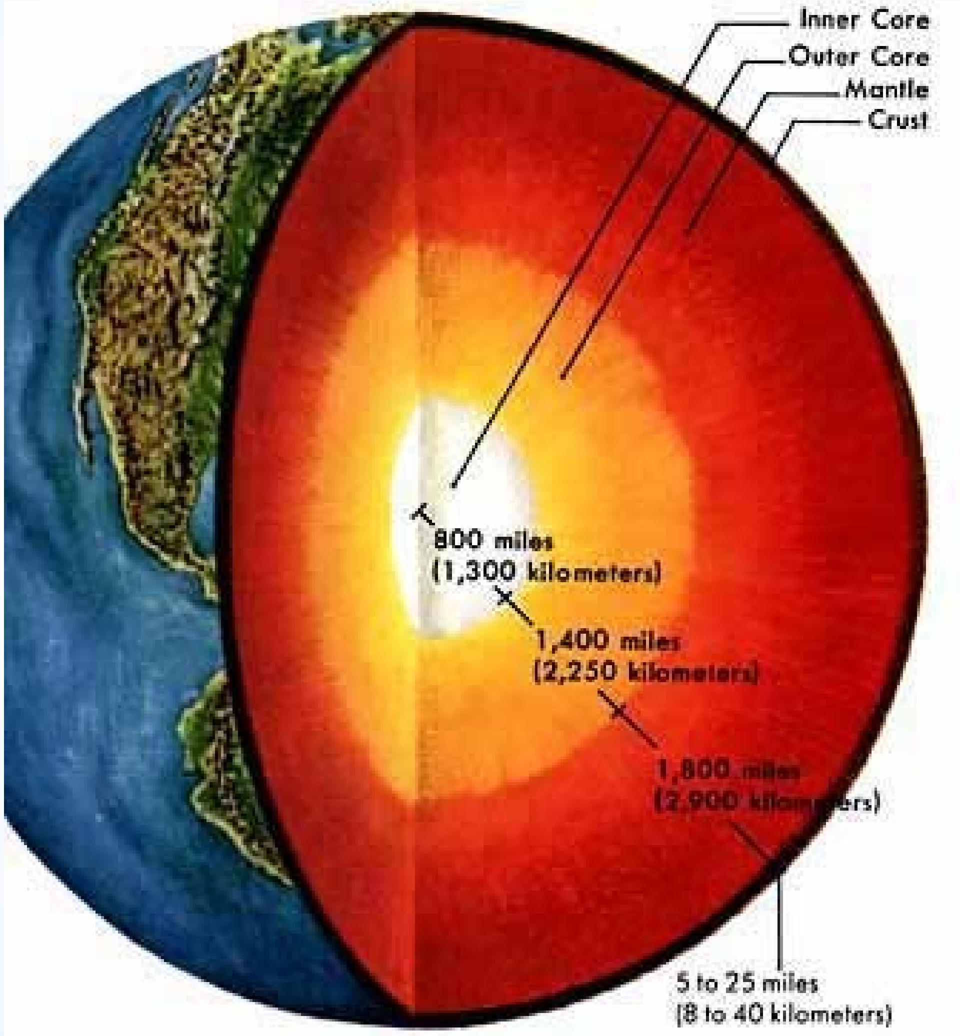
Geothermal Energy

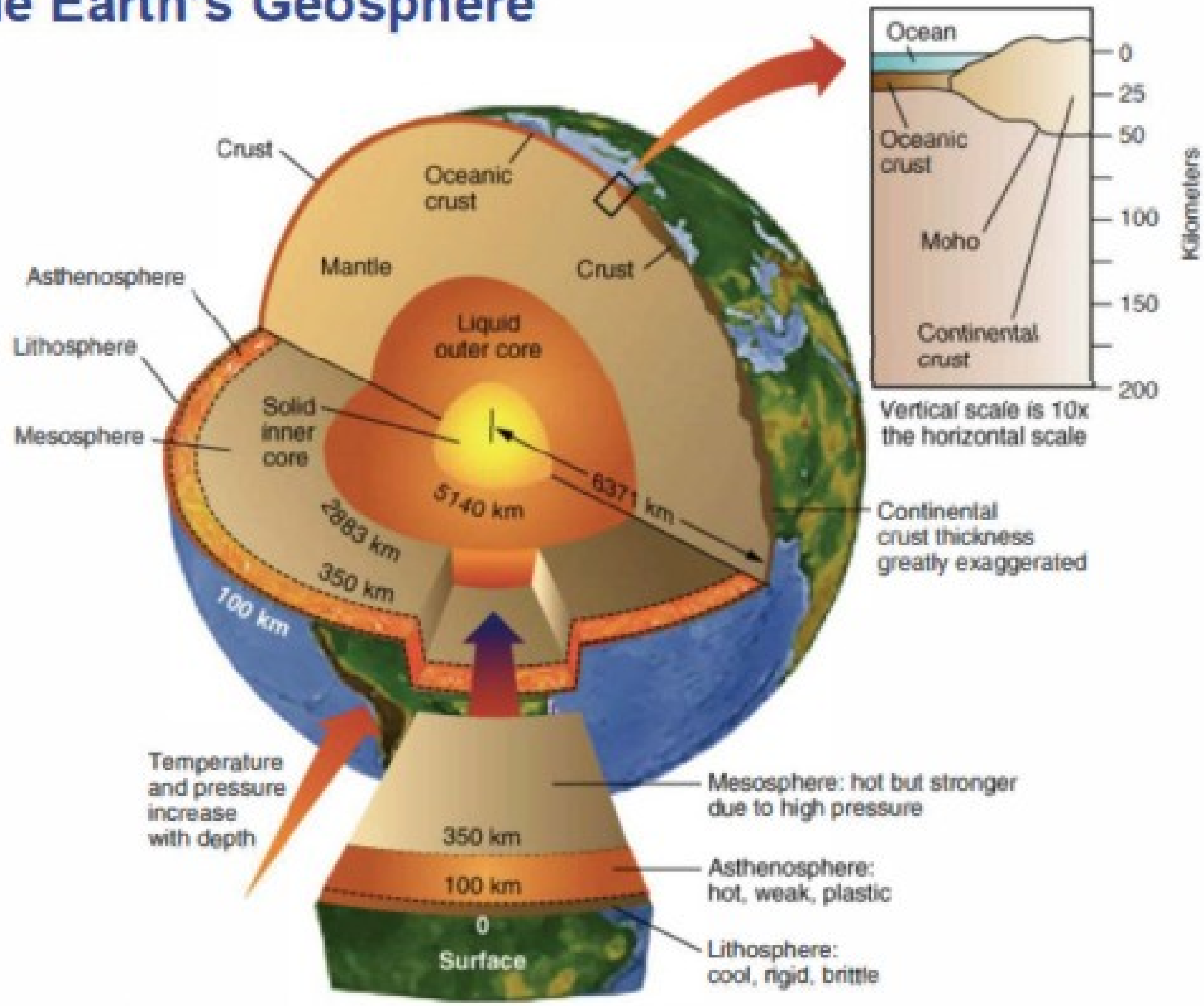
- Utilize temperature of the earth's core
- Direct use – District heating systems, Hot water spas, etc.
- Heat Pumps
- Electricity Generation

