General aspects of geothermal energy

Presented by Dr. Ólafur G. Flóvenz, general director of ISOR – Iceland GeoSurvey

for the World Bank at Renewable energy training program, July 2012.

Module 3 - geothermal energy

ÍSOR

History, objective and structure

History of Iceland GeoSurvey

- Established in 1945 as a part of the State Electrical Authority
- A division in the National Energy Authority (Orkustofnun) 1967-2003.
- Independent company from 2003.
- It is based on six decades of continuous experience in the field of geothermal and hydropower research and development.

Iceland GeoSurvey

- Owned by the Icelandic government.
- Provides specialist services to the geothermal industry based on long experience and active scientific research.
- Operates on the free market on competitive basis like any other company.
- None-profit organization: Profit goes exclusively into scientific research and to strengthen Iceland GeoSurvey .

ÍSOR

Fields of expertise

- Geothermal research, services and capacity building
- Environmental Studies
- Geological mapping
- Groundwater Studies
- Engineering Geology
- Marine Geophysics

78 employees 1. January 2012

Geologists	27
Geophysicists & physicists	21
Geochemists & chemists	7
Civil engineers & engineers	9
Other academic persons	8
Other education	6
	78

ISOR covers all aspects of geothermal research and services

- Exploration, resource assessment, environmental assessment and prefeasibility study.
- Siting of boreholes, well design, well logging, drilling supervision.
- Well testing, reservoir modeling and management, feasibility studies, fluid chemistry.
- Monitoring of reservoirs and production and environmental changes. Utilization technology.
- Geothermal training and capacity building.

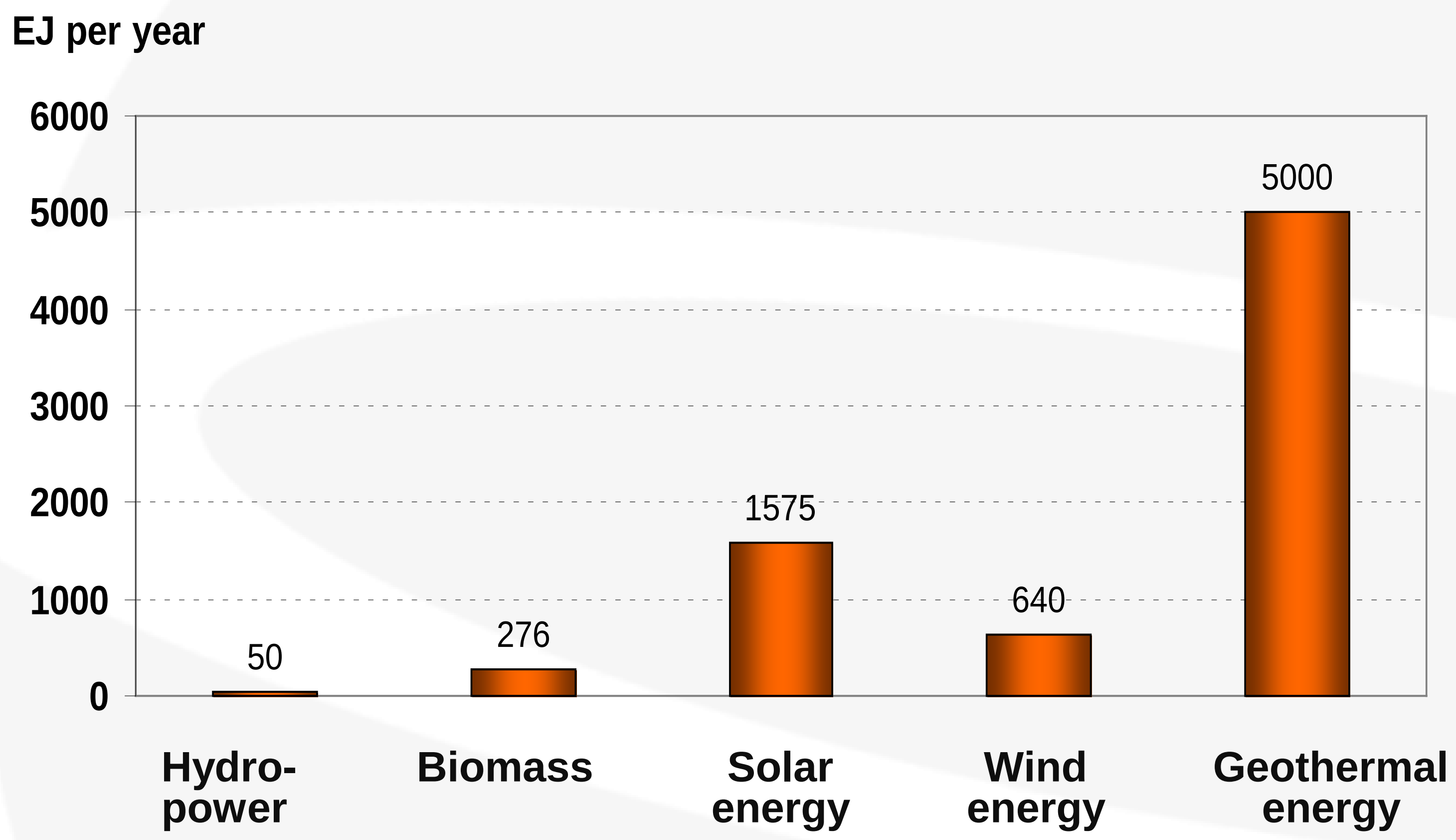
Activities abroad: Countries where ISOR has participated in geothermal projects

ÍSOR

The heat in the Earth's crust

- Has be estimated to be of the order of 5.4 billion EJ
- If we could harness only 0,1% of this energy it would satisfy the present consumption for 10.000 year.
- **The heat energy in the crust is huge but there are serious difficulties to harness it.**

Worldwide technical potential of renewable energy sources (EJ per year)



World Energy Assessment 2000

Geothermal - hydrothermal

- Confusing use of concepts.
- Geothermal refers to heat in the subsurface.
- Hydrothermal refers to geothermal systems driven by natural flow of hot water.
- Geothermal system: A large volume of rock containing all parts of the system, including up and down flow part.
- Geothermal field: A specific place with known hydrothermal activity

Geothermal system are mainly found:

- On plate boundaries, because of high temperature caused by volcanism and because of fractures that supply water down to the hot rock.
- In thick sedimentary basin in the Continents, where high permeability and rather high heat flow through the lithosphere co-exist.

  Examples: France, China, Central Europe North of the Alps.

Nature, classification and use of geothermal energy

Dallol Geothermal Field, Ethiopia

Photo: Hjalti Franzson, ,ISOR ©

Basic concepts - classification

Classification of geothermal fields:

- **Conventional geothermal system (CGS)**

- **Unconventional geothermal system (UGS)**
  - EGS: Enhanced (Engineered) Geothermal Systems
  - HDR: Hot Dry Rock
  - SGS: Supercritical Geothermal Systems

Classification according to temperature:

- High temperature fields
- Medium temperature fields
- Low temperature fields

Geothermal Energy is either used directly or to produce electricity

Electricity is produced from high and medium temperature geothermal systems.

Direct use includes space heating, green houses, bathing and swimming, drying, fish farming, heat pumps etc.

ÍSOR

Classification according to reservoir temperature

Low temperature fields

Temperature <100°C at 1 km. Not suitable for electricity production. Usually not connected to volcanic activity

The heat is derived from high heat flux from depths.

Heat extraction by convection in vertical fractures or circulation through sediments.

If the water contains small quantities of dissolved chemicals it is well suited for direct use without heat exchangers.

