GEOTHERMAL UTILIZATION: POWER GENERATION

Dr. Deirdre Clark

Geochemist, Iceland GeoSurvey (ÍSOR)

Photo Niels Giroud

ÍSOR – ICELAND GEOSURVEY

- Icelandic Energy Research Institute in Icelandic
- Owned by the Icelandic government.
- Provides specialized services to the Icelandic power industry, the Icelandic government, and international companies.
- Operates on the free market on a competitive basis.
- Profit goes exclusively into scientific research and to strengthen ÍSOR.

75 YEARS OF EXPERIENCE

- 1945 Established as a part of the State Electrical Authority.
- 1956 A Geothermal Division was formally established.
- 1967 National Energy Authority established.
- 1997 The GeoScience Division of the National Energy Authority of Iceland was established.
- 2003 Iceland GeoSurvey – ÍSOR


Photo Guðmundur Pálmason


Photo Jón Ragnarsson

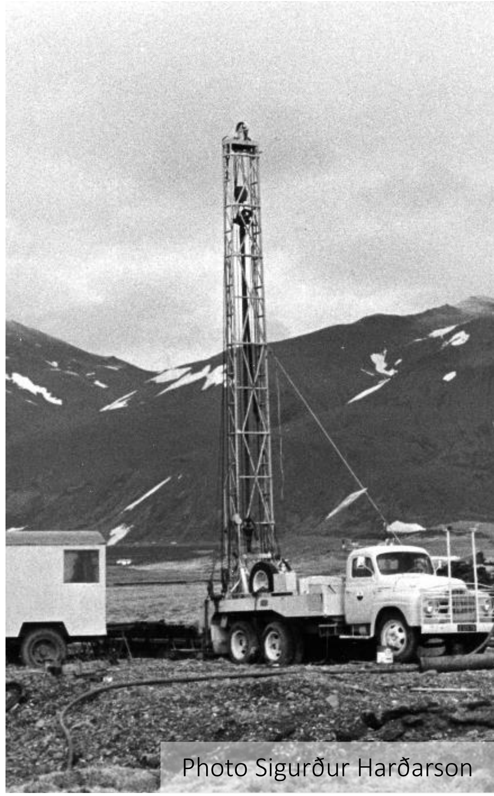
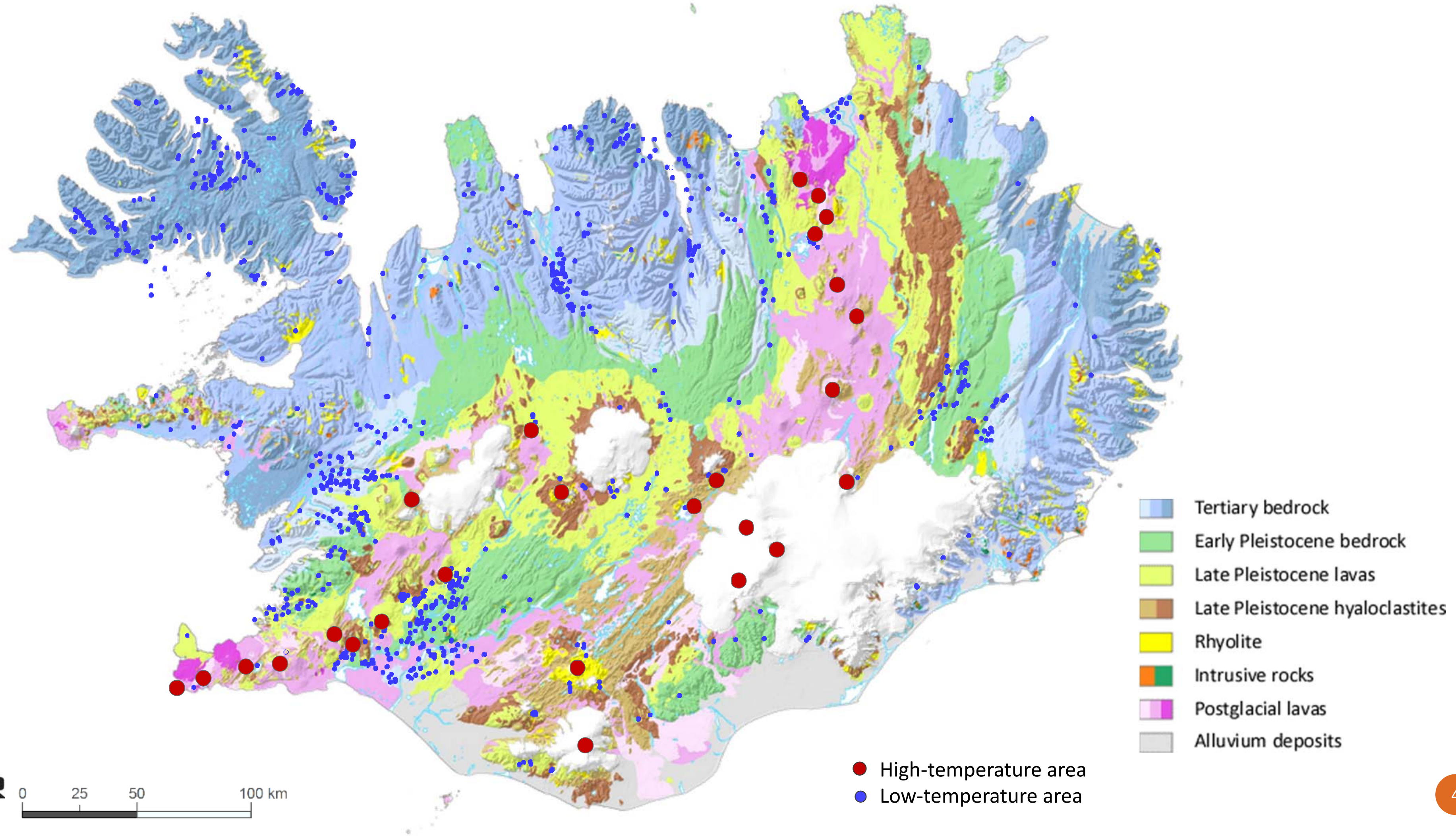