Earth's crust thickness = 5 – 60 km

Temperature gradient with depth = 17 – 30 °C/km

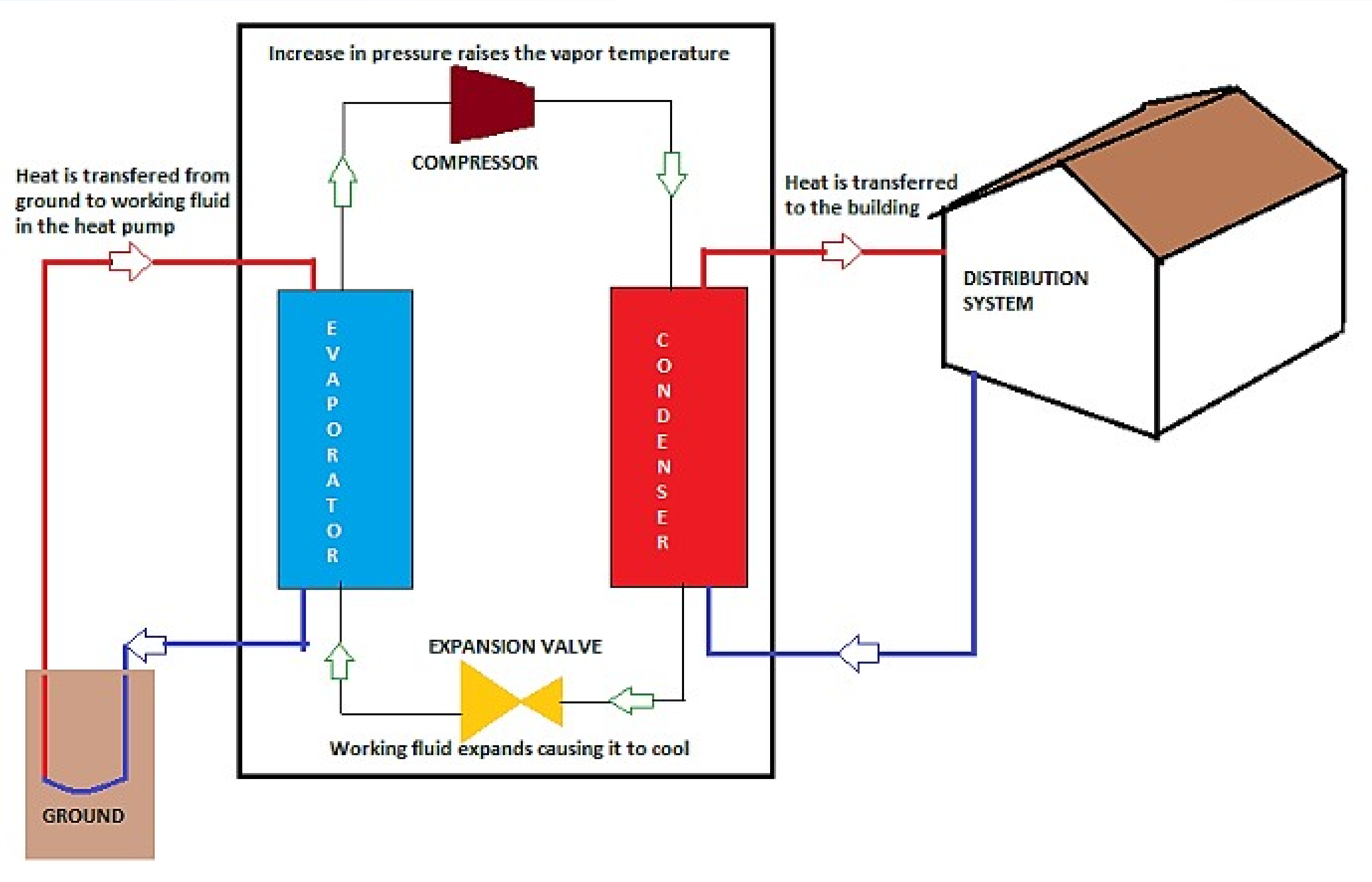


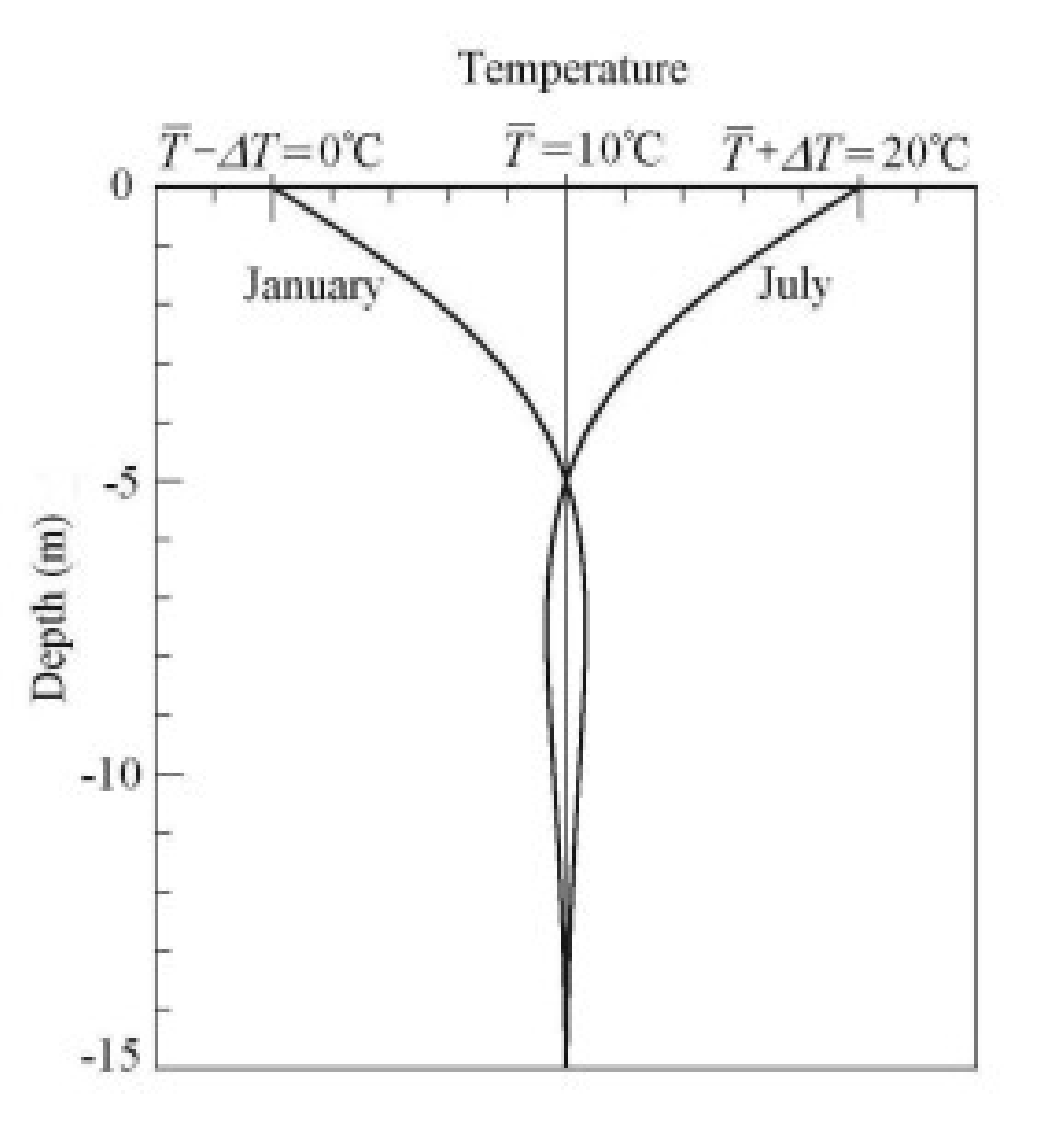
Looking to "inner space" for opportunities in the Earth's Geosphere



Heat Pumps