A hot spring in a low temperature filed in Iceland.
Photo Lúðvík Georgsson, OS

Low temperature fields

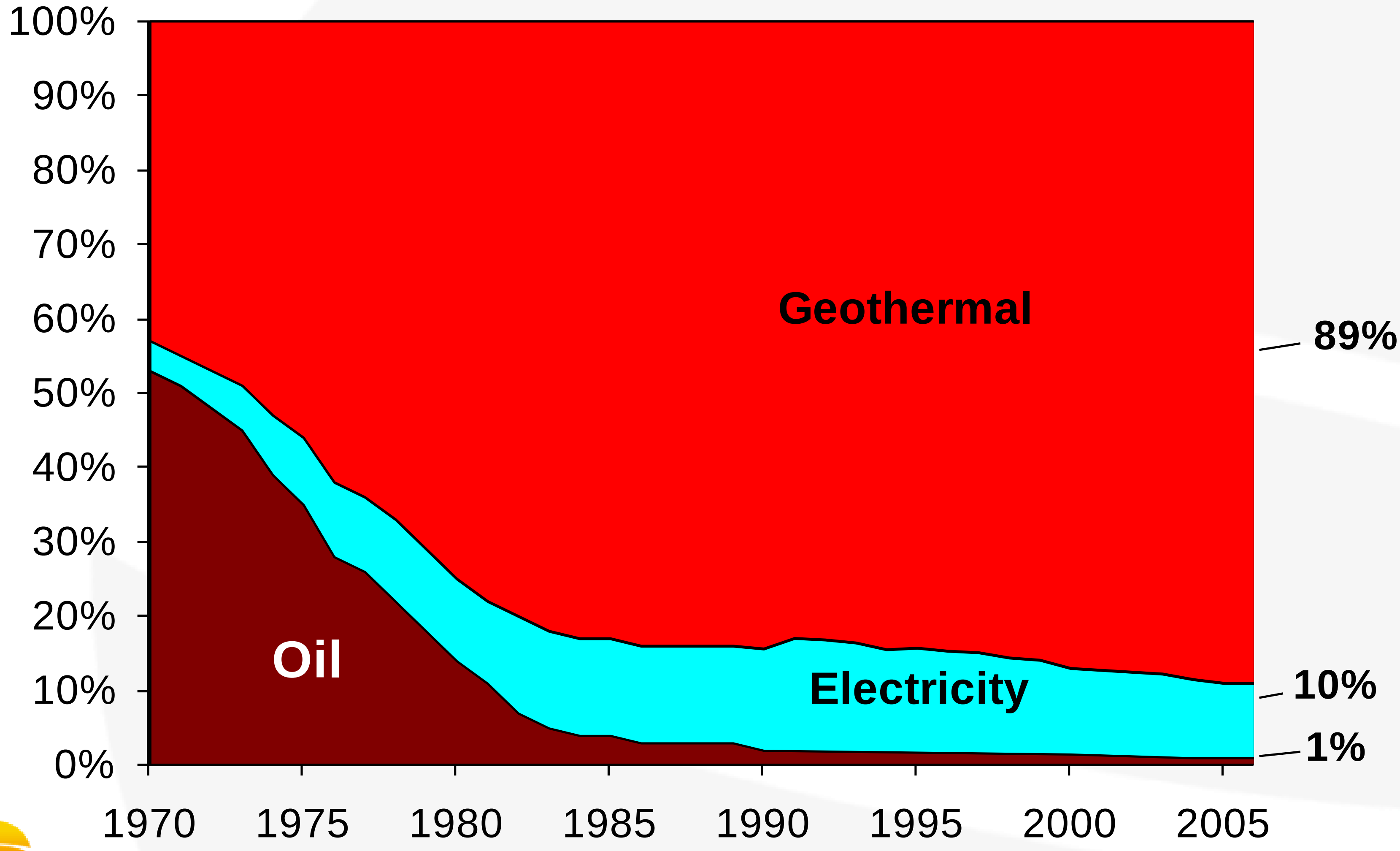
Mainly used for house heating, green houses, bathing and washing and fish farming.

Could contribute much more to the energy budget in the world:

- Almost half of the energy consumption in Europe is for heating purposes, only 11,9% was covered by renewables in 2008.

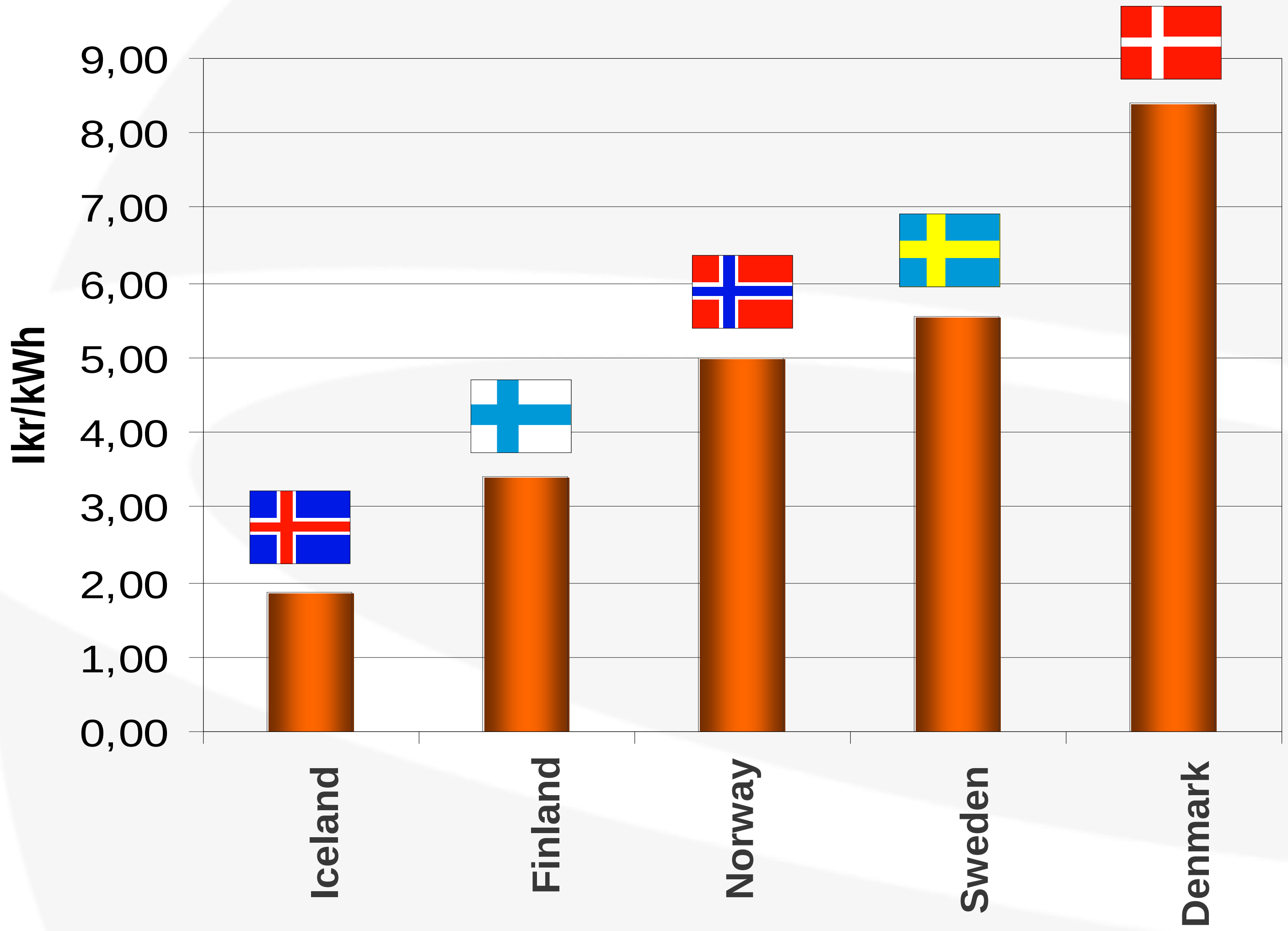
ÍSOR

Energy sources used for space heating in Iceland



ÍSOR

Cost of house heating in the Nordic countries, consumer price including taxes.



ÍSOR

www.isor.is

Source: Samorka, Iceland

From fossil fuel to geothermal: The environmental benefit

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

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

Medium temperature fields

Reservoir temperature 100-200°C. Suitable for electricity production with binary plants and heating.

Outside volcanic areas, often in thick sediments or as off-flow from high temperature fields and the heat comes from high background heat flow.

Heat extraction from sedimentary layers or by convection in vertical fractures or.

The water usually contains dissolved chemicals, so heat exchangers are necessary.

Unterhacking, Germany is a medium temperature field. (From the website of GtV

ÍSOR

High temperature fields

- Reservoir temperature 200 – 350°C.
- Related to volcanism and plate boundaries.
- The heat source is cooling magmatic intrusions relatively shallow in the crust.
- Suitible for electricity production with conventional turbines.

