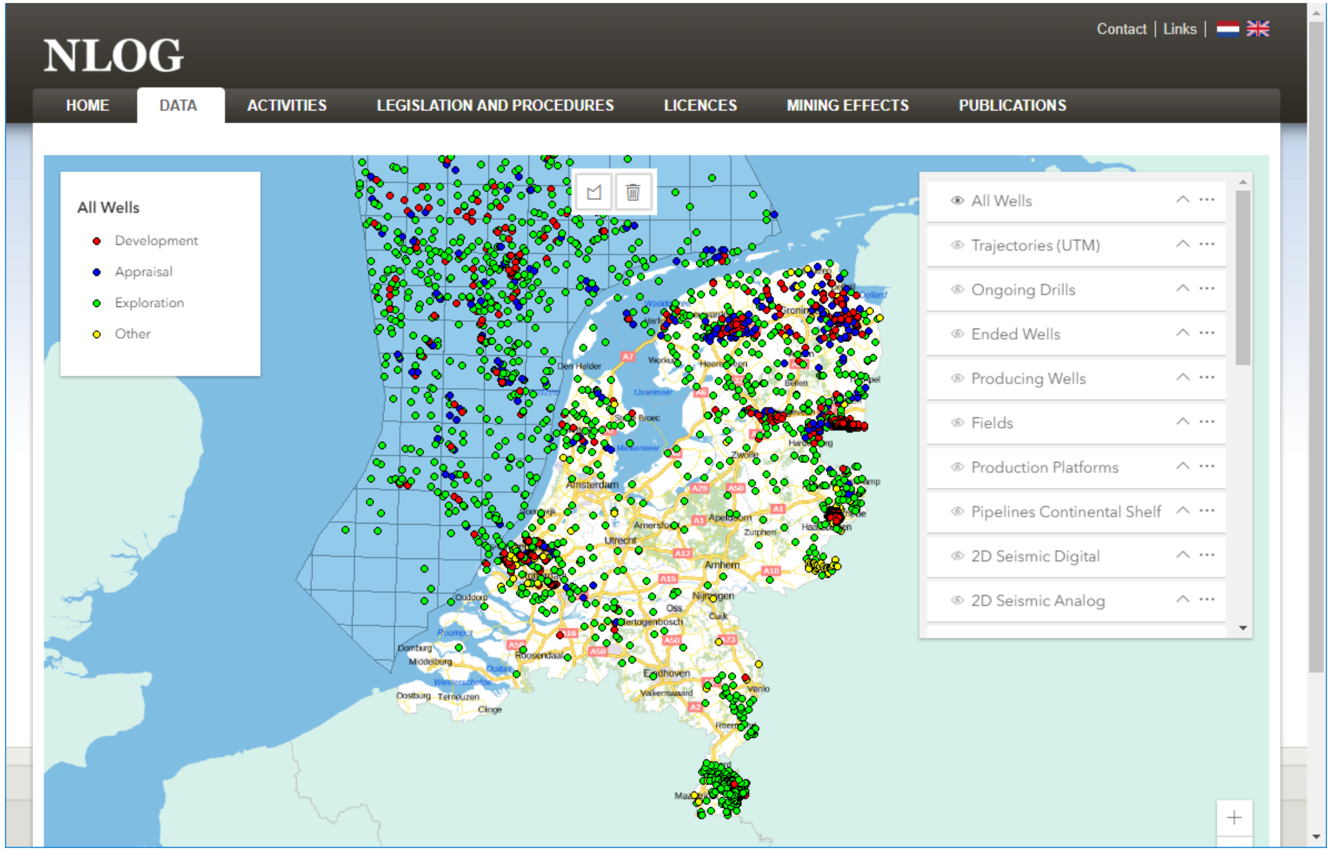
An example – the Dutch NLOG Subsurface Database

- Record of all subsurface information in The Netherlands
  - Many countries have similar national data repositories
- All data older than five years in public domain
- Very comprehensive database



https://www.nlog.nl/en/map-boreholes

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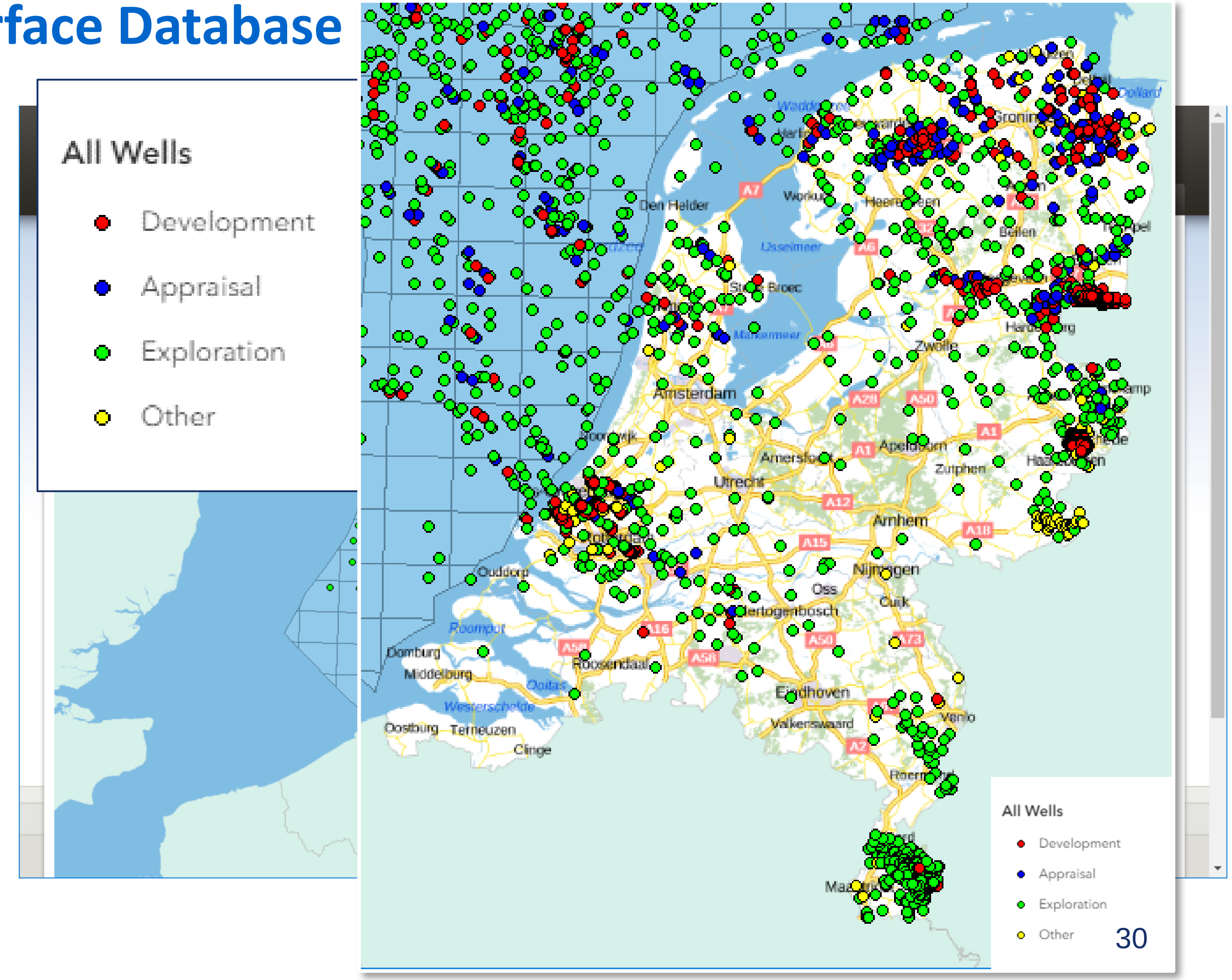