- Utilizes constant temperature of upper 3 m of the Earth's surface.
- Similar to ordinary heat pumps, but they rely on more stable source than air.



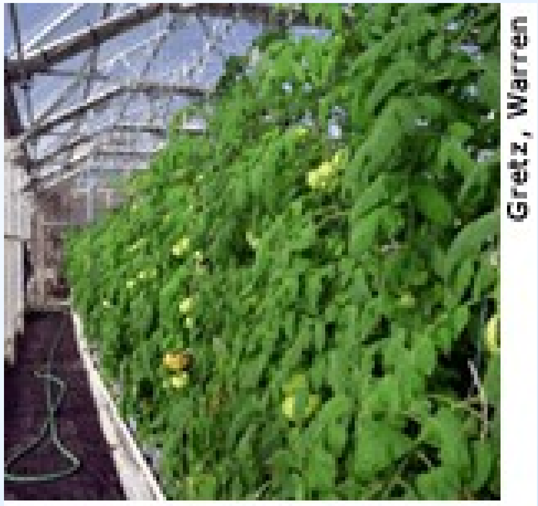


Temperature
$\bar{T}-\Delta T=0$°C
$\bar{T}=10$°C
$\bar{T}+\Delta T=20$°C
0
-5
-10
-15
Depth (m)
January
July