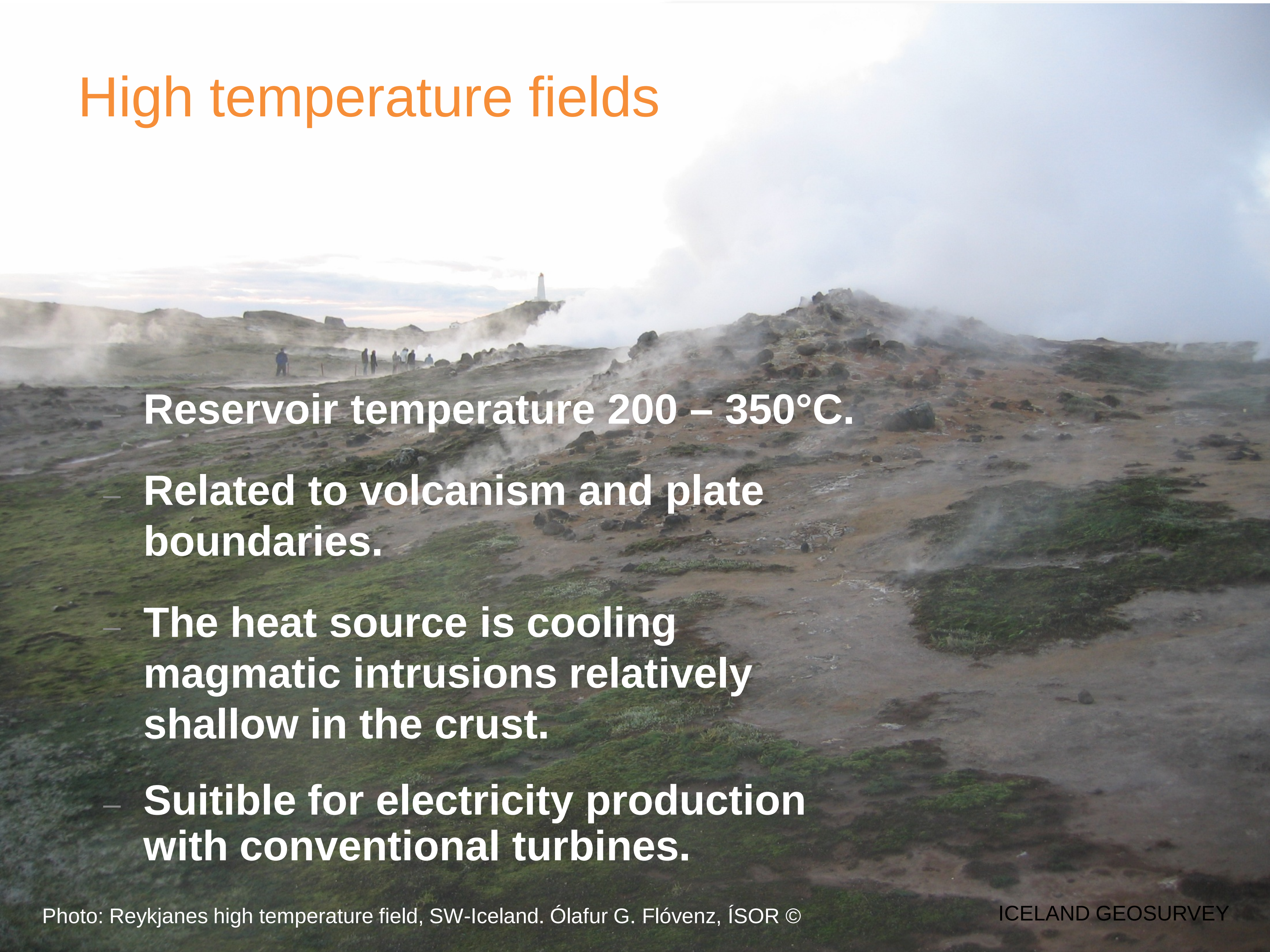


Photo: Reykjanes high temperature field, SW-Iceland. Ólafur G. Flóvenz, ÍSOR ©

Conceptual model of a high temperature

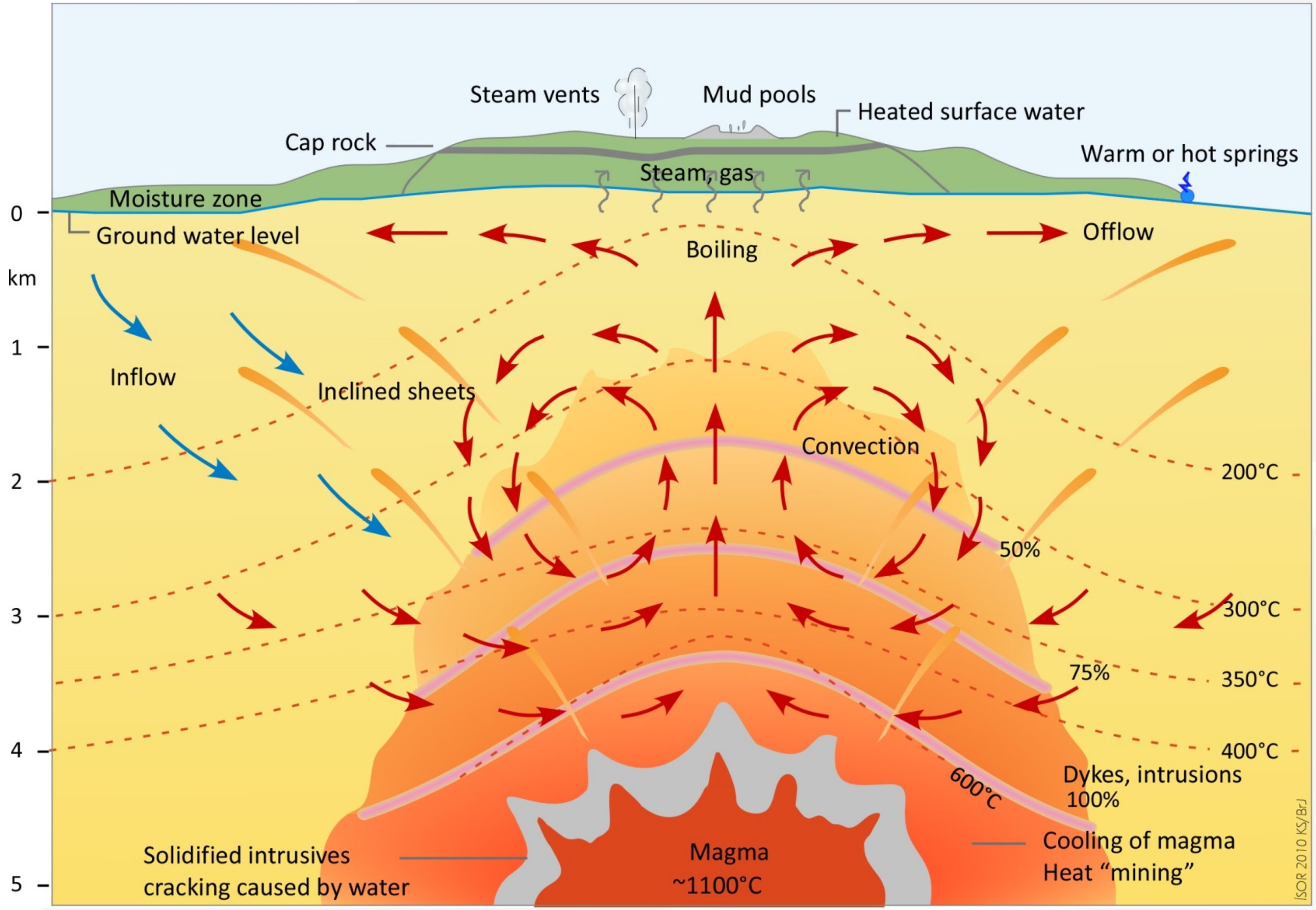
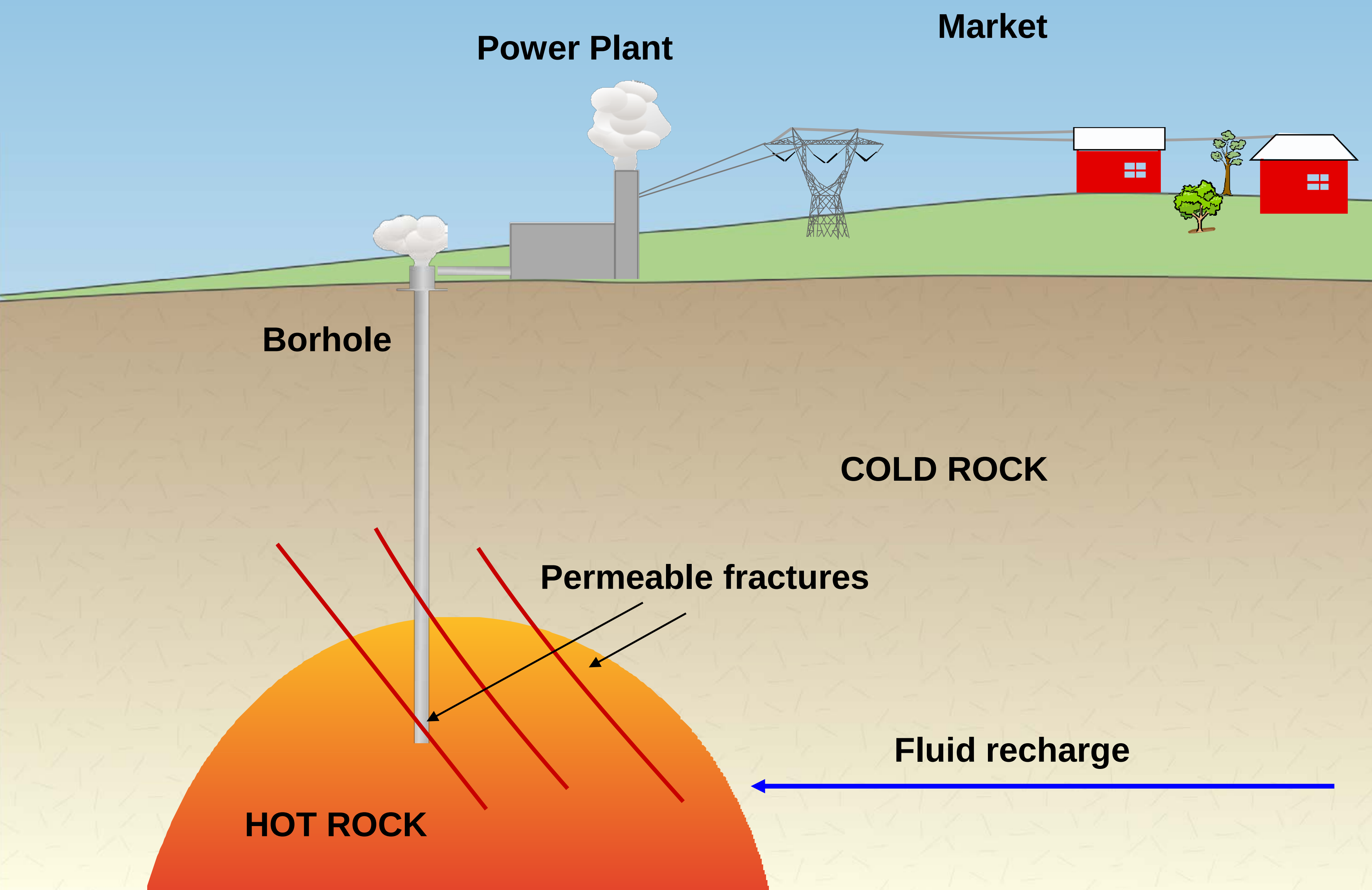