Information from Public Data

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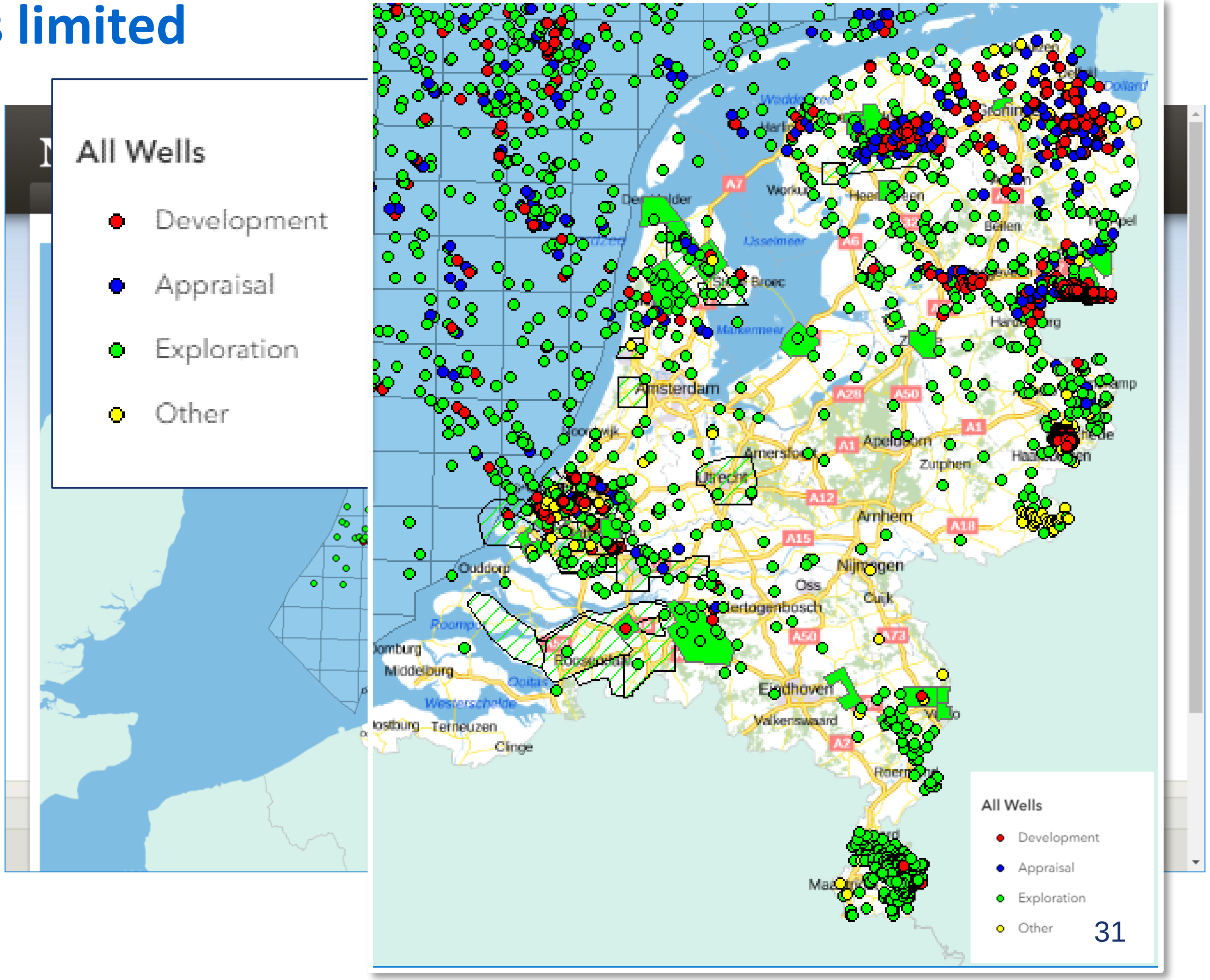
BUT key information for geothermal is limited

- Data concentrated in oil and gas areas
- Data in geothermal plays (green) is rather old (1900's to 1980's) and limited
- Geothermal prospects are 'dry' for oil and gas. Little recent exploration or data.
- Lots of uncertainty