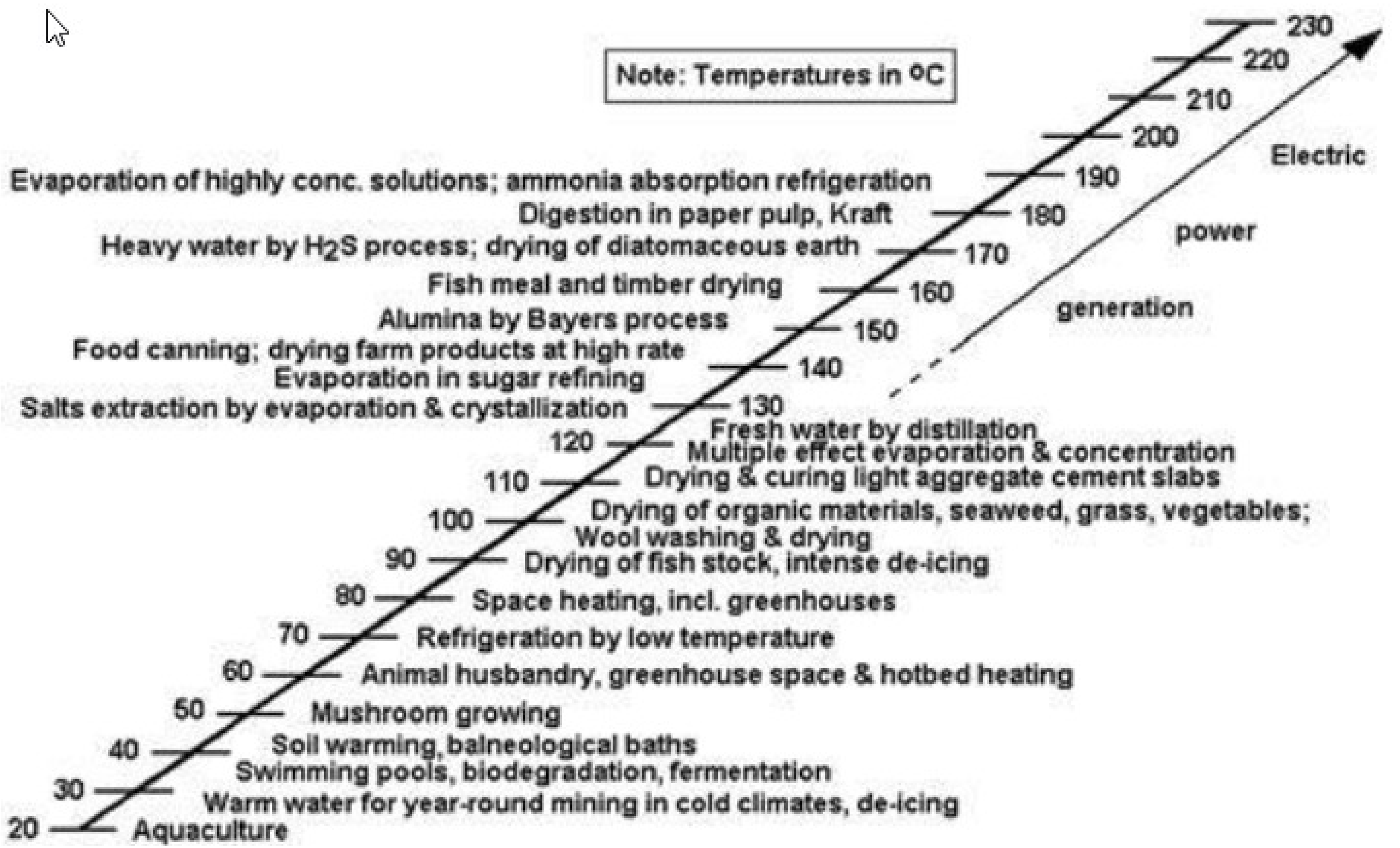
Geothermal Energy – Direct use

- Space heating
- Air conditioning
- Industrial processes
- Drying
- Greenhouses
- Aguaculture
- Hot water
- Resorts and pools
- Melting snow

A fish farm in Colorado



Greenhouse in Colorado


Note: Temperatures in °C
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
Electric
power
generation
Evaporation of highly conc. solutions; ammonia absorption refrigeration
Digestion in paper pulp, Kraft
Heavy water by H2S process; drying of diatomaceous earth
Fish meal and timber drying
Alumina by Bayers process
Food canning; drying farm products at high rate
Evaporation in sugar refining
Salts extraction by evaporation & crystallization
Fresh water by distillation
Multiple effect evaporation & concentration
Drying & curing light aggregate cement slabs
Drying of organic materials, seaweed, grass, vegetables;
Wool washing & drying
Drying of fish stock, intense de-icing
Space heating, incl. greenhouses
Refrigeration by low temperature
Animal husbandry, greenhouse space & hotbed heating
Mushroom growing
Soil warming, balneological baths
Swimming pools, biodegradation, fermentation
Warm water for year-round mining in cold climates, de-icing
Aquaculture