Photo Sigurður Harðarson

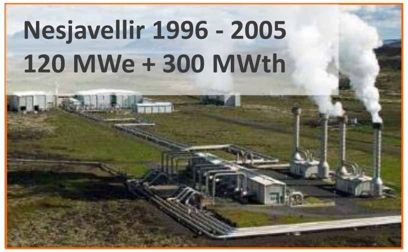
GEOTHERMAL MAP OF ICELAND

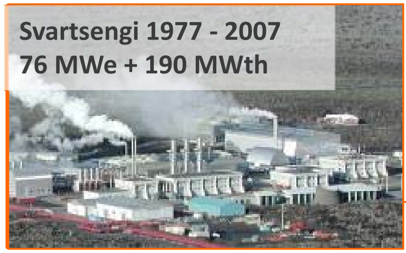


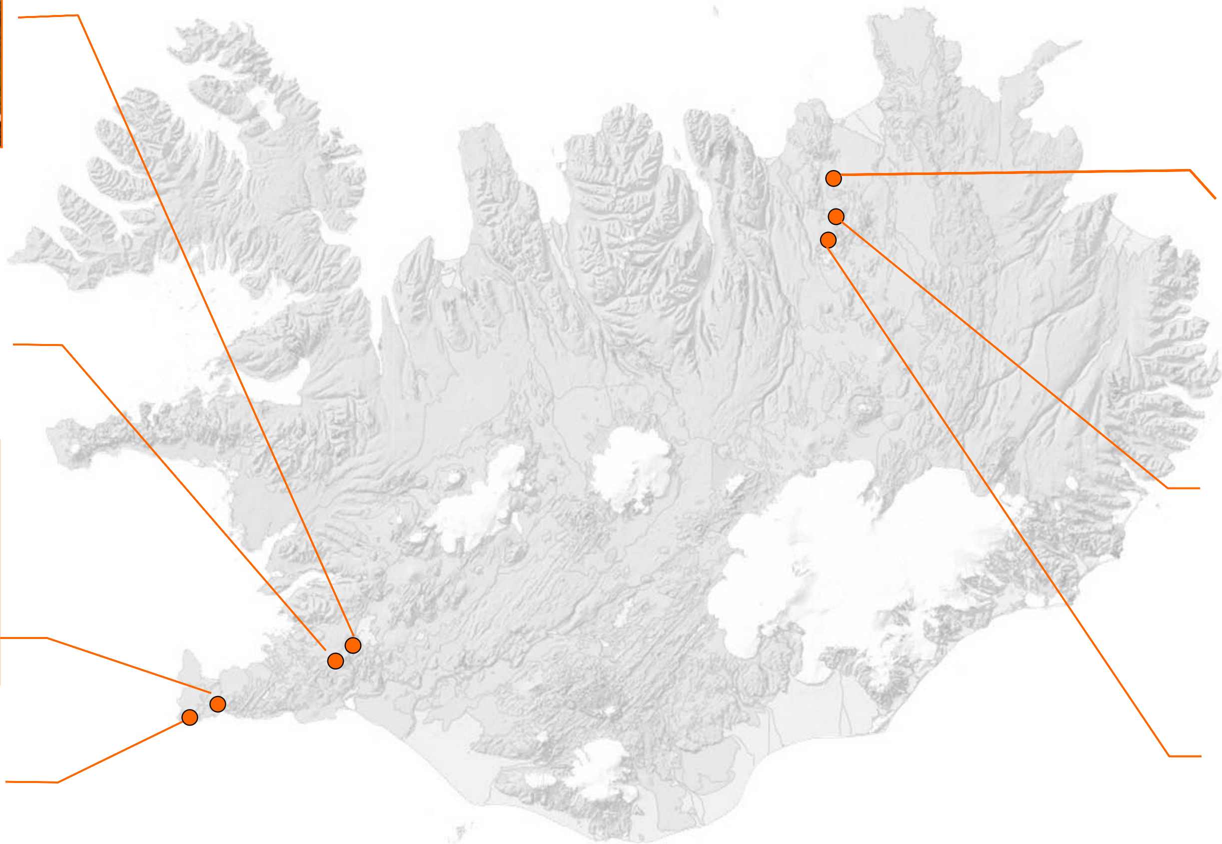
ÍSOR

GEOTHERMAL POWER STATIONS IN ICELAND

Total Installed Capacity
755 MWe

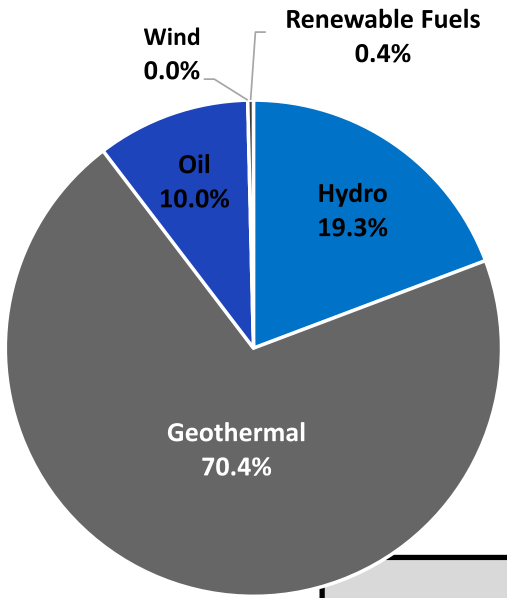






Iceland GeoSurvey has been a key actor in all development of geothermal power production in Iceland.

PRIMARY ENERGY CONSUMPTION IN ICELAND 2021



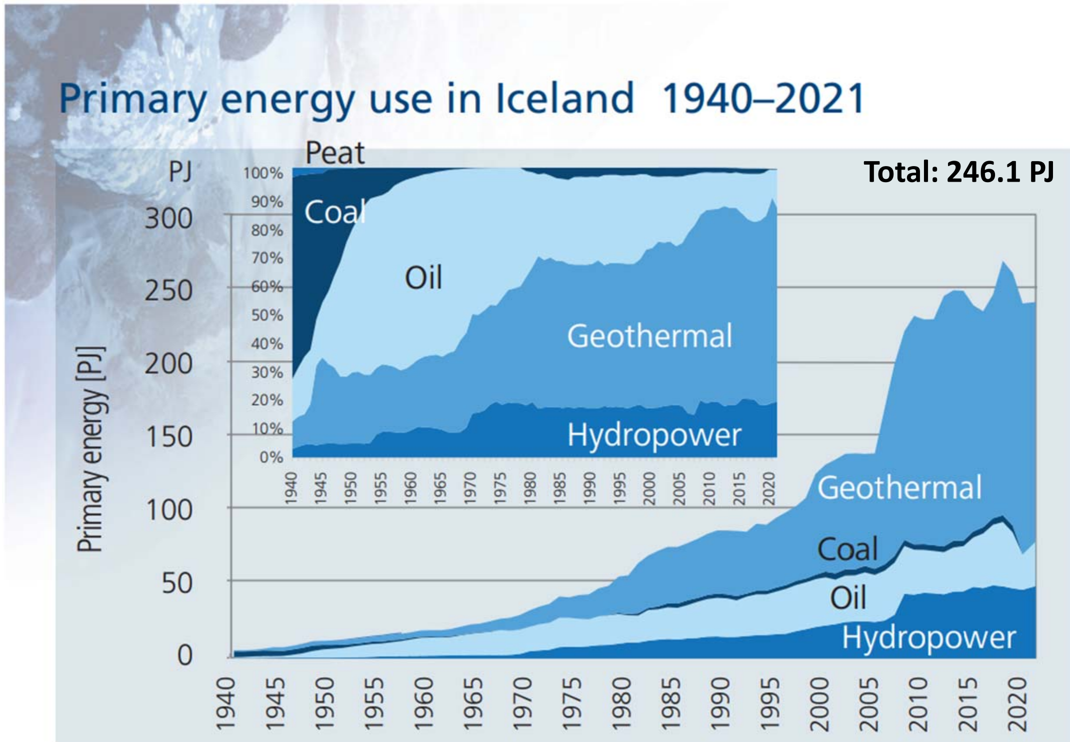
Primary energy consumption **661 GJ/capita**