Figure: Kristján Sæmundsson, ÍSOR ©

www.isor.is

Conventional and unconventional geothermal systems

Conventional geothermal system



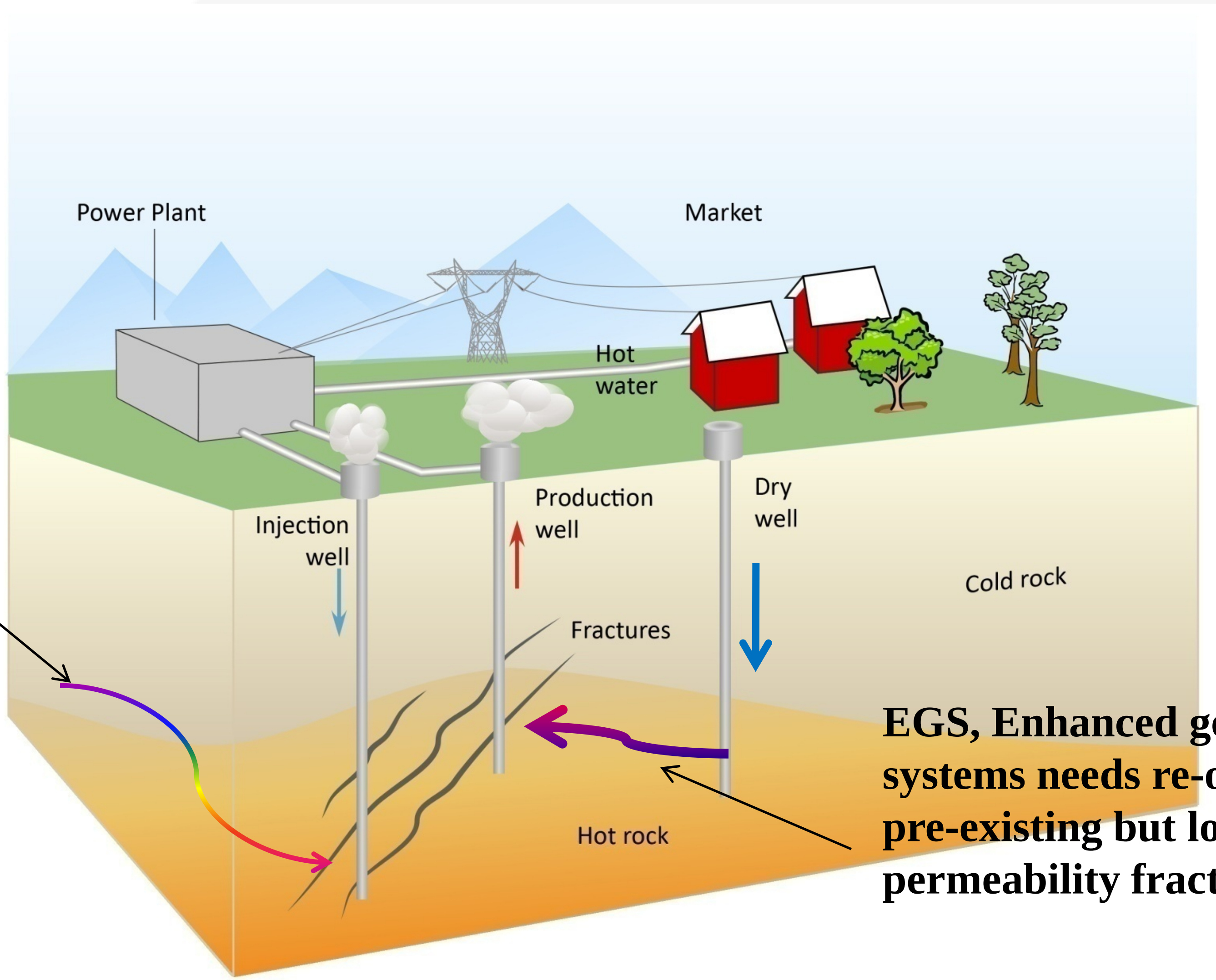
Conventional geothermal systems

- Geothermal systems where energy can be produced from boreholes either from self-discharging boreholes or by pumping.
- They can be high, medium or low temperature systems.

Krafla, Iceland

Conventional geothermal systems form where hot rock is naturally permeable or fractured

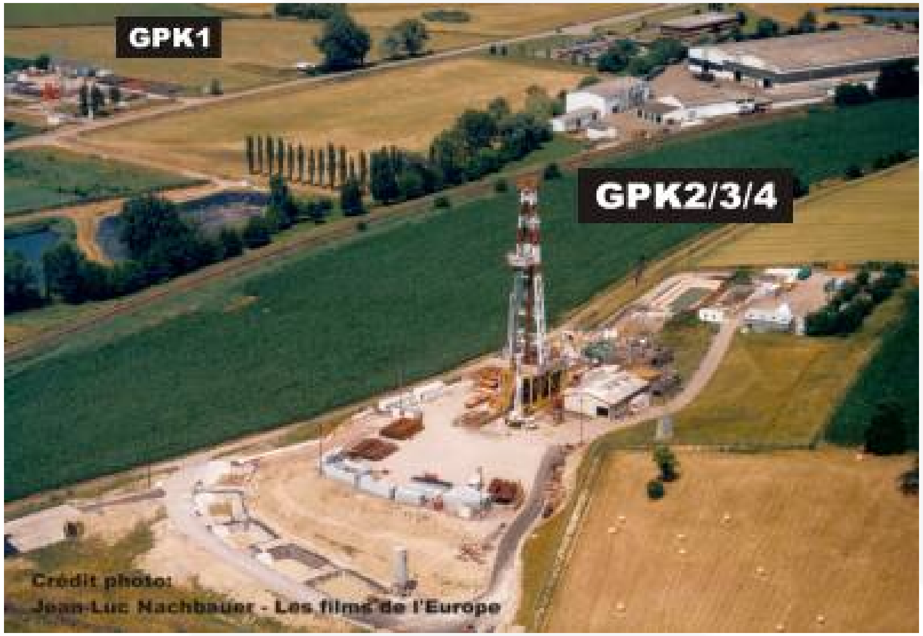
Natural recharge



EGS, Enhanced geothermal systems needs re-opening of pre-existing but low permeability fractures

Unconventional geothermal fields are of two main types:

Enhanced Geothermal Systems (EGS)