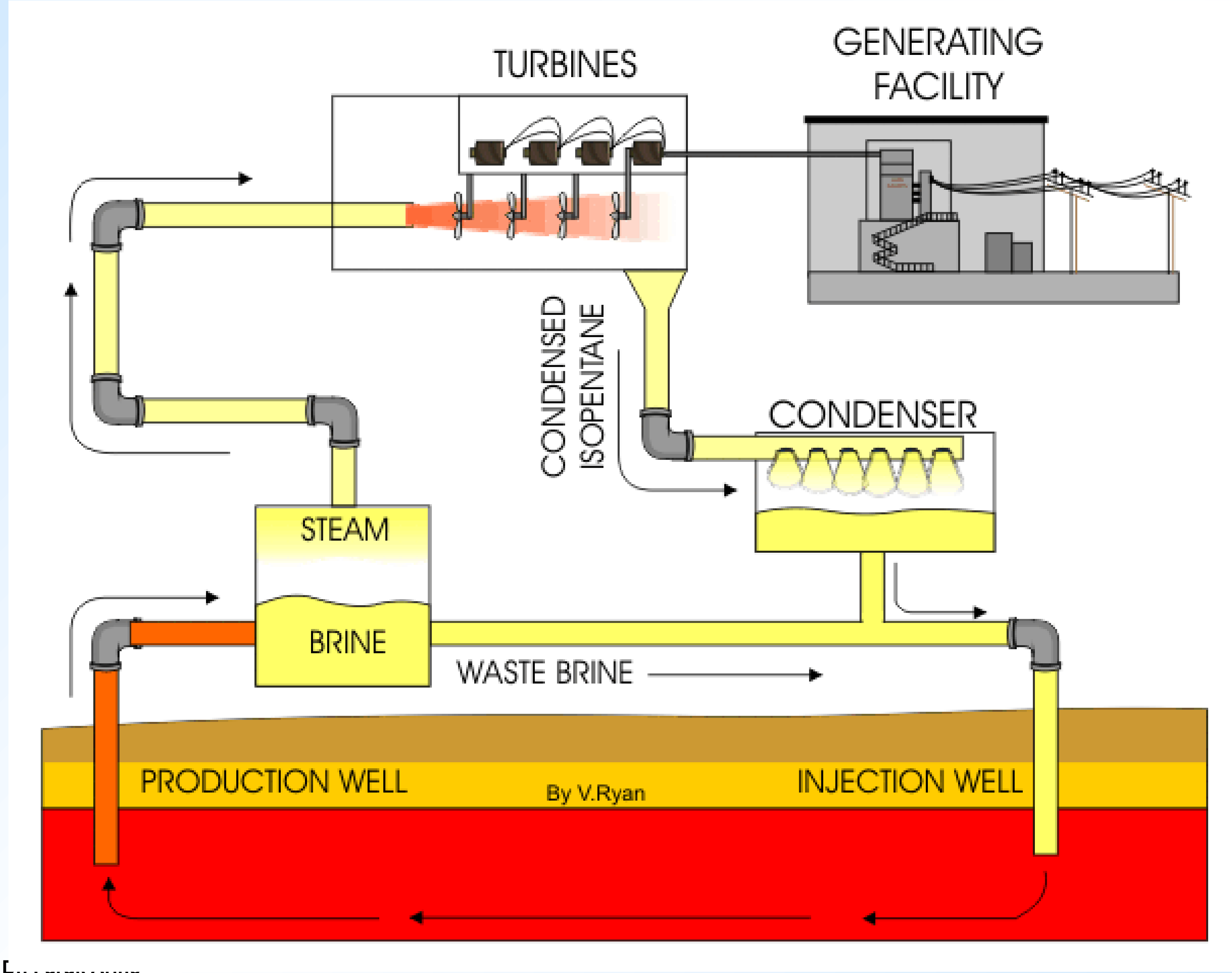
Geothermal Energy – Basic Principles of Power Generation

Geothermal energy can be available as dry steam, boiling water (with steam) as hot water (or **brine**) or as dry hot rock.

When steam can be tapped from the geothermal source, it might be used directly in a steam turbine. The superheating is small and mainly caused by throttling of the steam.

In case boiling water or hot water is tapped, the pressure is reduced and steam that can be **flashed off** is used for power generation.

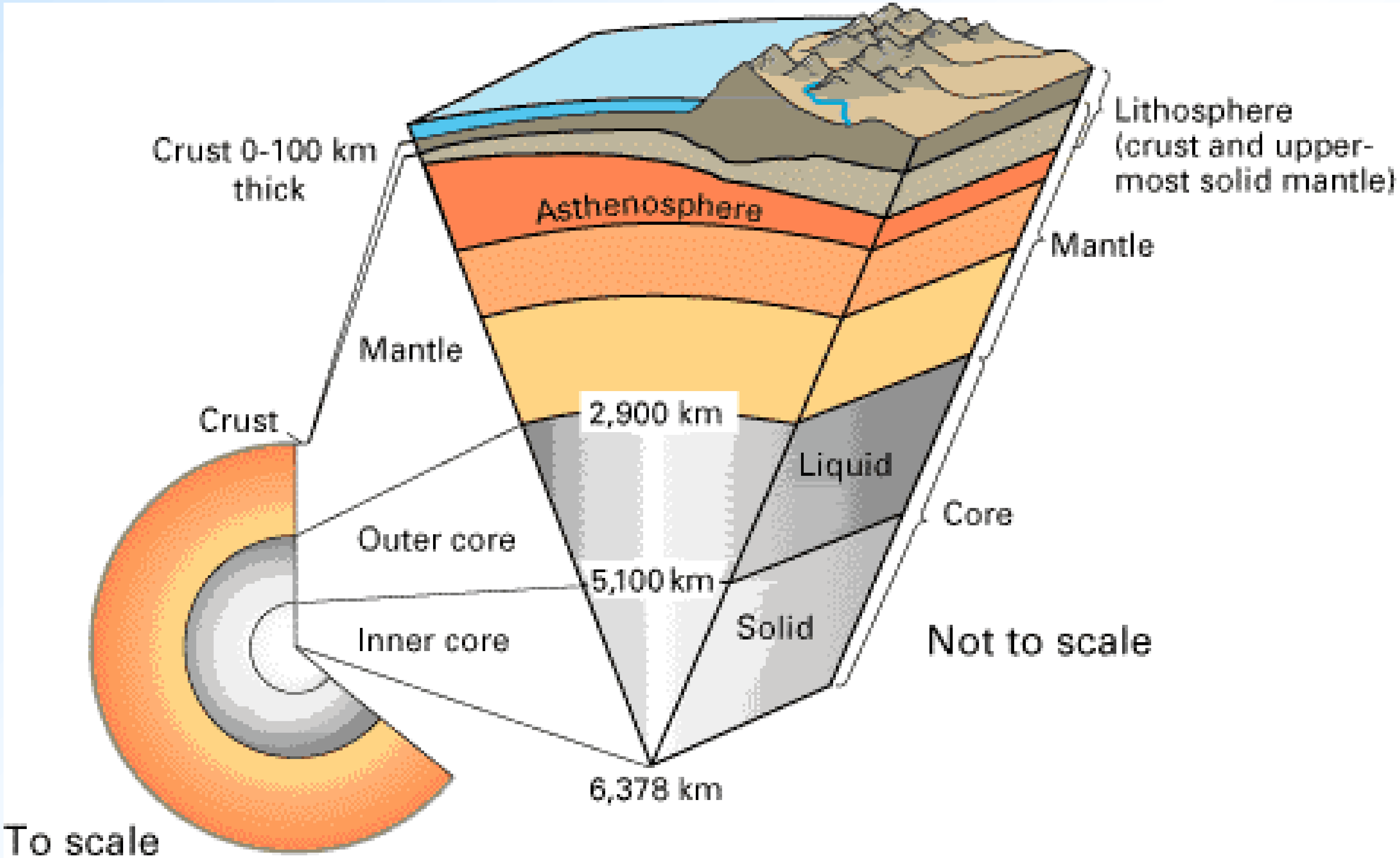
An indirect system where the hot water (or brine) is used to generate hot gas in a heat exchanger (not necessarily steam) can also be used. In particular when the water is highly corrosive, this solution may be the only practical one.