1 PJ = 1000 TJ = 1,000,000 GJ

1kWh = 3,600 kJ

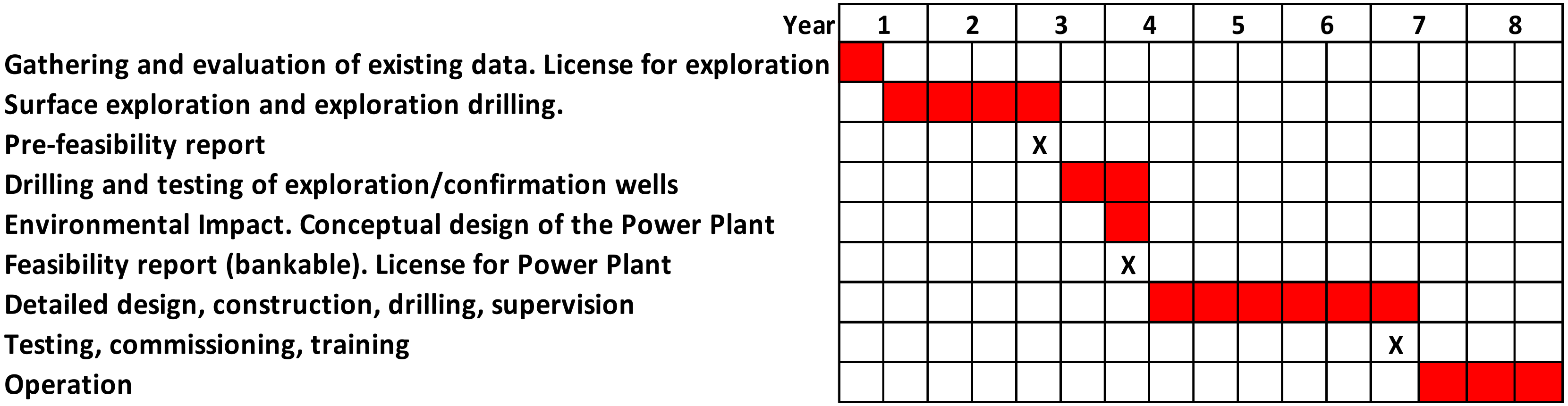
1 toe = 41.868 GJ

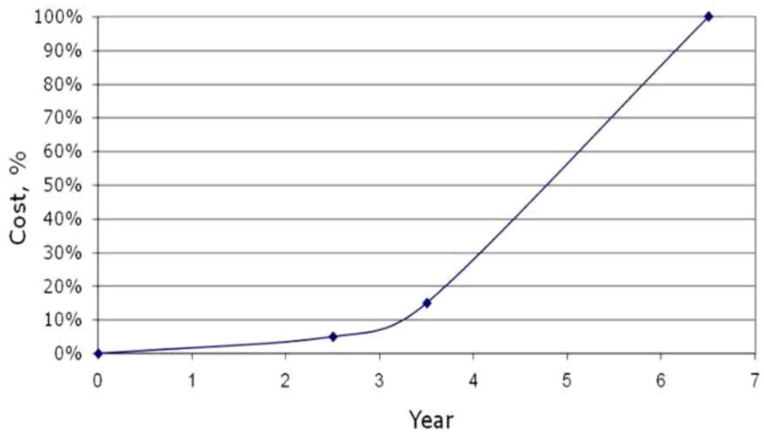
	PJ	Ktoe	%
Hydropower	47.4	1,132	19.3
Geothermal	173.2	4,137	70.4
Oil	24.6	588	10.0
Wind	0.02	0.48	0.01
Renewable Fuels	0.89	21.3	0.36
Total	246.1	5,878	100



Source: Iceland National Energy Authority

PROJECT DEVELOPMENT TIME AND COST





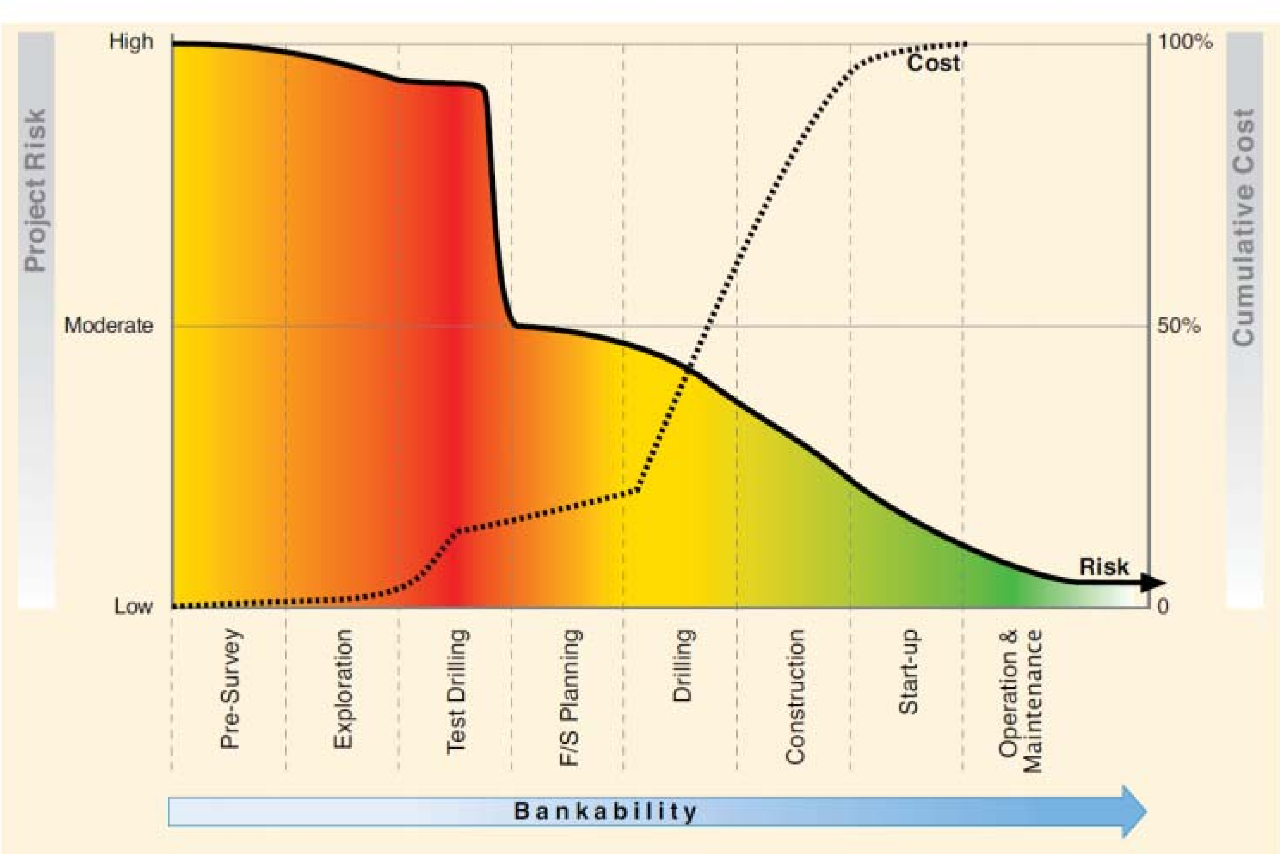
On average:

Flash power plant, the cost is $3.5 – 4 Mill USD/MW installed, for binary, the cost is $4 – 6 Mill USD/MW installed

Binary Plants (~1-50 MW) are usually smaller than Flash Plants (~5-300 MW)

Cost of drilling is around 40%, power plant construction around 40%, other cost 20%

TYPICAL RISK PROFILE FOR GEOTHERMAL DEVELOPMENT



Geothermal Handbook (ESMAP, 2012)
https://openknowledge.worldbank.org/handle/10986/23712

EXPLORATION – THE FIRST PHASE OF DEVELOPMENT

By geothermal exploration, we mean the acquisition of knowledge about possible geothermal fields in order to identify a geothermal energy resource for viable energy production and utilization.

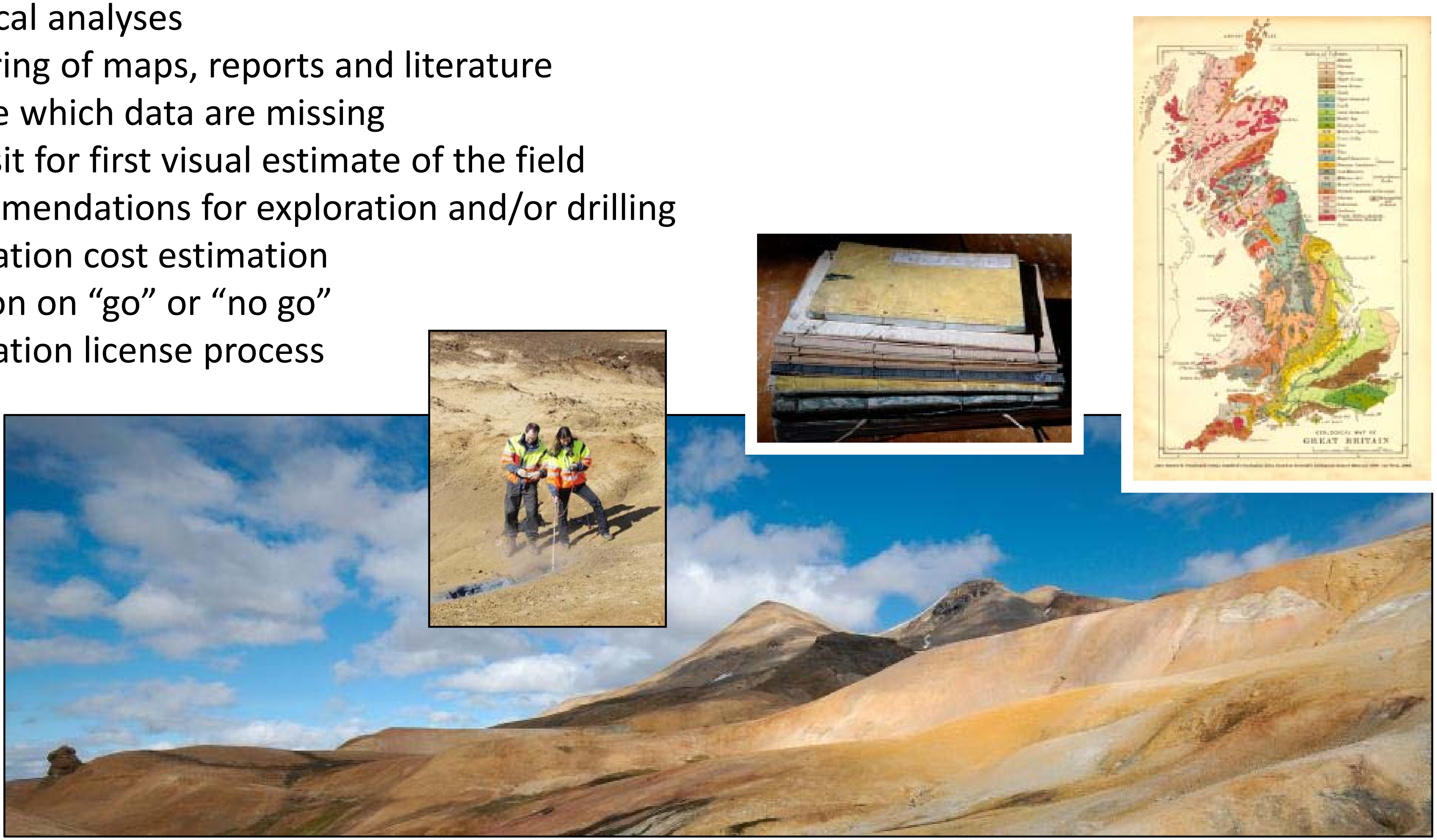
Methods applied in geothermal exploration include numerous geo-scientific methods as well as drilling of exploratory wells.

However, exploration requires considerable up-front cost prior to exploration drilling. Therefore:

- Exploration methods must be selected with respect to the site
- Exploration must be carried out in professional manner
- Stepwise approach is recommended, i.e. the strategy must be revised as the results appear.

1. GATHERING AND EVALUATION OF EXISTING DATA

- Information on the geothermal field
- Chemical analyses
- Gathering of maps, reports and literature
- Outline which data are missing
- Site visit for first visual estimate of the field
- Recommendations for exploration and/or drilling
- Exploration cost estimation
- Decision on “go” or “no go”
- Exploration license process



ÍSOR

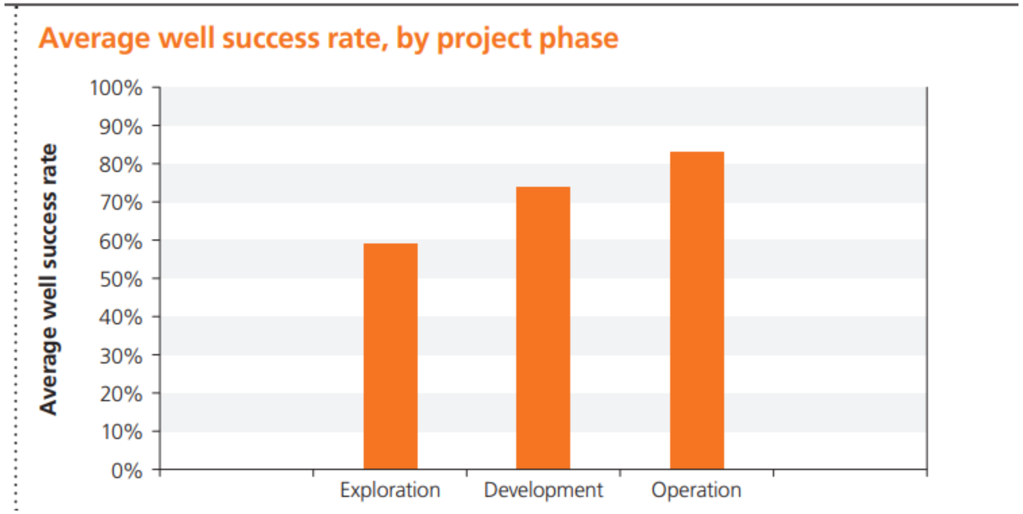
2. SURFACE EXPLORATION AND EXPLORATION DRILLING

- Geological-, geothermal-, and structural mapping
- Geochemical sampling, analyses, and interpretation
- Geophysical surface exploration
- Initial conceptual model and preliminary resource assessment
- Designing, siting, and supervision of exploration wells
- EIA for exploration drilling
- Drilling and testing of exploration wells