Many other countries face similar challenges



Showing the Value of Data – A Case Study

The Implications Of Limited Subsurface Knowledge

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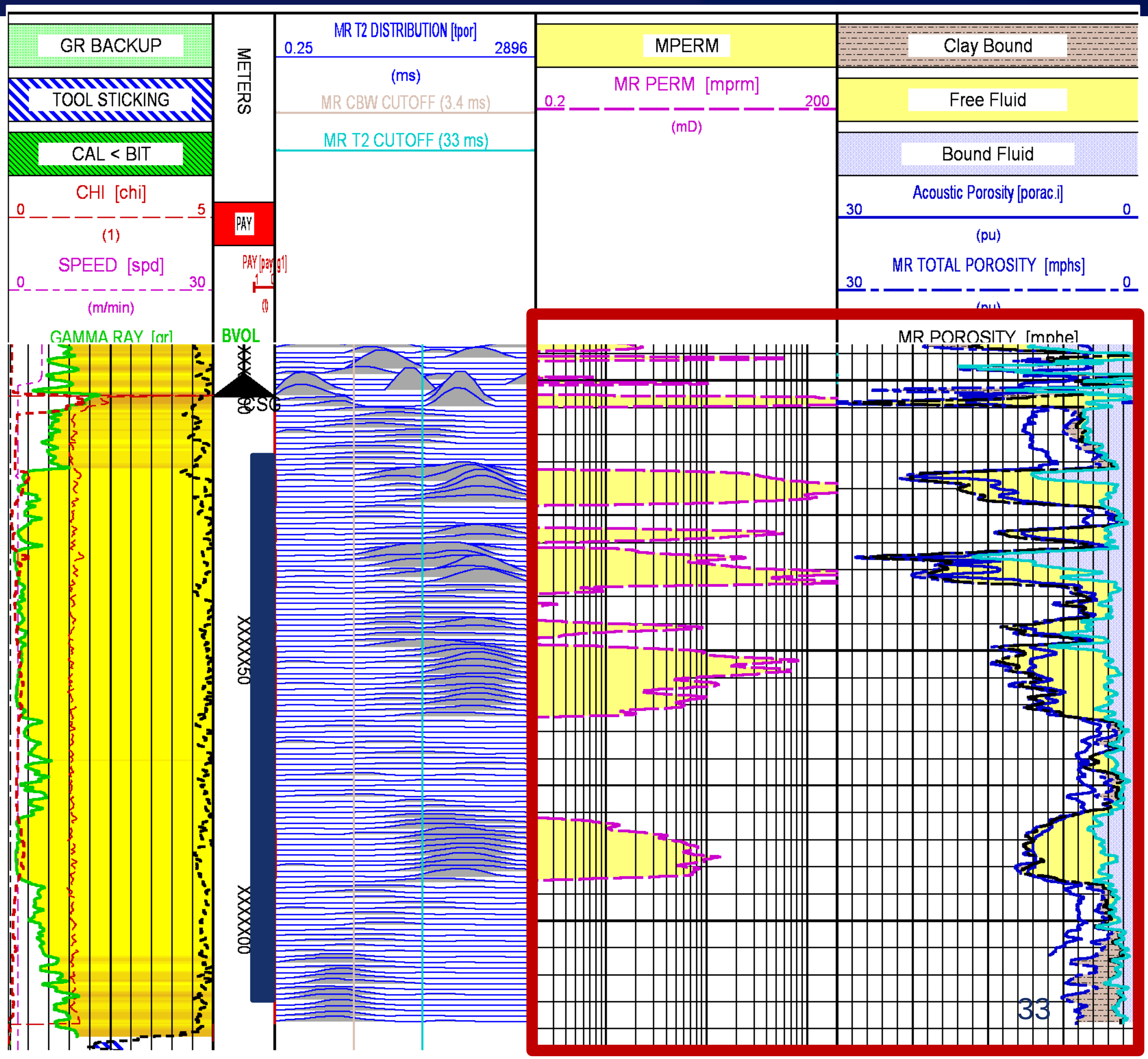
A Case Study

- Fractured carbonate geothermal well – 113m open hole completed interval
- Assumed majority of interval will flow
- Nuclear Magnetic Resonance (NMR) and acoustic logs run for porosity determination
- Porosities up to 15%, NMR derived Coates permeability up to 200mD



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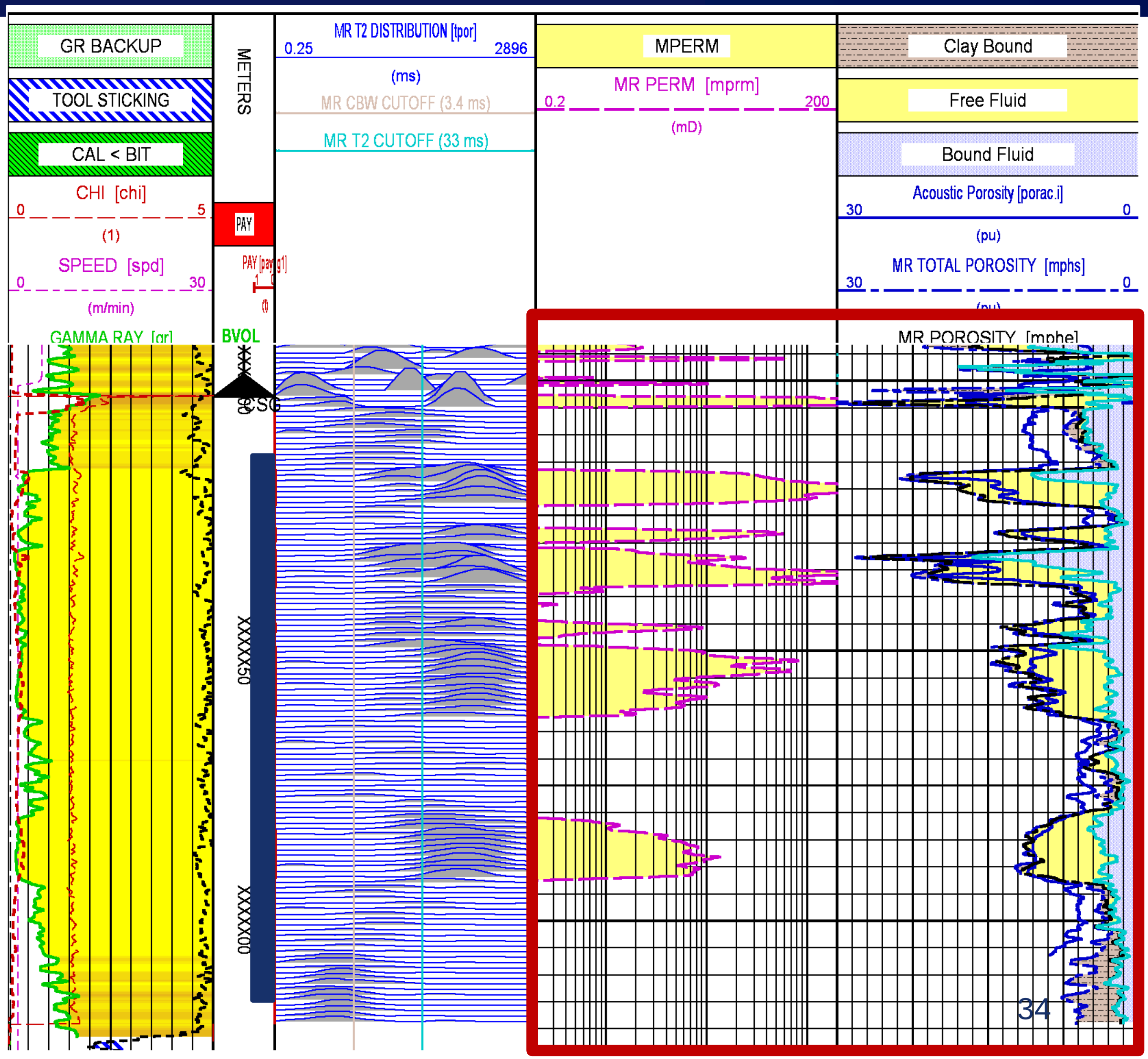
Min Moveable Porosity (%)	Min Permeability (mD)	Productive Interval (m)	Net/Gross
5	2	36.5	0.323



Where's The Flow Coming From?