TURBINES
GENERATING FACILITY
CONDENSED ISOPENTANE
CONDENSER
STEAM
BRINE
WASTE BRINE
PRODUCTION WELL
By V.Ryan
INJECTION WELL

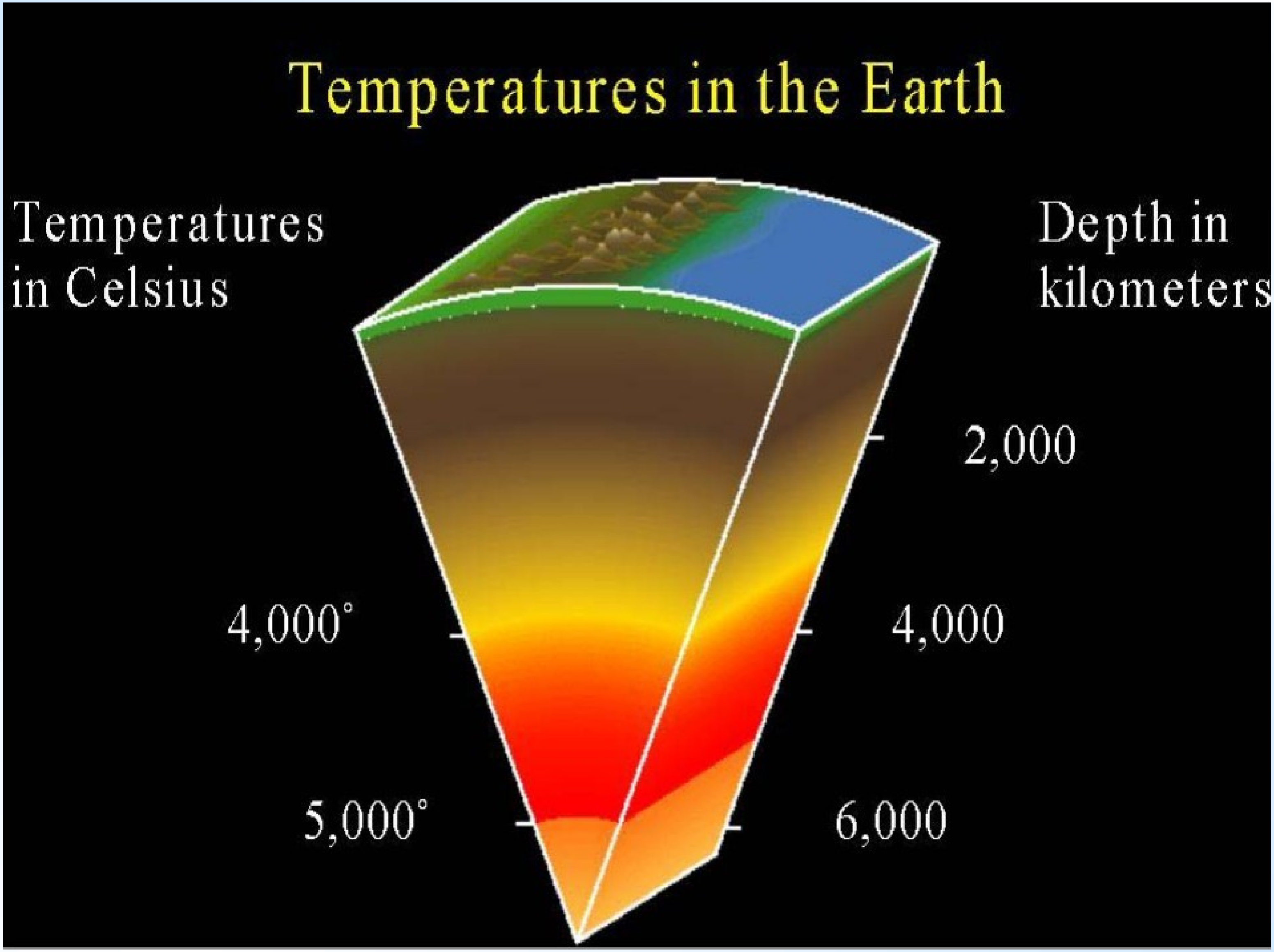
Engineering data for some commercial geothermal power plants