ÍSOR

EXPLORATION DRILLING

To investigate a new geothermal field where surface mapping by a host of geo scientific methods (3G) has indicated a resource, exploration drilling is the next phase.



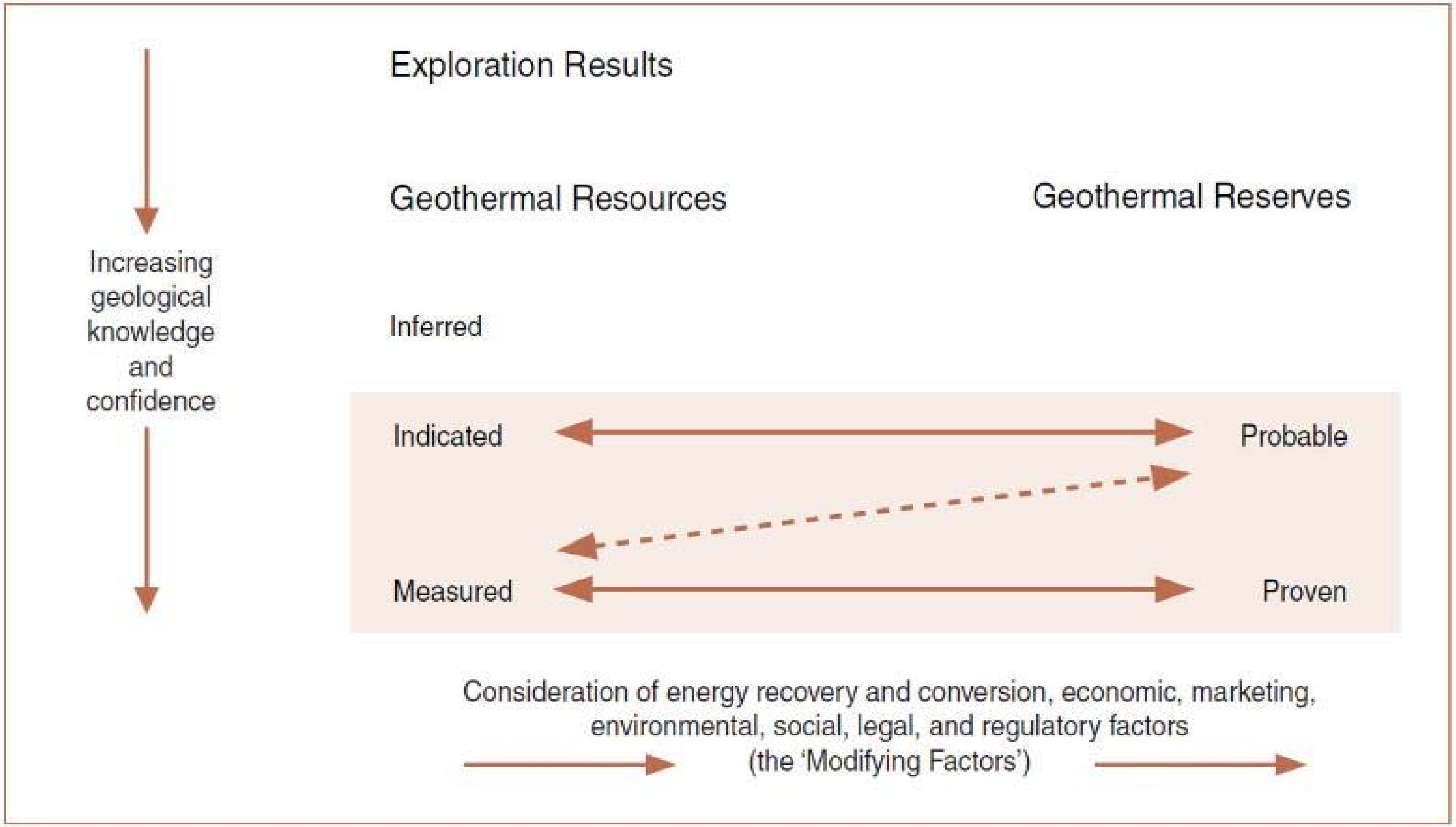
Such wells can serve three purposes:

A. To provide additional information to some key questions for proper understanding of the earlier surveys, e.g., resistivity and temperature gradient. These wells can be slim holes and not so very deep.