The Soultz-sous-Forêts EGS project in France

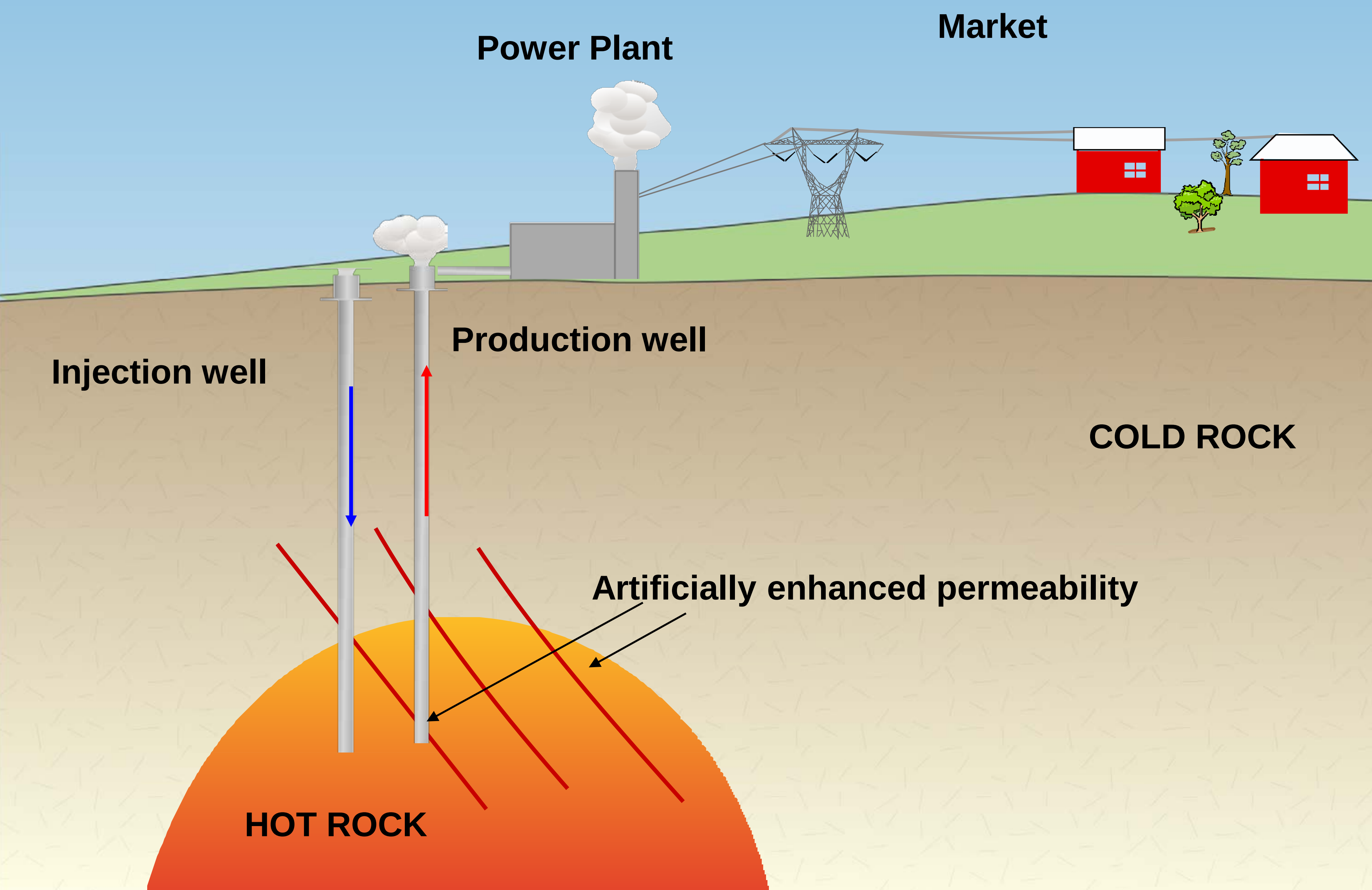
Photo: Homepage of the Soultz project ©

Supercritical Geothermal Systems (SGS)

Krafla Iceland. Drilling into magma

Photo: Elfar J. Eiríksson, ÍSOR ©

Enhanced geothermal system (EGS)

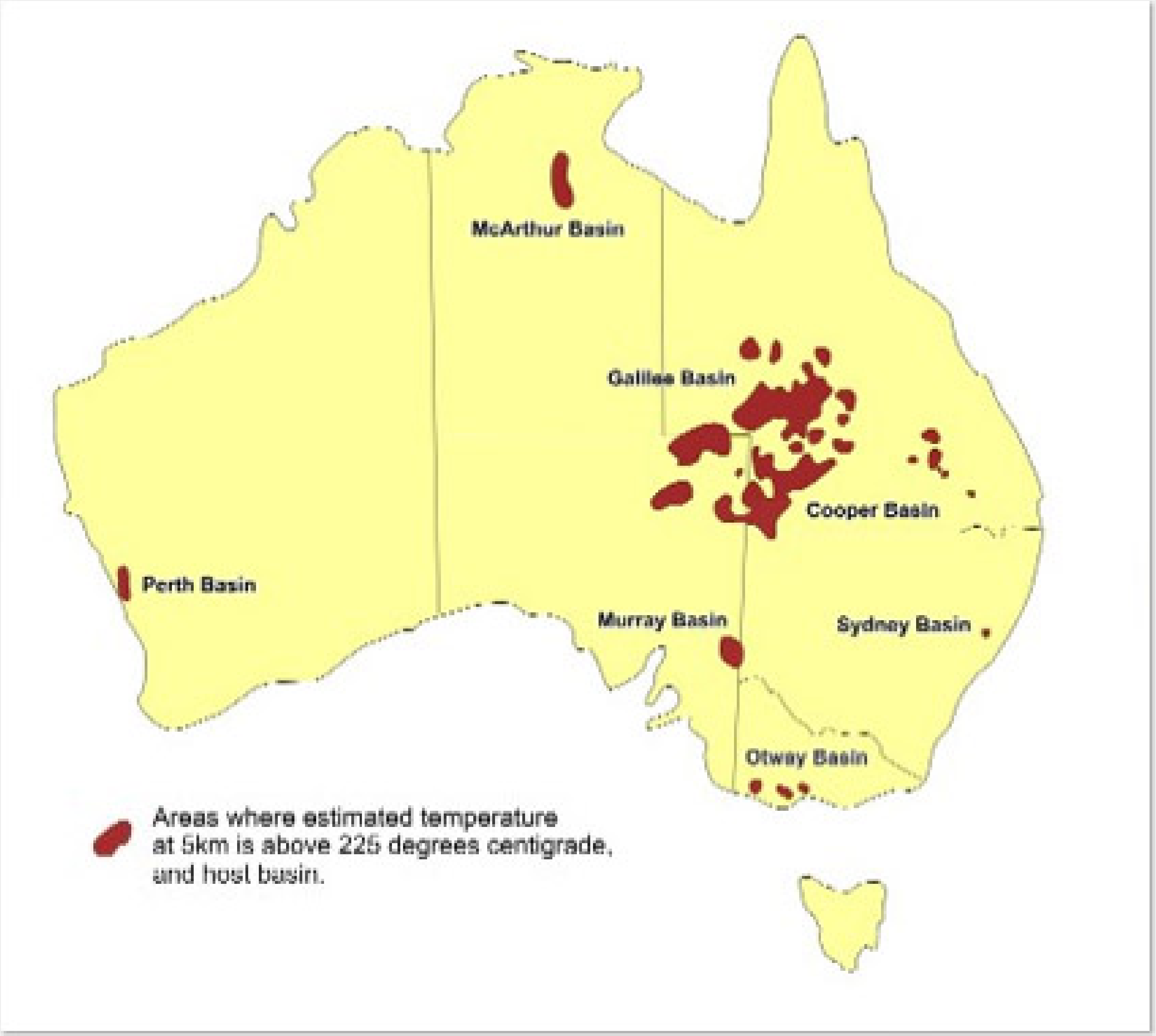


Enhanced geothermal systems (EGS)

- Geothermal systems where special measures have to be taken to increase or maintain sustainable production
- Expand existing fractures or create new to increase the contact area between the fluid and the hot subsurface rock
- Artificial water injection needed

Gross Schönebeck, near Berlin in Germany

The Australian Geothermal project



The resource in Cooper Basin, Australia

- The resource is a considerable reserve of energy stored in deep granitic layers below a thermally insulating cap-rock of re-crystallized sandstone