	Larderello	Wairakei	Geysers	Ahuachapan	Cerro Prieto
Country	Italy	New Zealand	USA	El Salvador	Mexico
Start year	1904	1957	1960	1975	1972
Capacity MW(el)	440	180	908	60	150
Steam temp °C	140 – 190	260	172 - 240	250	167
Steam pressure bar	7 – 40	12	6,5 – 7,5	14,6	5
Type of source	dry steam	wet steam	dry steam	dry steam	hot water
Well depth m	< 1000	171-1220	1200-3000		1100-1400

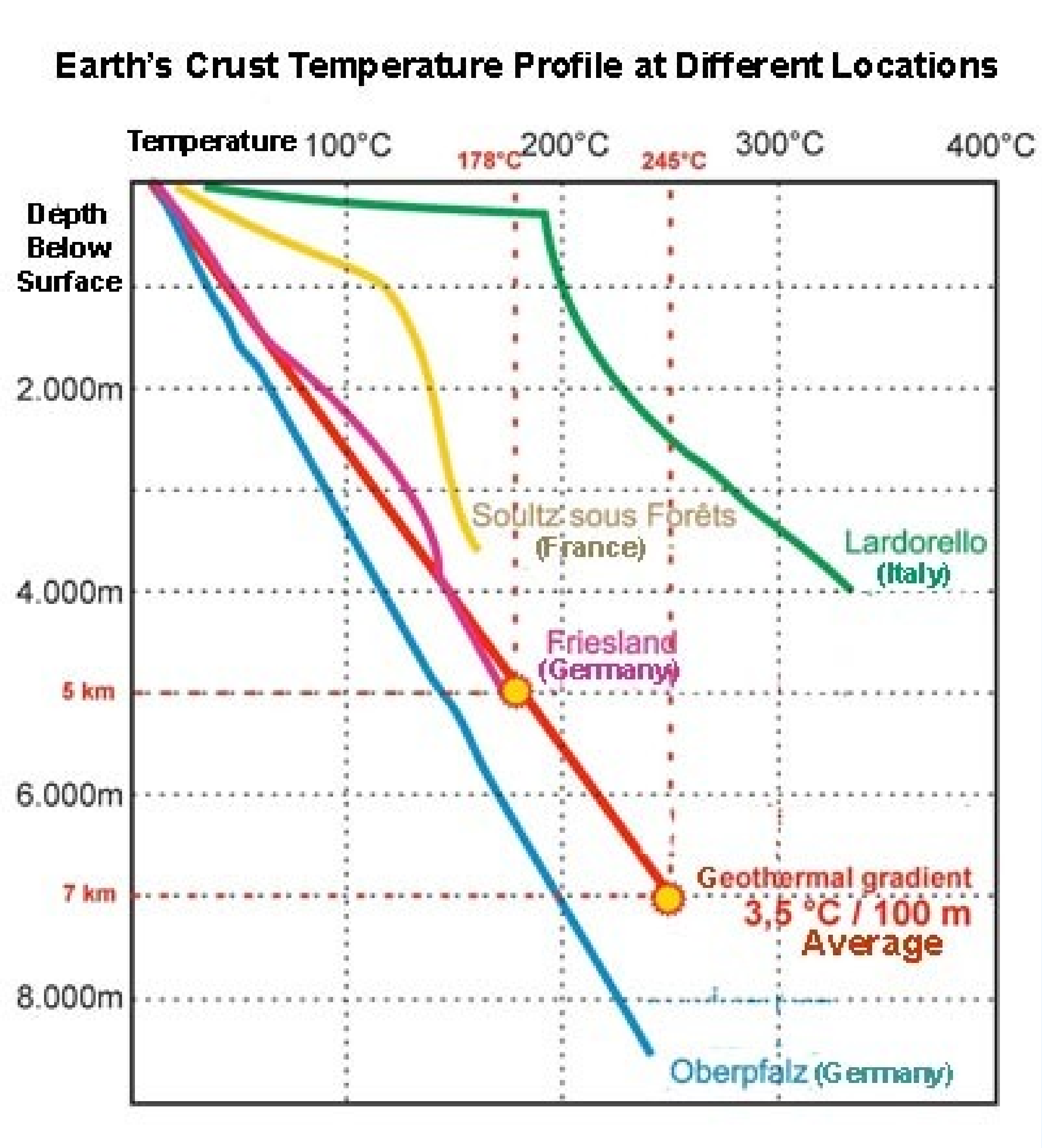
Hot water at lower temperatures may be used for district heating either directly, or if the temperature is below about 70 – 90 °C, after increasing the temperature by means of a heat pump.