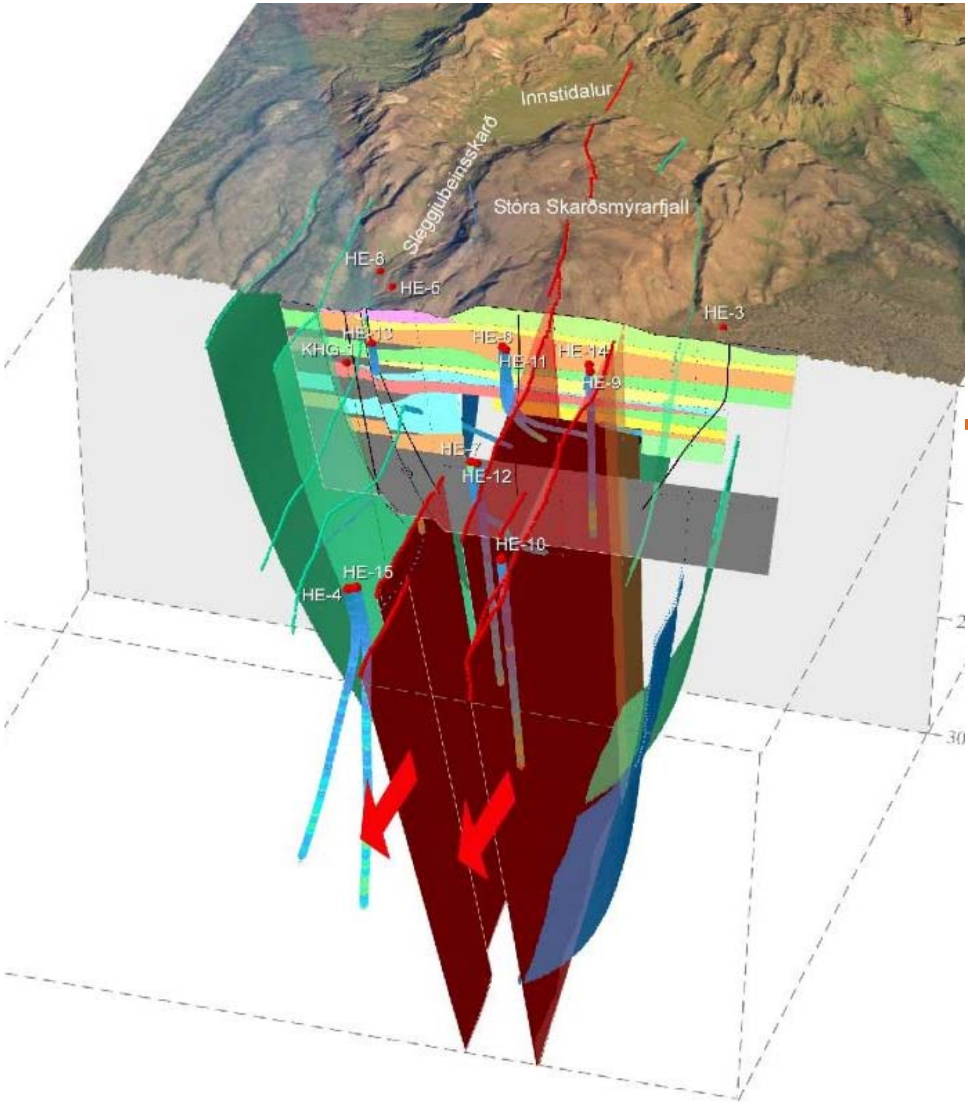
B. To confirm the existence of a viable resource and provide information on the reservoir and its potential. A "conceptual model" combines results of surveys and drilling results and aids in the site selection for new wells. Reservoir simulation allows a developer to evaluate the commercial potential and decide whether to proceed to production drilling. Such exploration wells need to be deep enough to penetrate the reservoir and of large enough diameter to allow fluid to be produced. These wells can also be of slim design.

C. To bring the knowledge and confidence of the geothermal resource to a level that meets the requirements of "Measured" or even as "Proven" reserves. (See next slide)

THE REPORTING CODE



Australia: The Geothermal Reporting Code (2010)
Canada: The Canadian Geothermal Code for Public Reporting.
Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves (2010)



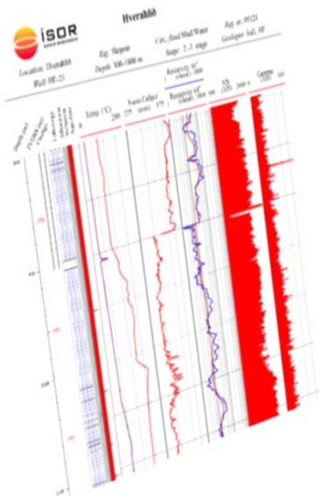
3. PRE-FEASIBILITY REPORT

- Conceptual geothermal model of the geothermal field
- First evaluation of field capacity (volumetric assessment)
- Basic process design of power plant and steam field
- Prospective Drilling Sites
- Preliminary cost estimate of further development and financing
- Recommendations for next step
- Decision on “go” or “no go”

ÍSOR

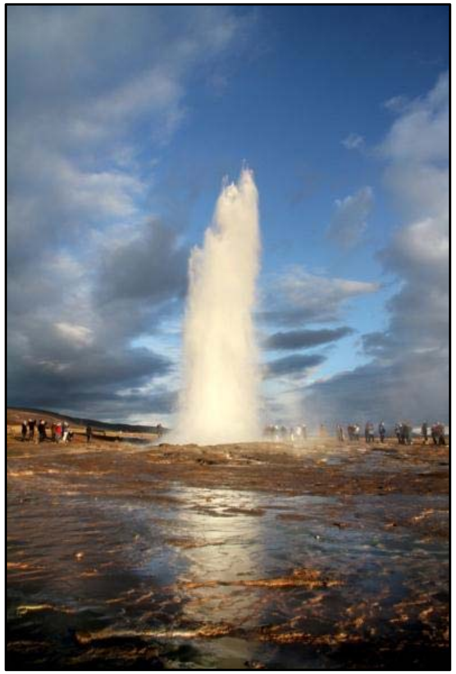
4. DRILLING AND TESTING OF CONFIRMATION WELLS

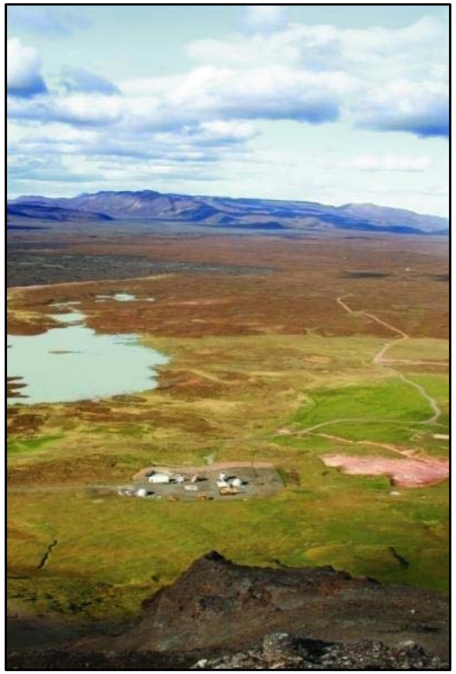
- Confirming the conceptual geothermal model
- Confirming the reservoir size and boundaries
- Location of additional wells, are based on the pre-feasibility report and conceptual model.
- Confirmation well design and well test procedure
- Drilling, testing, and evaluation of test results