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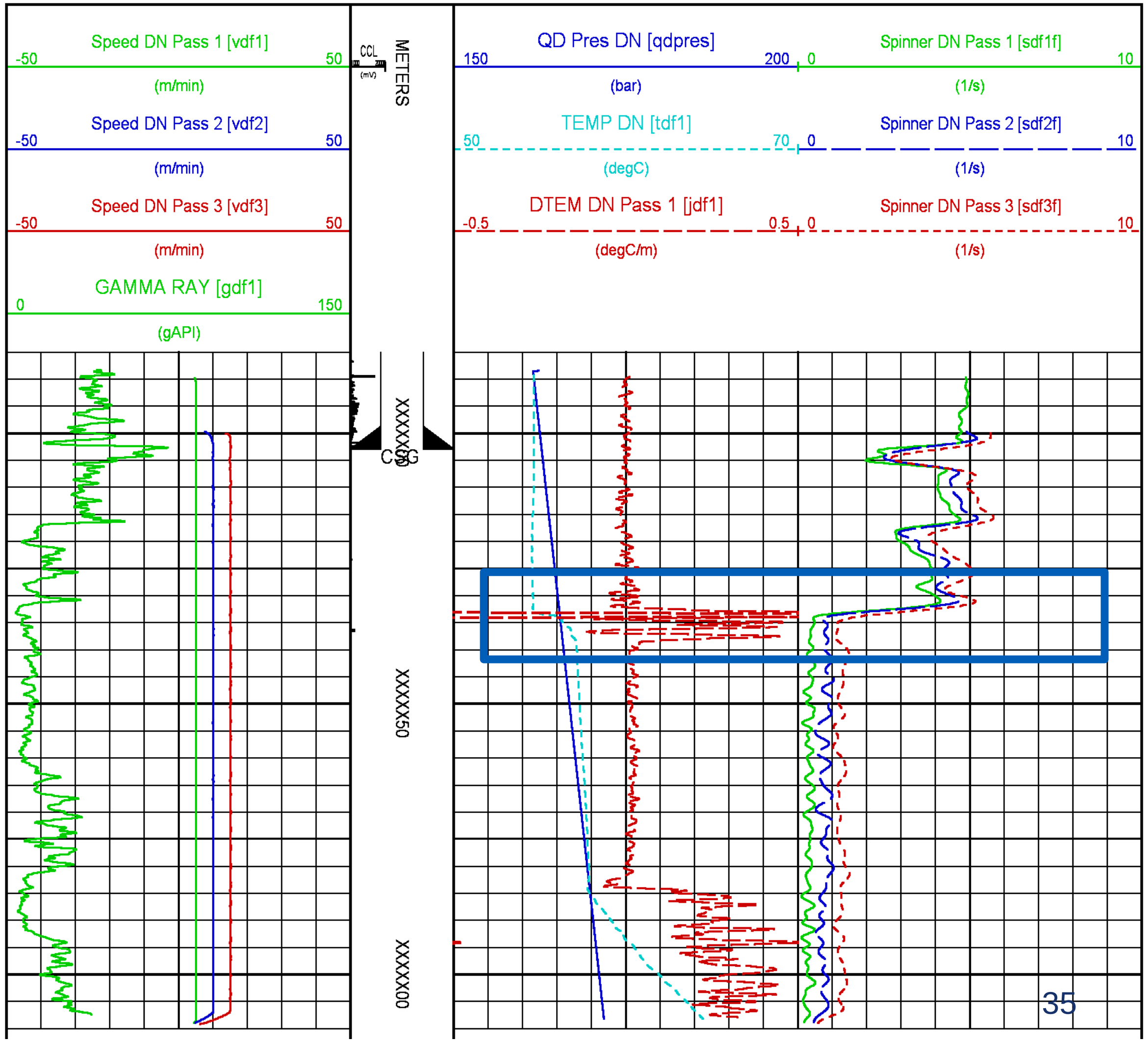
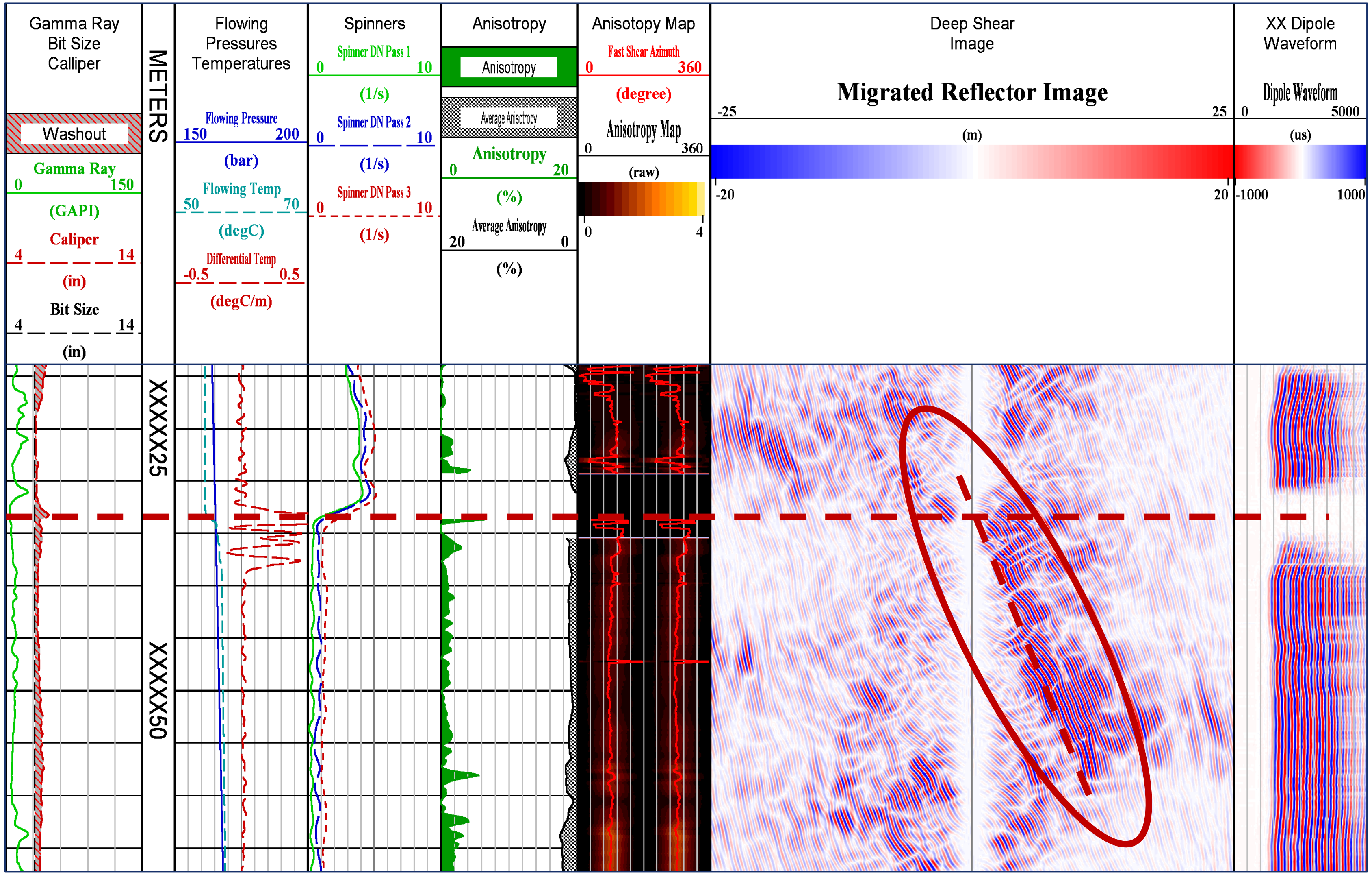
But does it all flow?