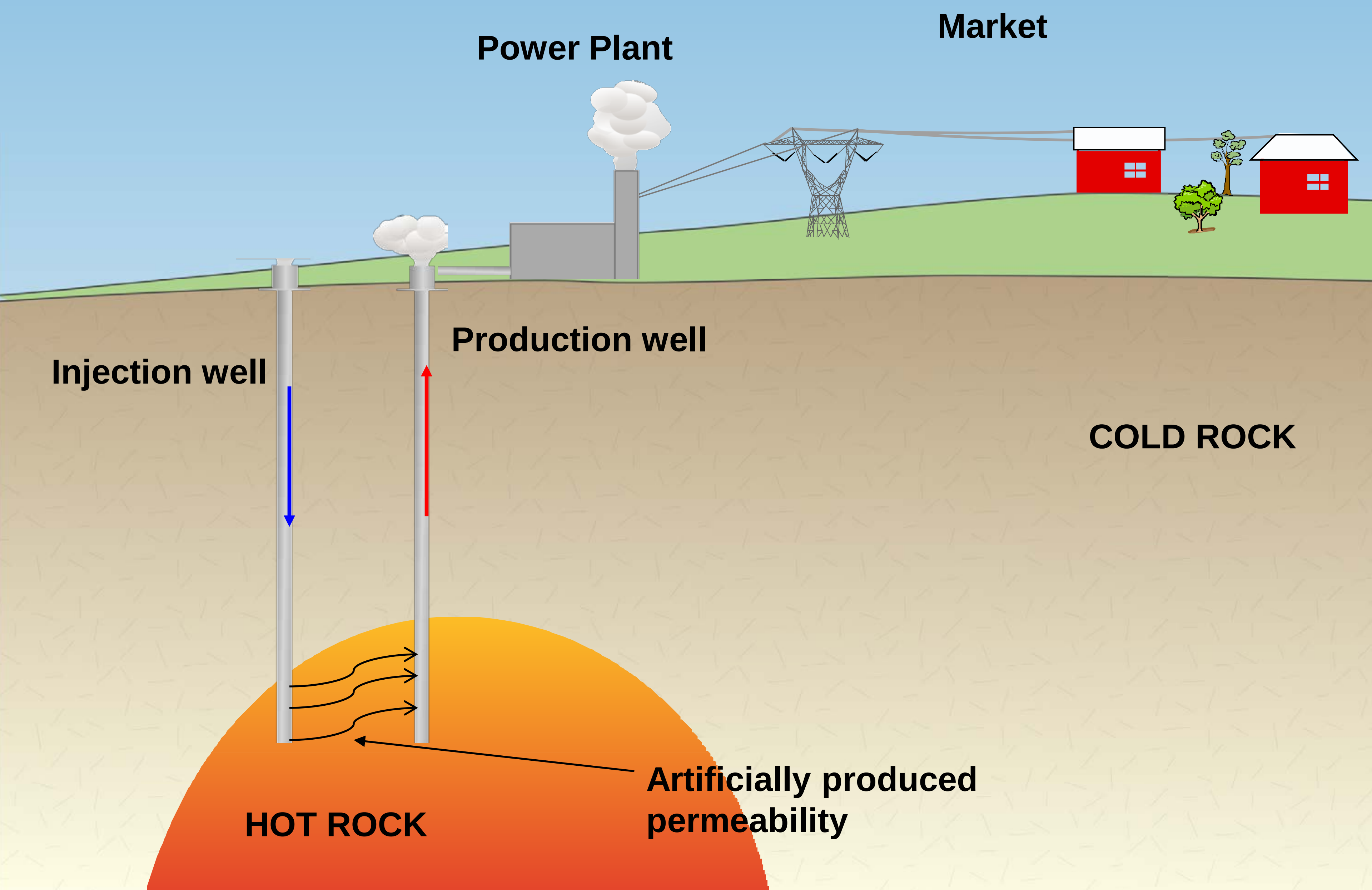
- It is over-pressured

- The water is heated as a result of the radioactive decay of the granitic basement

- Temperature up to 230-270°C has been found through drilling

ÍSOR

Hot Dry Rock systems (HDR)



EGS/HDR summary

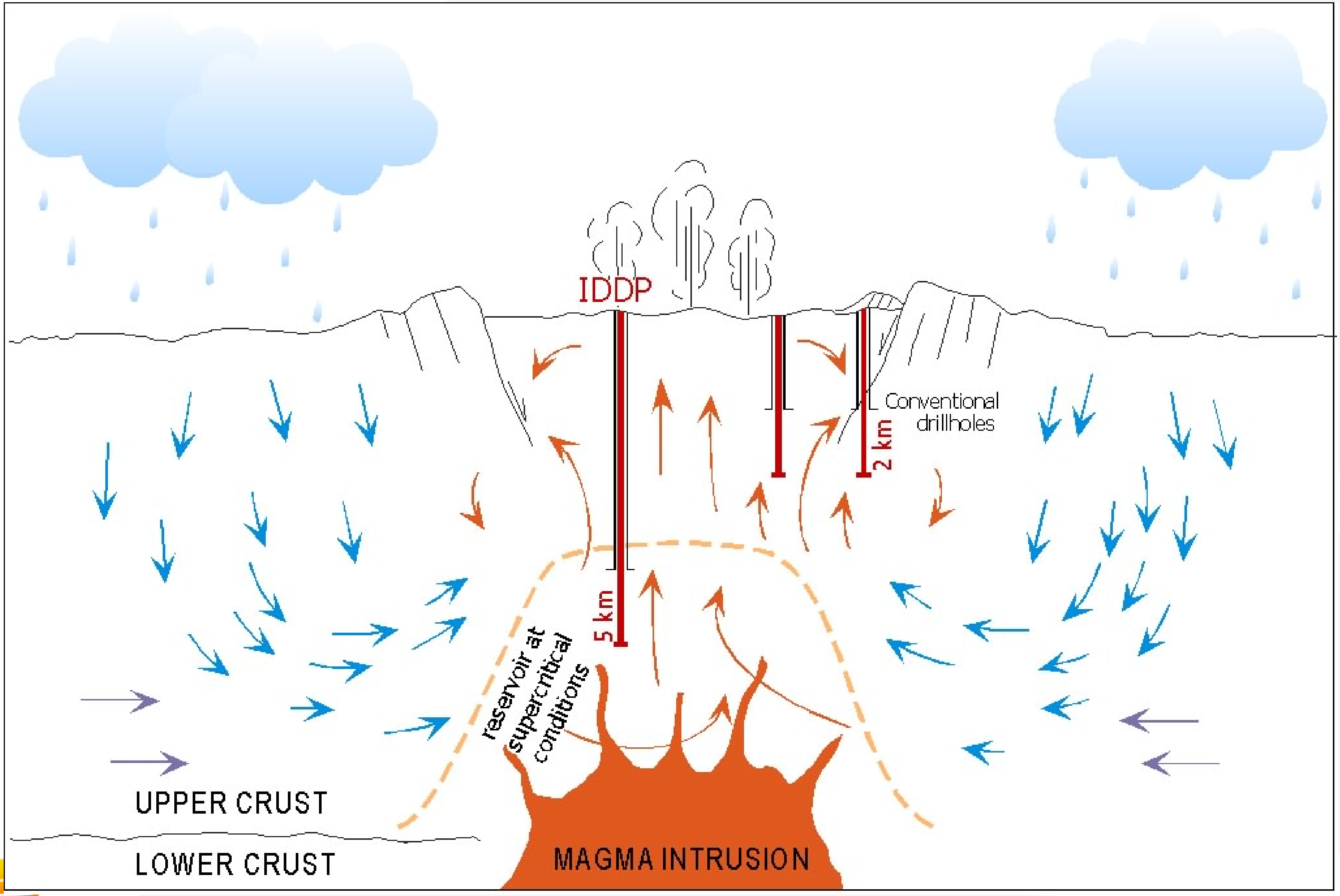
- EGS has been under development for 35 years.
- Strong interest in 1973-1986 but then a pause.
- Renewed interest after 2000.
- High potential if technical problems are solved.
- No brake-through yet.
- Many research questions remains to be answered.
- Only a few very small demonstration plant operating.
- Problems with induced seismicity.
- Energy prices far from being competitive for triplets in medium temperature areas of Europe.