ÍSOR

5. ENVIRONMENTAL IMPACT ASSESSMENT AND CONCEPTUAL DESIGN OF THE POWER PLANT

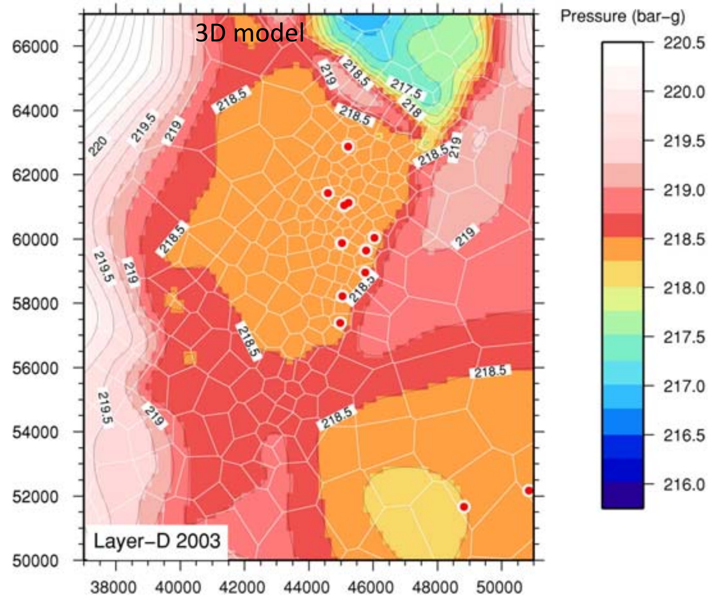


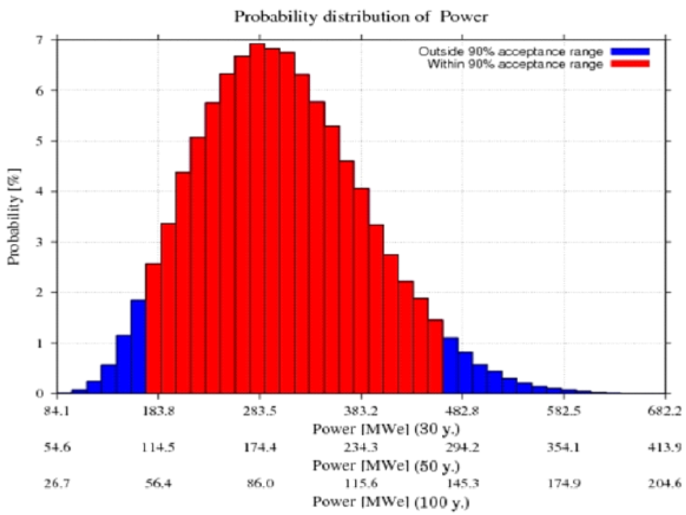


- Environmental and Social Impact Study for production drilling and Power Plant
- Design of production and reinjection wells
- Update evaluation of field capacity
- Update on basic process design
- Update on the fluid treatment
- Recommended field operation

6. FEASIBILITY REPORT. EXPLOITATION LICENSE

- Update on field capacity (resource assessment)
- Process design (PF&ID)
- All main equipment specified
- Investment and Operational cost (cost pr. kWh)
- Environmental Impact for the whole project
- Recommendations for next step
- Exploitation license process





Volumetric assessment, using the Monte Carlo method

Statistical sizes	Values [MWe] (30 y.)	Values [MWe] (50 y.)	Values [MWe] (100 y.)
Most probable value (with 7% probability)	275-290	165-175	85-90
90% confidence interval	170-460	100-270	50-140
Mean	300	180	90
Median	300	180	90
Standard deviation	80	50	20

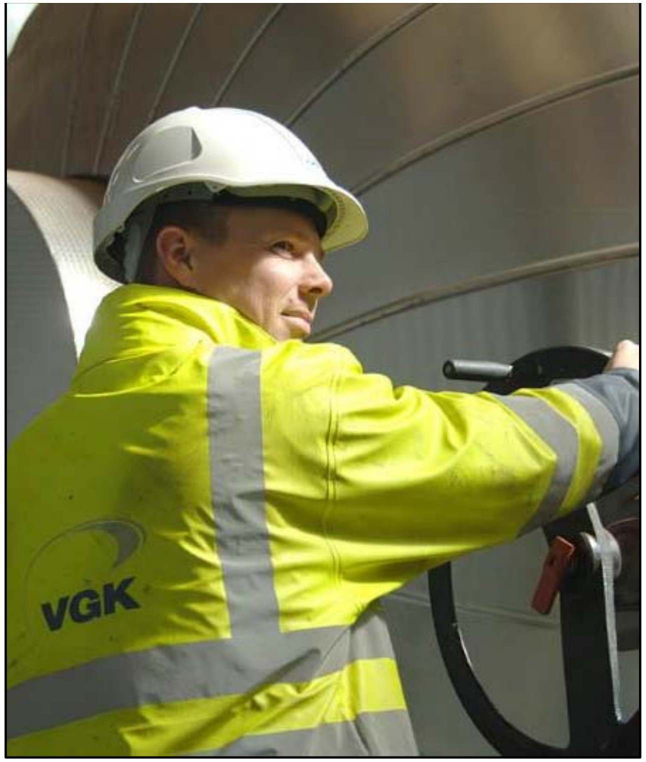
7. DETAILED DESIGN, CONSTRUCTION, DRILLING, SUPERVISION

- Detailed design based on concept design
- Supervision of detailed design
- Tender documents for civil construction
- Production and Injection Drilling
- Supervision of drilling

- Manufacturing, delivery, and installation of equipment
- Civil construction
- Supervision of construction

8. TESTING, COMMISSIONING, TRAINING

- System tested to specification from equipment manufacturers.
- Power plant started up (commissioned) and starts producing energy to the grid and potentially fluids for direct use (cascaded use).
- Training of operators of the plant during the first weeks/months of operation.



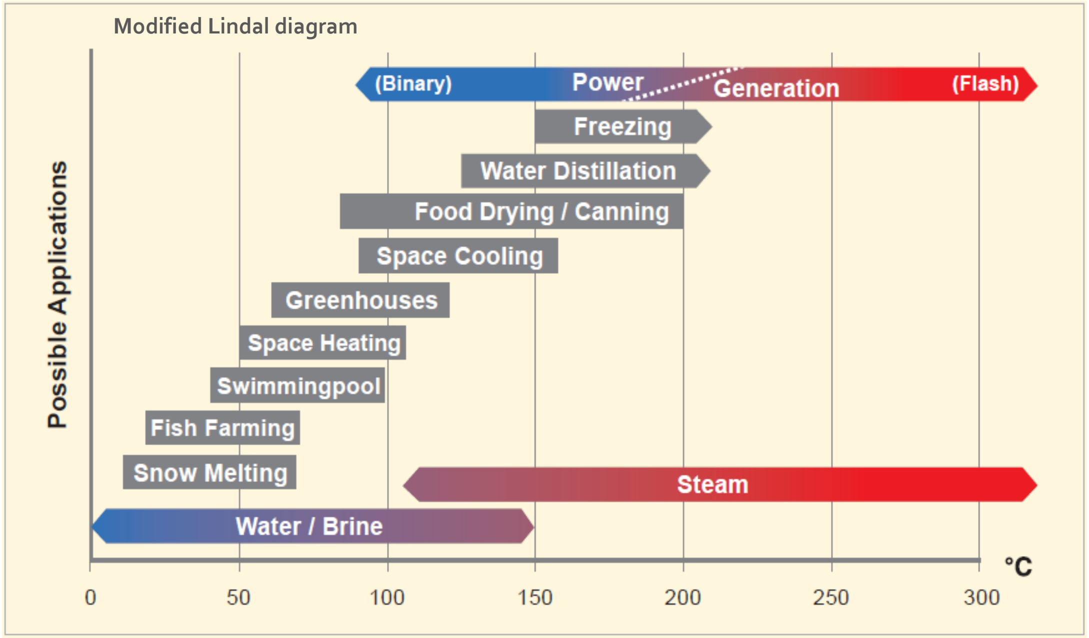
ÍSOR

9. OPERATION

… AND DECOMMISSIONING DECADES LATER.