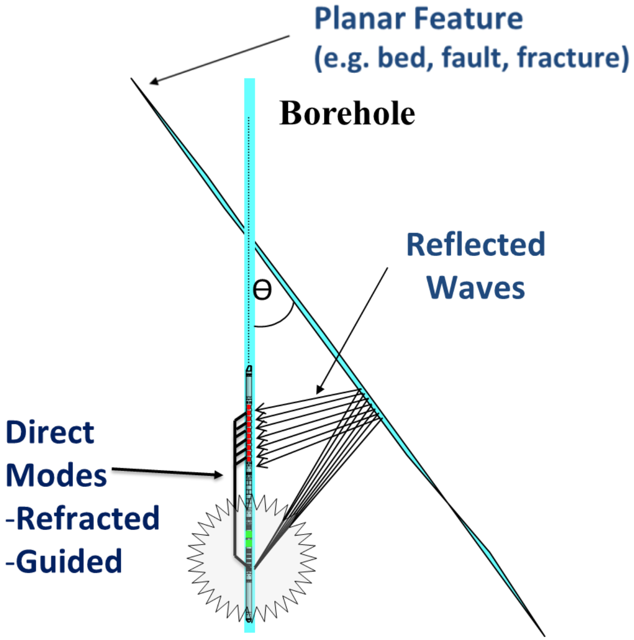
- Production logs (spinners, pressure, temperature) run for flow identification
- Significant flow over only one interval
- Why?



Why Is Only This Interval Flowing?



Reflection Imaging Theory



What Are The Implications?

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How can lack of subsurface knowledge affect a project?

- Poorer performance than expected
- Lower economic return - Less attractive to investors
- Lack of geochemical knowledge? – Corrosion, Scaling?
- Unexpected solids production? Pump Wear?
- Reactivation of faults? – Seismicity?
- What else?

How Can Subsurface Knowledge Benefit Geothermal?

Increasing Energy Production - The Base Case

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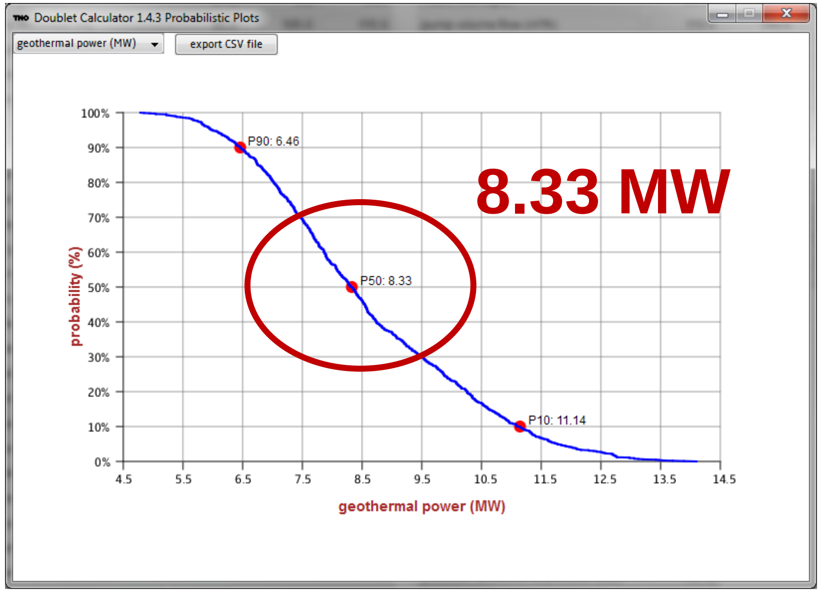
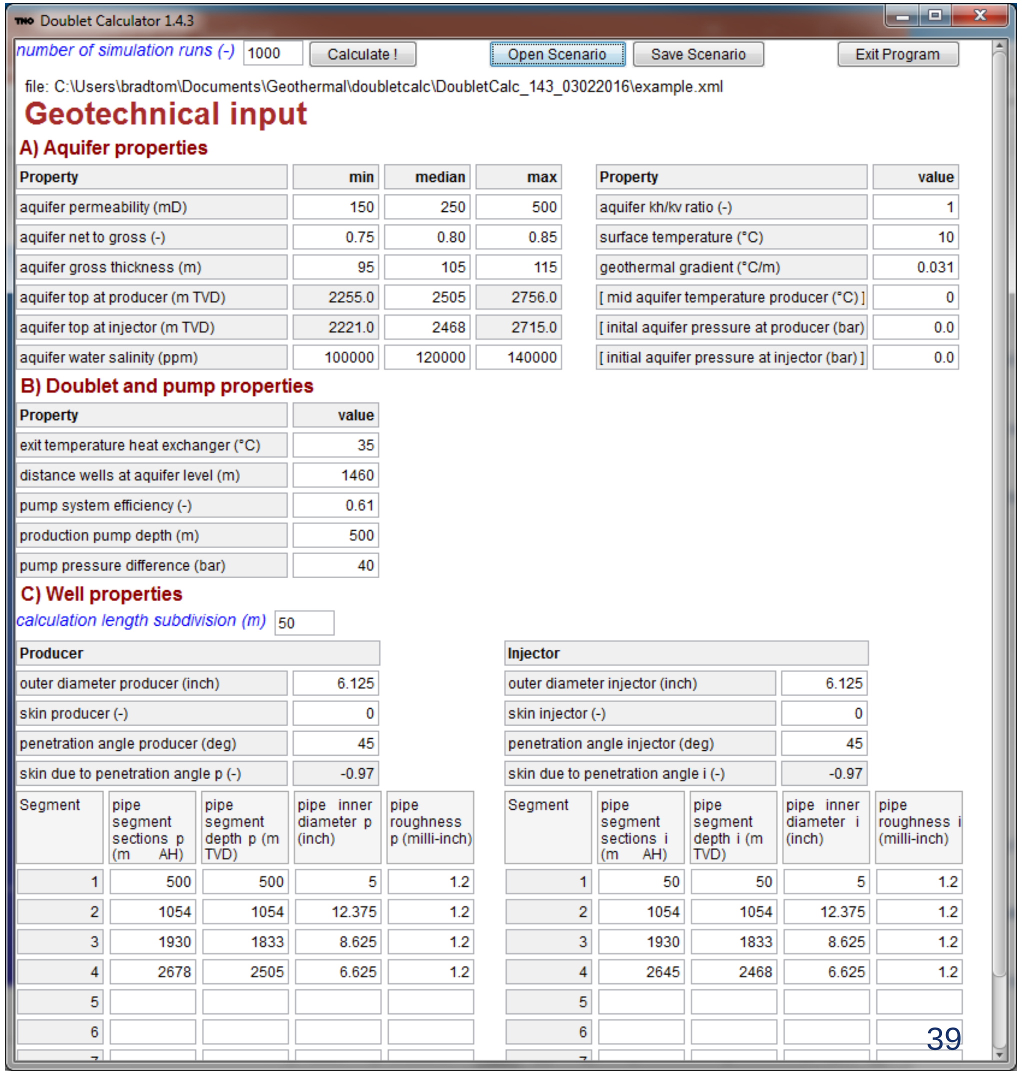
DoubletCalc – energy production estimation