Supercritical geothermal systems (SGS)

- Systems where water in supercritical state can be found
- Supercritical fluid can give up to 10 times as much energy per well as conventional steam well
- Expected to be found at greater depths below conventional high temperarture fields
- Their existence is not proven but likely

ÍSOR

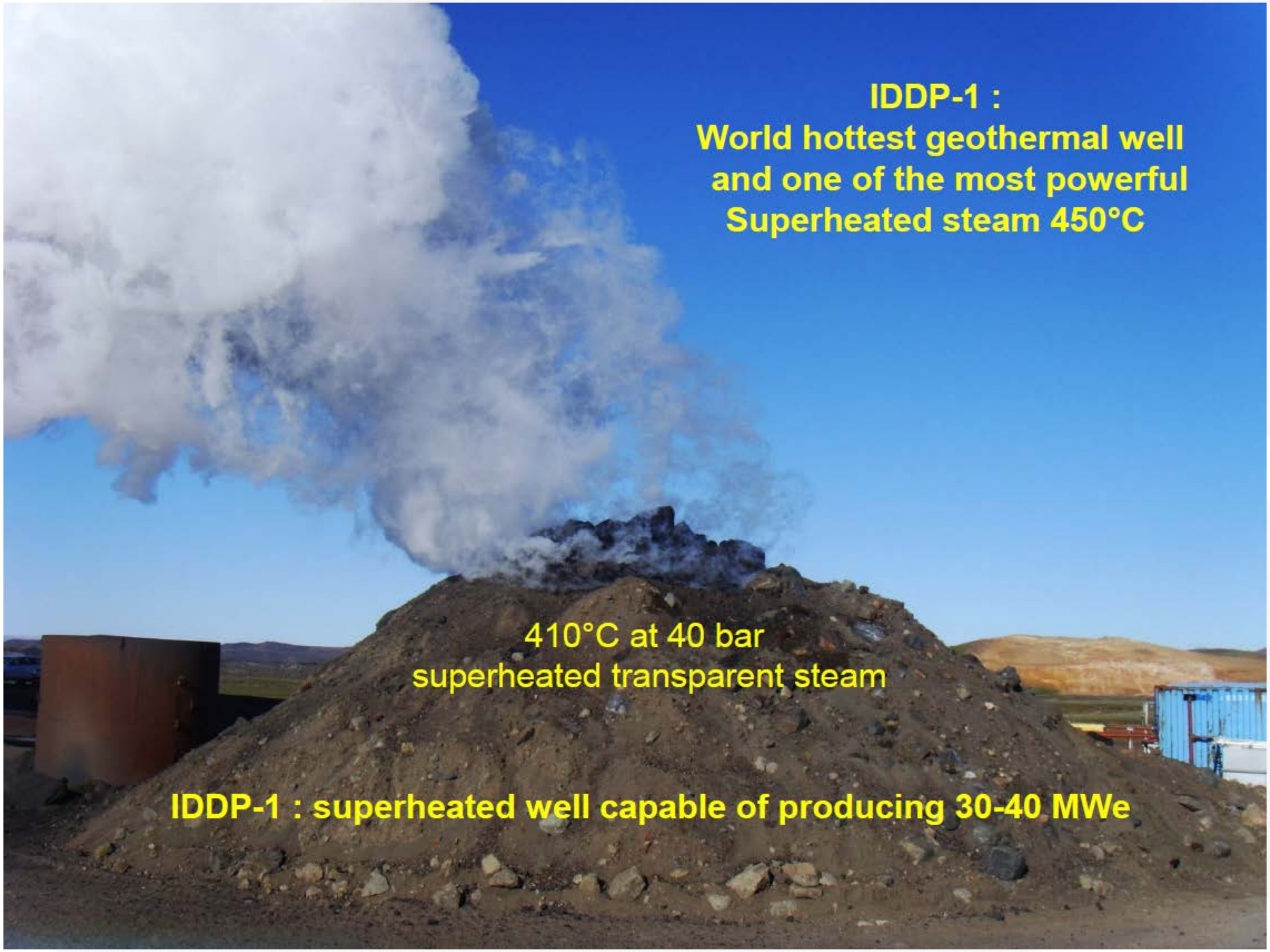
Simplified model of a high-temperature geothermal system



Superheated steam – hottest in the world

Flow test continued 17. May 2011 – but needed to be stopped few days later. Continued 9. August 2011 but stopped 11. August for further modification.Opened again 27th September 2011 for wet scrubbing and heat exchange test.

Superheated steam – hottest in the world



Slide from G.Ó. Friðleifsson, HS-Orka

Production of electricity from geothermal: Basic concepts

Discharging   HT-well with separator at Hellisheiði

ÍSOR

Different types of geothermal wells

1. Single phase wells:
   - ❑ Hot water (only liquid)
   - ❑ Dry steam
2. Two-phase wells:
   - ❑ Liquid phase inflow, boiling starts in well
   - ❑ Two-phase inflow, boiling starts in reservoir

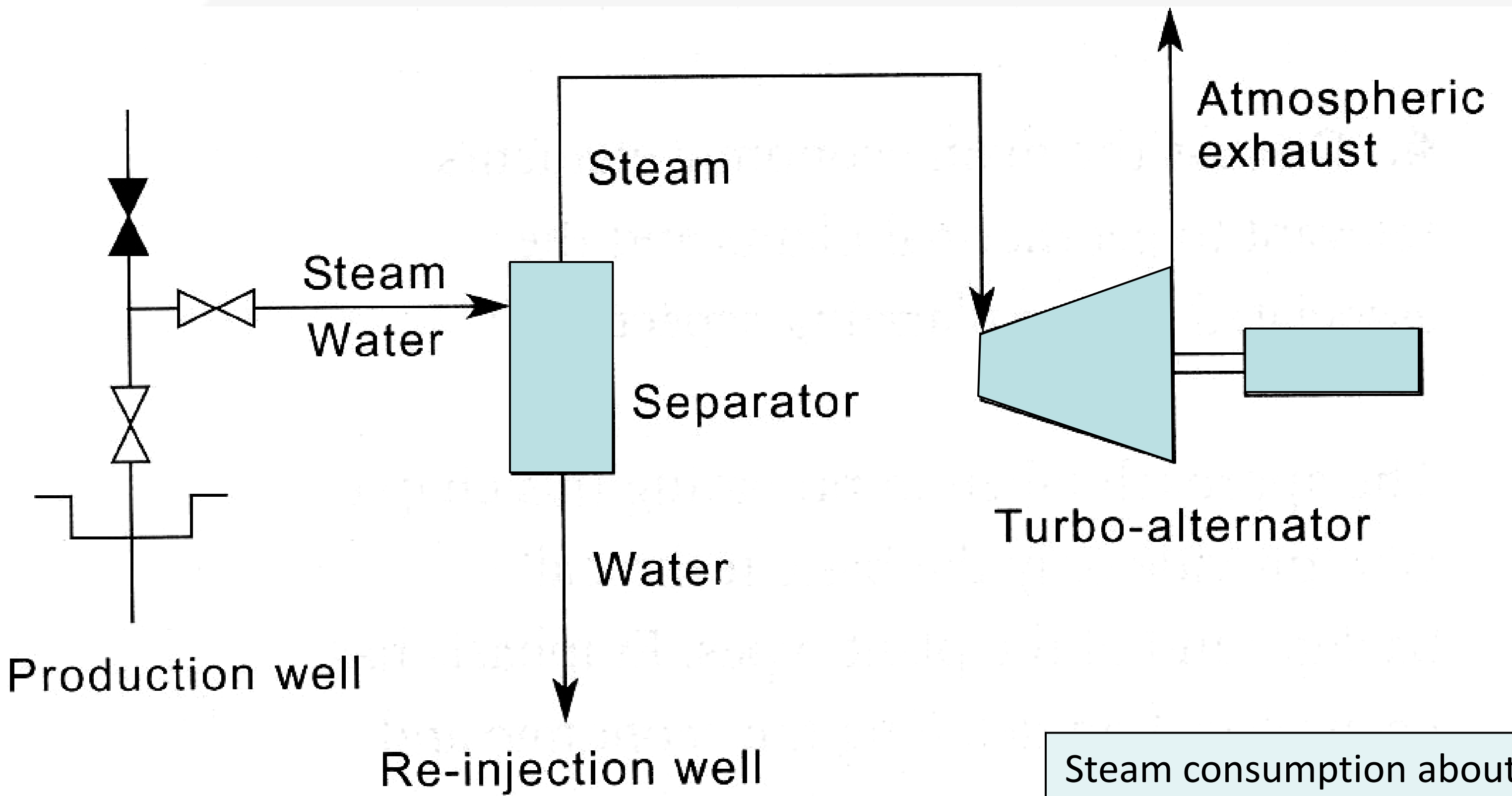
Difficult to measure two-phase flow accurately

Geothermal electricity:
The three basic turbo generating systems

- Flashed steam *back pressure system*; resource temperature range from about 320°C to some 200°C
- Flashed steam/dry steam *condensing system*; resource temperature range from about 320°C to some 230°C
- *Binary or twin-fluid system* (based upon the Organic Rankine or the Kalina cycle); resource temperature range between 100°C to about 200°C