ÍSOR

GEOTHERMAL RESOURCES AND POTENTIAL USE



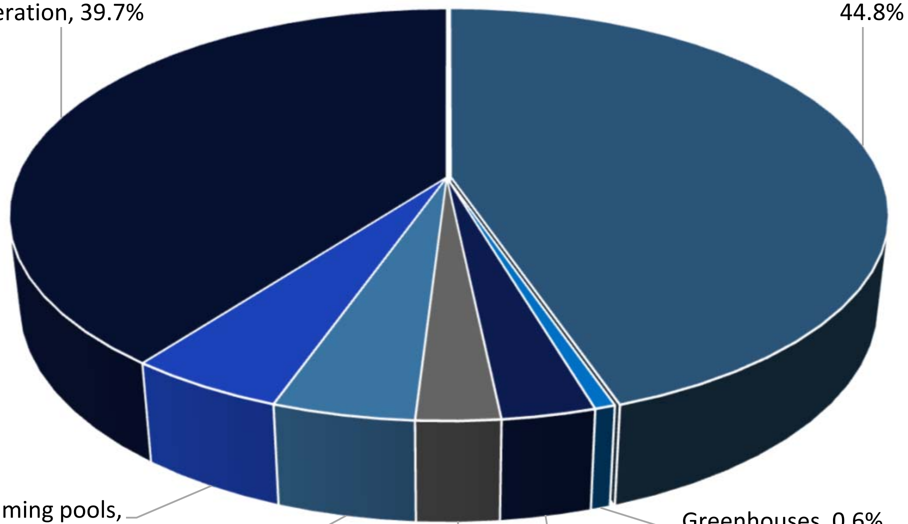
Source: Gehringer and Loksha, Geothermal Handbook: Planning and Financing Power Generation, ESMAP 2012

- Low-temperature resources if the temperature of the source is below ~120°C
- Intermediate temperature resources ~120-200°C
- High-temperature resources if the temperature of the source is higher than 200°C

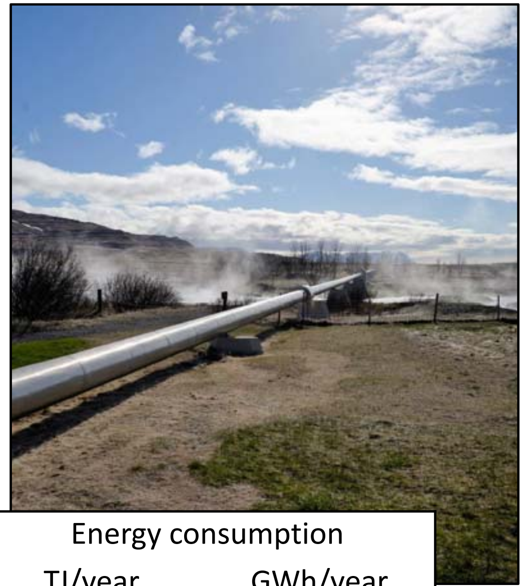
- The resource temperature limits the possible uses
- Cascade and combined uses enhance the feasibility
- Example:

  A geothermal plant that produces both electricity and hot water for district use applications at different temperatures (combined heat and Power and cascaded use)

GEOTHERMAL UTILIZATION IN ICELAND 2020



Source: Iceland National Energy Authority



2020	Energy consumption	
	TJ/year	GWh/year
Space heating	24,205	6,724
Greenhouses	348	96.7
Fish farming	1,585	440
Industry	1,418	394
Snow melting	2,403	668
Swimming pools	2,657	738
Direct uses total, 43.7 PJ	32,616	9,060
Electricity generation	21,458	5,961
Geothermal Utilization total	54,074	15,020

ÍSOR

THE ENVIRONMENTAL BENEFIT

From fossil fuel to geothermal

Before geothermal space heating:
Reykjavik in 1933 covered with smoke from coal heating.

With geothermal space heating:
Reykjavik in 2008, almost same view but without visible air pollution.

ÍSOR

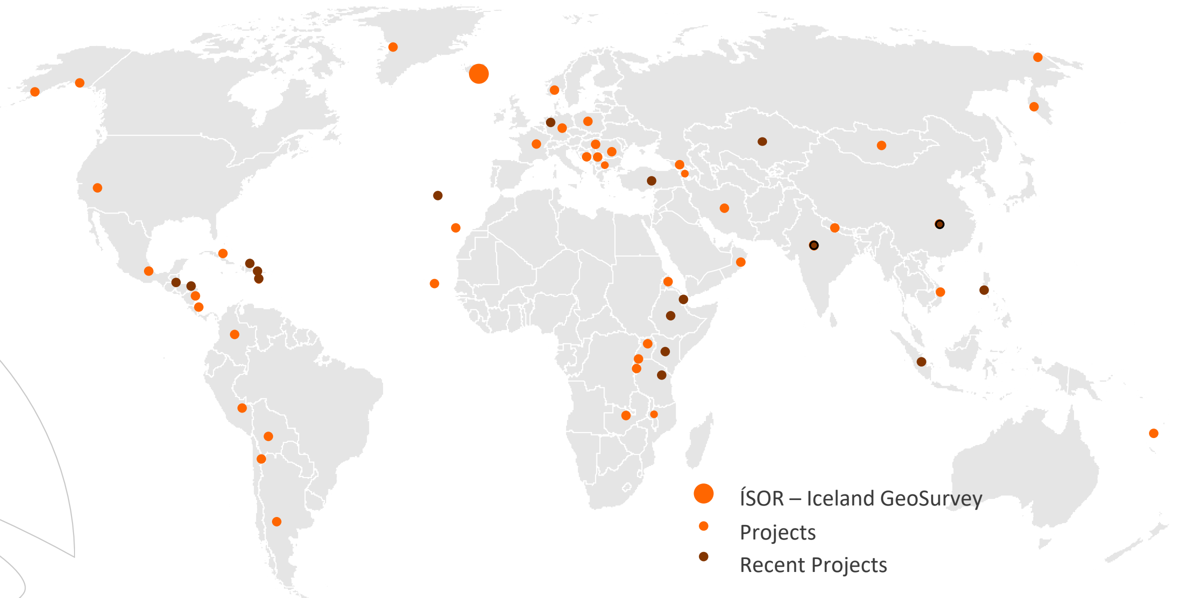
SERVICES OFFERED BY ÍSOR

- Geothermal exploration
- Drilling consultancy
- Well logging and mud logging
- Well testing and evaluation
- Resource assessment and management
- Due Diligence and Feasibility reports
- Geothermal training
- Environmental and Groundwater studies
- Engineering geology
- Offshore exploration
- Information technology

ÍSOR

- ÍSOR has been involved in most geothermal projects in Iceland, both for power production and direct usage of geothermal fluids.
- ÍSOR has also been involved in geothermal development all over the world for many decades.
- Successful harnessing of geothermal energy, i.e., power or direct use, needs well executed exploration, proper data processing and combined interpretation of available data.

ÍSOR PROJECTS AROUND THE WORLD



THANK YOU

DEIRDRE CLARK

Geochemist

deirdre.clark@isor.is

@clarkdeirdre

BJARNI RICHTER

Director of Business Development and Marketing

bjarni.richter@isor.is

www.isor.is

ÍSOR