- TNO example DoubletCalc scenario
- Base case – 0.8 net to gross
- What if we steered well to improve net-to-gross by 5%?




Doublet Calculator 1.4.3

number of simulation runs (-) 1000 | Calculate ! | Open Scenario | Save Scenario | Exit Program

file: C:\Users\bradtom\Documents\Geothermal\doubletcalc\DoubletCalc_143_03022016\example.xml

Geotechnical input

A) Aquifer properties

Property	min	median	max
aquifer permeability (mD)	150	250	500
aquifer net to gross (-)	0.75	0.80	0.85
aquifer gross thickness (m)	95	105	115
aquifer top at producer (m TVD)	2255.0	2505	2756.0
aquifer top at injector (m TVD)	2221.0	2468	2715.0
aquifer water salinity (ppm)	100000	120000	140000

Property	value
aquifer kh/kv ratio (-)	1
surface temperature (°C)	10
geothermal gradient (°C/m)	0.031
[mid aquifer temperature producer (°C)]	0
[inital aquifer pressure at producer (bar)	0.0
[initial aquifer pressure at injector (bar)]	0.0

B) Doublet and pump properties

Property	value
exit temperature heat exchanger (°C)	35
distance wells at aquifer level (m)	1460
pump system efficiency (-)	0.61
production pump depth (m)	500
pump pressure difference (bar)	40

C) Well properties

calculation length subdivision (m) 50

Producer	
outer diameter producer (inch)	6.125
skin producer (-)	0
penetration angle producer (deg)	45
skin due to penetration angle p (-)	-0.97

Segment	pipe segment sections p (m AH)	pipe segment depth p (m TVD)	pipe inner diameter p (inch)	pipe roughness p (milli-inch)
1	500	500	5	1.2
2	1054	1054	12.375	1.2
3	1930	1833	8.625	1.2
4	2678	2505	6.625	1.2
5				
6				

Injector	
outer diameter injector (inch)	6.125
skin injector (-)	0
penetration angle injector (deg)	45
skin due to penetration angle i (-)	-0.97

Segment	pipe segment sections i (m AH)	pipe segment depth i (m TVD)	pipe inner diameter i (inch)	pipe roughness i (milli-inch)
1	50	50	5	1.2
2	1054	1054	12.375	1.2
3	1930	1833	8.625	1.2
4	2645	2468	6.625	1.2
5				
6				

https://www.nlog.nl/en/nieuws/doubletcalc-2d-v10

Increasing Energy Production – Steering A Well

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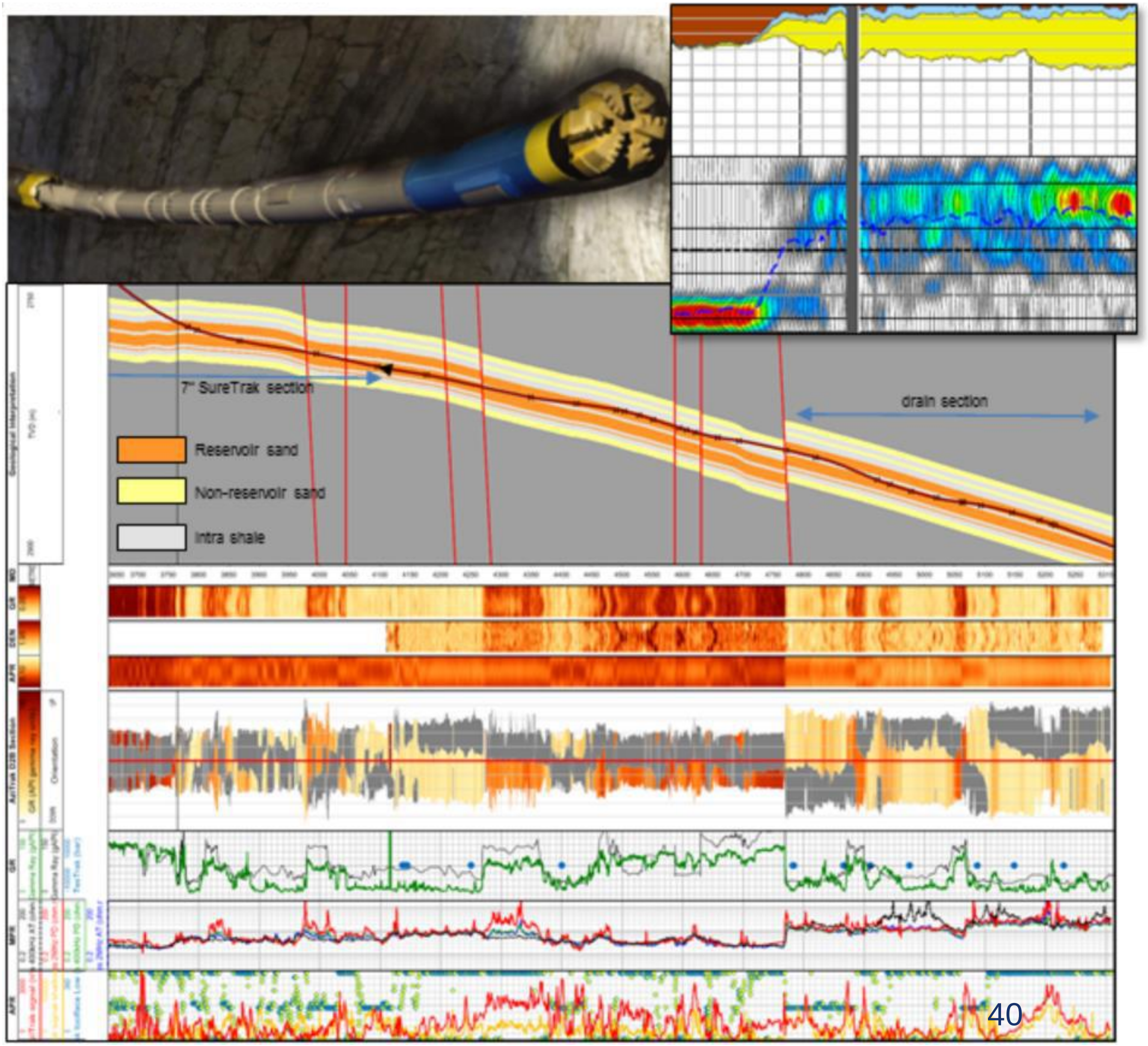
- Sand-shale sequence
- Well steered using porosity logs
  - e.g. deep azimuthal resistivity, azimuthal density, Nuclear Magnetic Resonance
- Stay in most productive (porous/permeable) zone.
- Improve net/gross