Electricity generation – back pressure

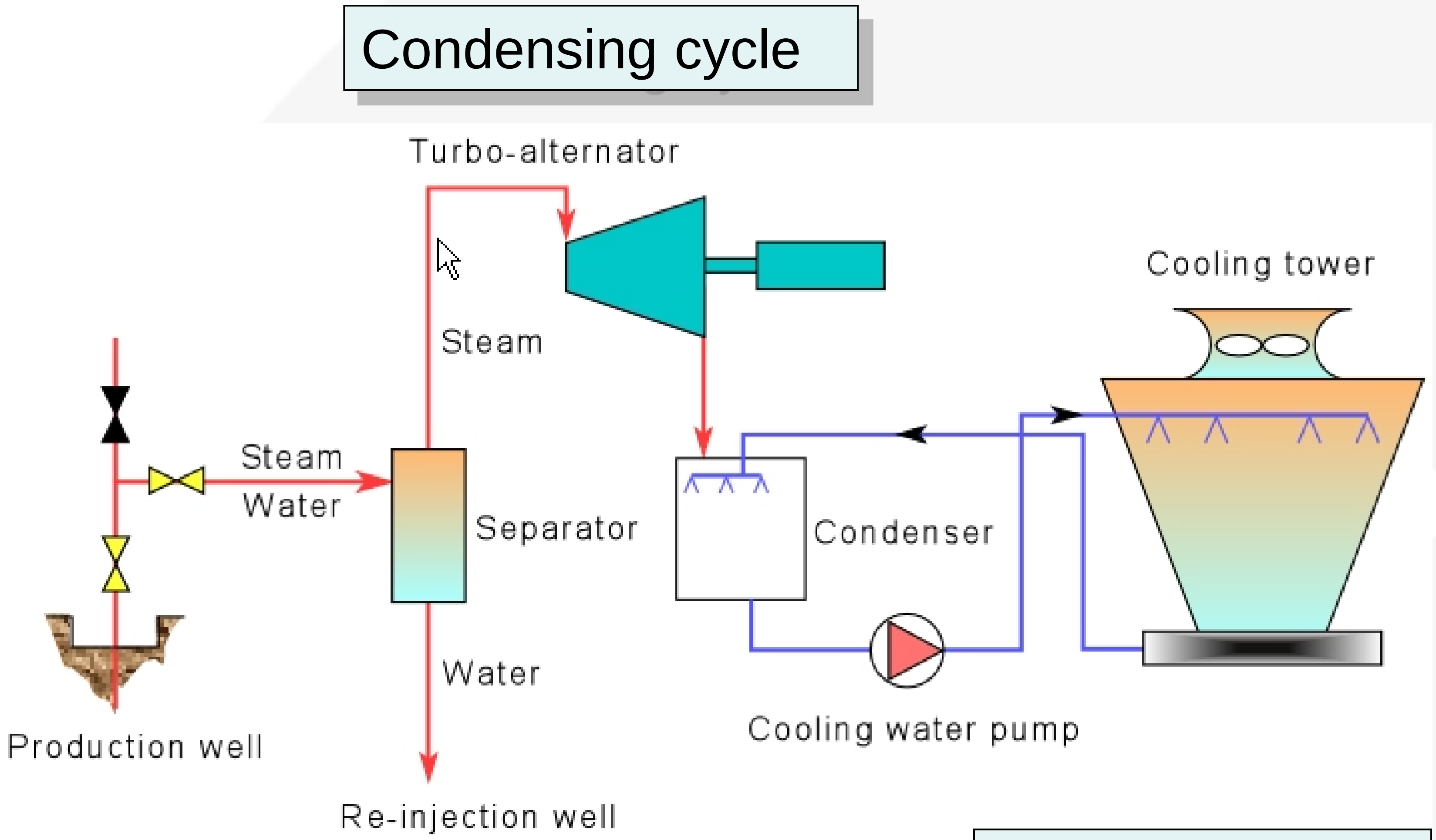
Atmospheric exhaust cycle (back pressure turbine)



Steam consumption about 3.5-4 kg/s per 1 MW generated

Slide from Arni Ragnarsson, ISOR

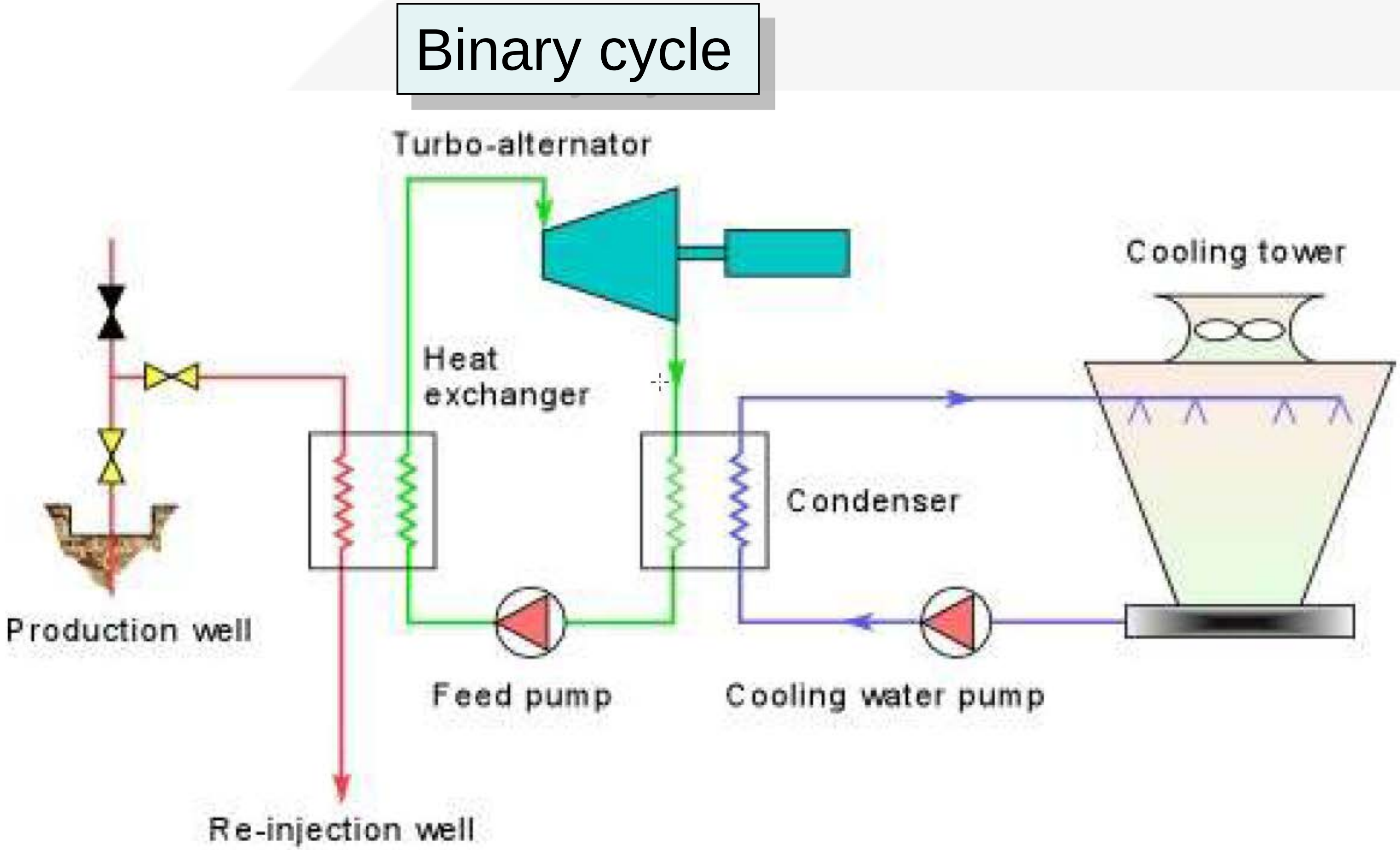
Electricity generation – condensing



Steam consumption about
2 kg/s per 1 MW generated

Slide from Arni Ragnarsson, ISOR

Electricity generation – binary cycle



www.isor.is

Slide from Arni Ragnarsson, ISOR

ÍSOR

Steam fraction for electricity production

X = steam fraction at wellhead (at inlet pressure)

H_t = well inflow enthalpy (kJ/kg)

H_s = steam enthalpy at wellhead (kJ/kg)

H_w = water enthalphy at wellhead (kJ/kg)

$$X = (H_t - H_w)/(H_s - H_w)$$

Steam fraction - example

Calculate the steam ratio at wellhead if the wellhead pressure is 7 bar (165°C) and the temperature of the inflow water is 270°C.

In steam tables we find the following:

$$H_t = 1185 \text{ kJ/kg}$$

$$H_s = 2764 \text{ kJ/kg}$$

$$H_w = 693 \text{ kJ/kg}$$

Thus X = (1185 – 693)/(2764-693) = 0.238 (23.8%)

Hence, if we use 270°C hot water and let it boil at 7 bars we will get 23.8% of steam for the generation turbines and 76.2% of 165°C hot waste water.

Electricity from geothermal

- About 2 kg/s of high pressure steam yield 1 MW of electrical power in a condensing turbine.
- Example: To produce 100 MW of electricity from 270°C hot water 200 kg/s of steam are required. The steam is only 23.8% of the total mass flow and we need 200/0.238 = 840 kg/s total mass flow (water + steam). Thus we will have 640 kg/s of 165°C “waste” water. The “waste” water can in principle be used for (a) electricity production in a binary tubine, (b) direct use (heating, etc.) or (d) reinjection.


The end