5% net to gross increase = >440kw (5.3%) power increase at P50

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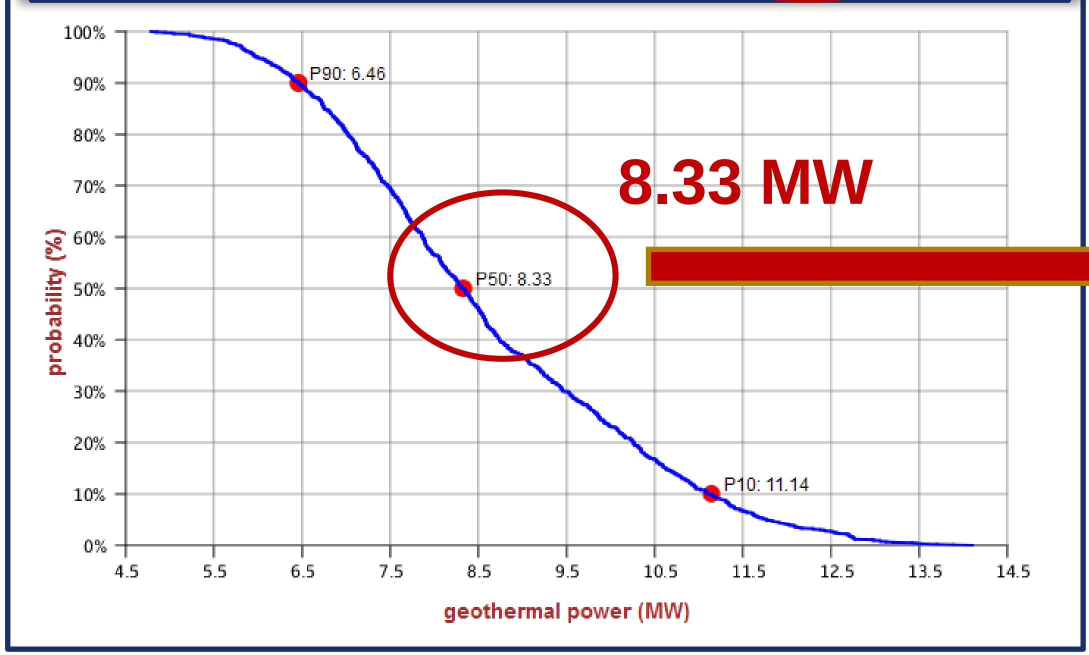
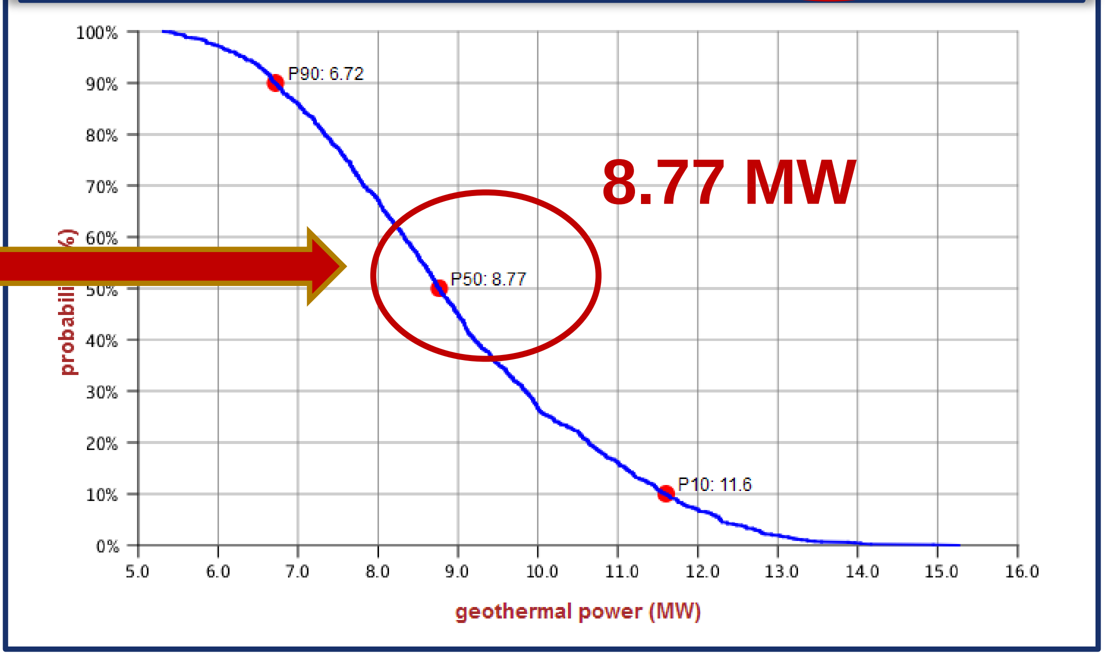
Property	min	median	max
aquifer permeability (mD)	150	250	500
aquifer net to gross (-)	0.75	0.80	0.85



Property	min	median	max
aquifer permeability (mD)	150.0	250.0	500.0
aquifer net to gross (-)	0.8	0.85	0.9



+440kW = 

At wholesale electricity price of €0.1/kWh, almost €400,000 additional revenue per year!

Not Just Net-to-Gross

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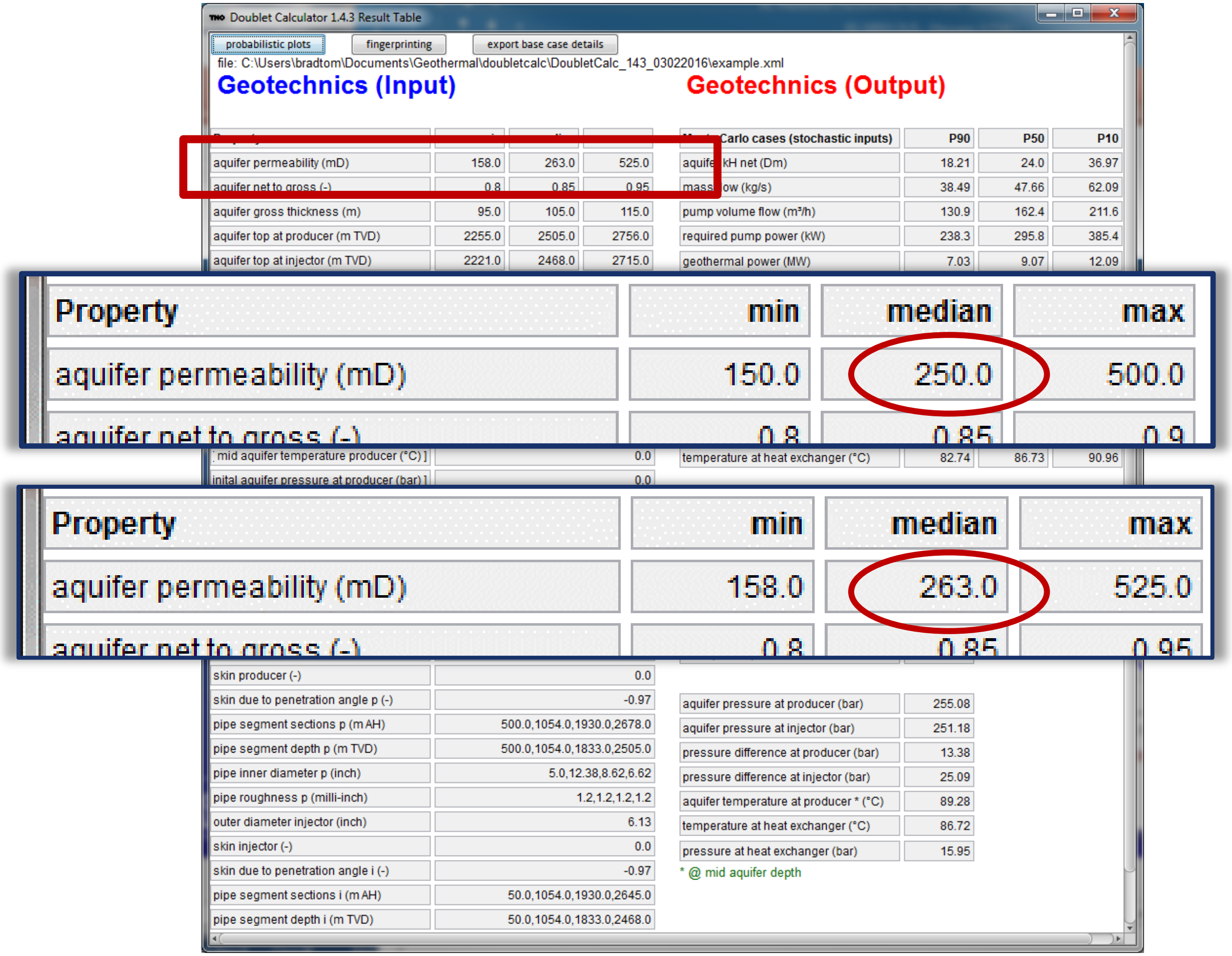
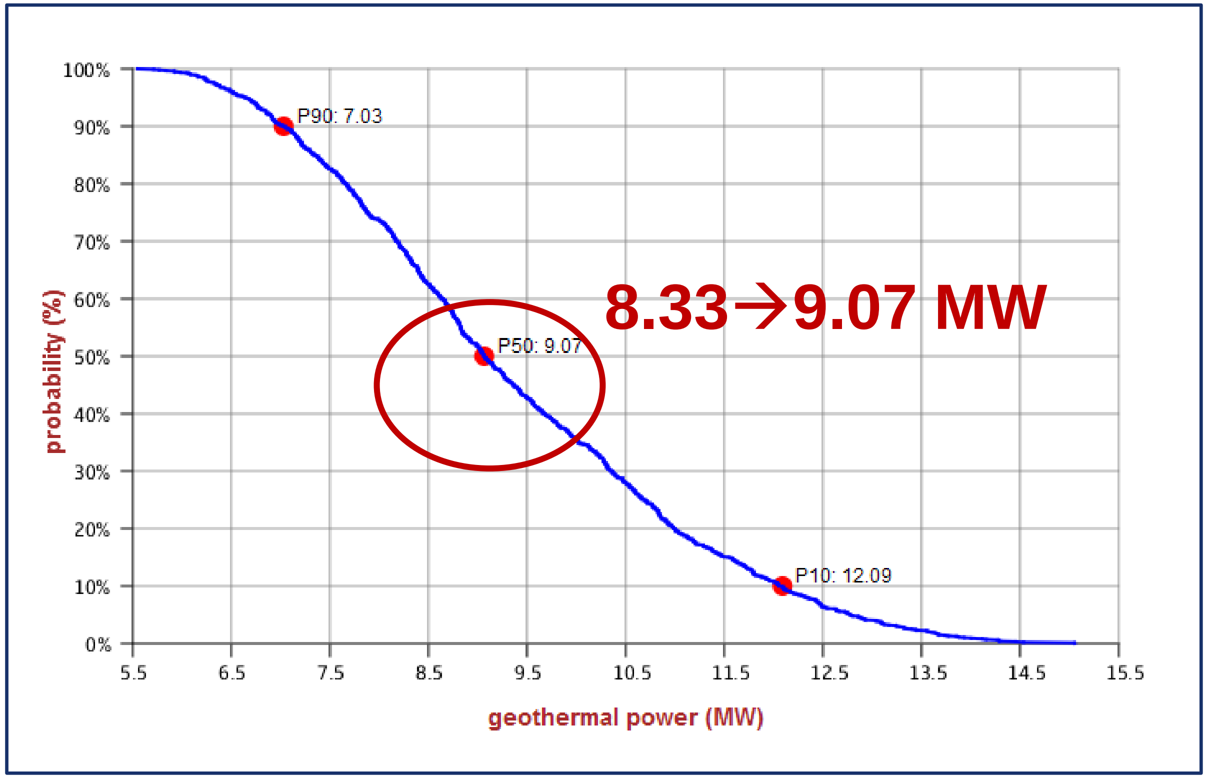
5% increase in permeability gives further 300kW output





+740kW = € 650,000 extra revenue per year

Conclusions

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- Geothermal is a viable economic environmentally friendly energy source
- Current application of subsurface evaluation to geothermal is often limited
- Well established oil and gas evaluation principles equally applicable to geothermal
- Subsurface data acquisition often seen as unnecessary expense that should be minimised
- Additional direct measurement of certain key properties would be very beneficial
  - May only become apparent many years in the future
  - Acquisition later in life of well may be impractical or impossible, and expensive
- Potential to increase heat production and cost savings through efficiency and optimisation of prospects

A Final Conclusion

- As SPE members, we know the subsurface
- **We as an industry have the knowledge to help make geothermal energy technically and economically viable**

Credit: https://www.hortipoint.nl/

Acknowledgements

- SPE
- Baker Hughes Company
- Engie Reseaux