Thickness of the crust: 35 km on the average
Temperature change with depth: 25-30 °C per km, on the average



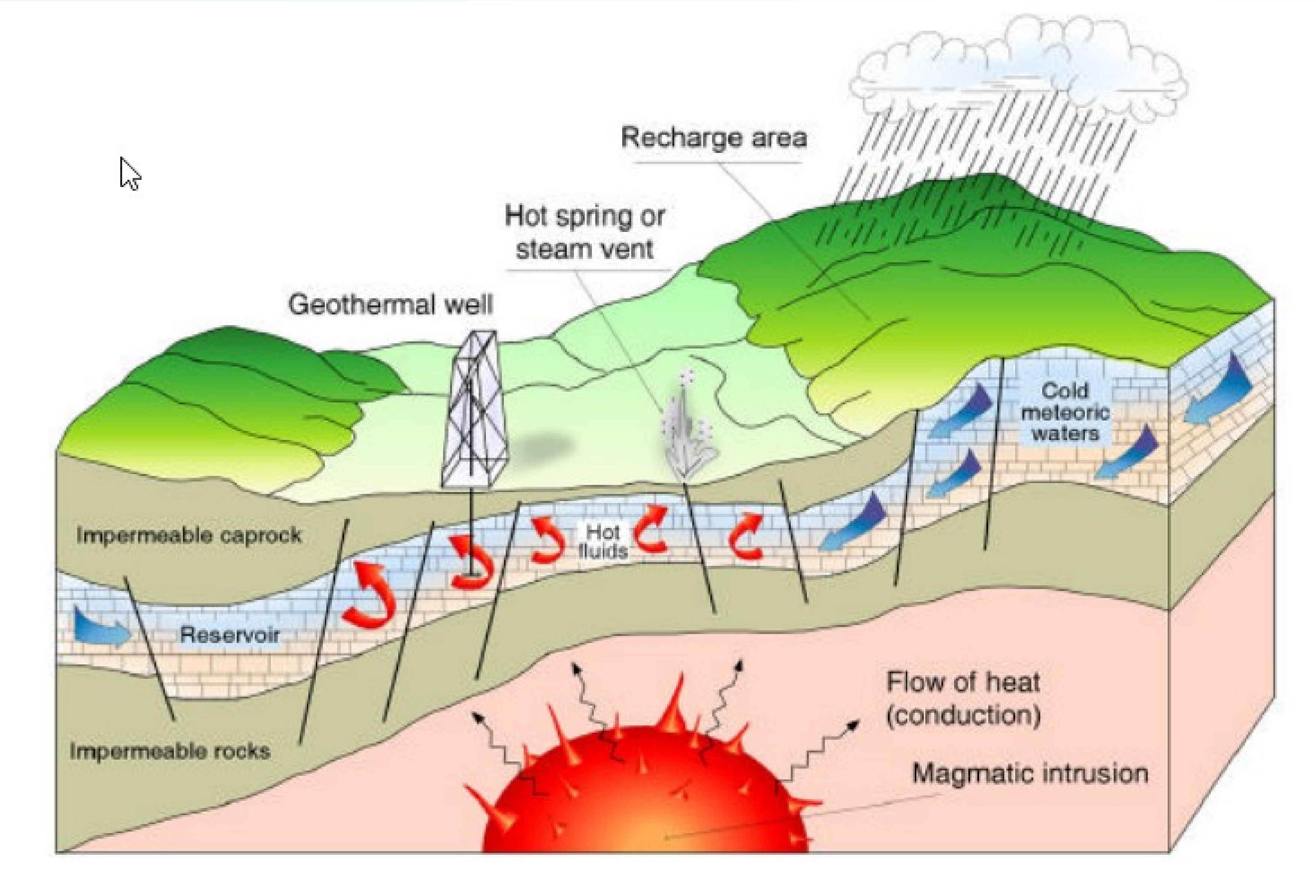
Temperatures in the Earth
Temperatures in Celsius
Depth in kilometers
2,000
4,000°
4,000
5,000°
6,000


Earth's Crust Temperature Profile at Different Locations
Temperature
100°C
178°C
200°C
245°C
300°C
400°C
Depth Below Surface
2.000m
4.000m
5 km
6.000m
7 km
8.000m
Soultz sous Forêts
(France)
Lardorello
(Italy)
Friesland
(Germany)
Geothermal gradient
3,5 °C / 100 m
Average
Oberpfalz (Germany)

There appear to be five features that are essential to making a hydrothermal (i.e., hot water) geothermal resource commercially viable for electricity generation. They are:

a) A large heat source
b) A permeable reservoir
c) A supply of water
d) An overlying layer of impervious rock
e) A reliable recharge mechanism.

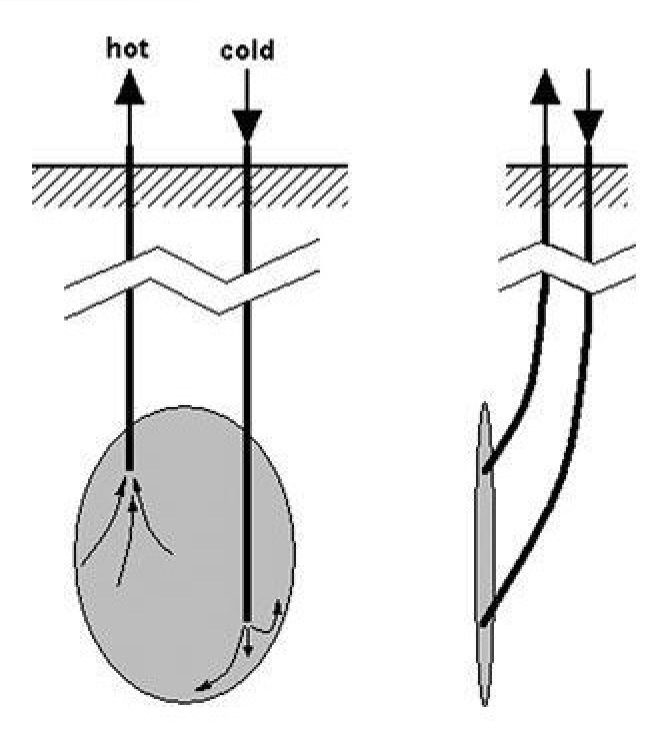
If any one of the five features listed as needed for a viable hydrothermal resource is lacking, the field generally will not be worth exploiting. The features (a) and (d) are essential. Deficiencies in the others may be surmounted with research and field practice.

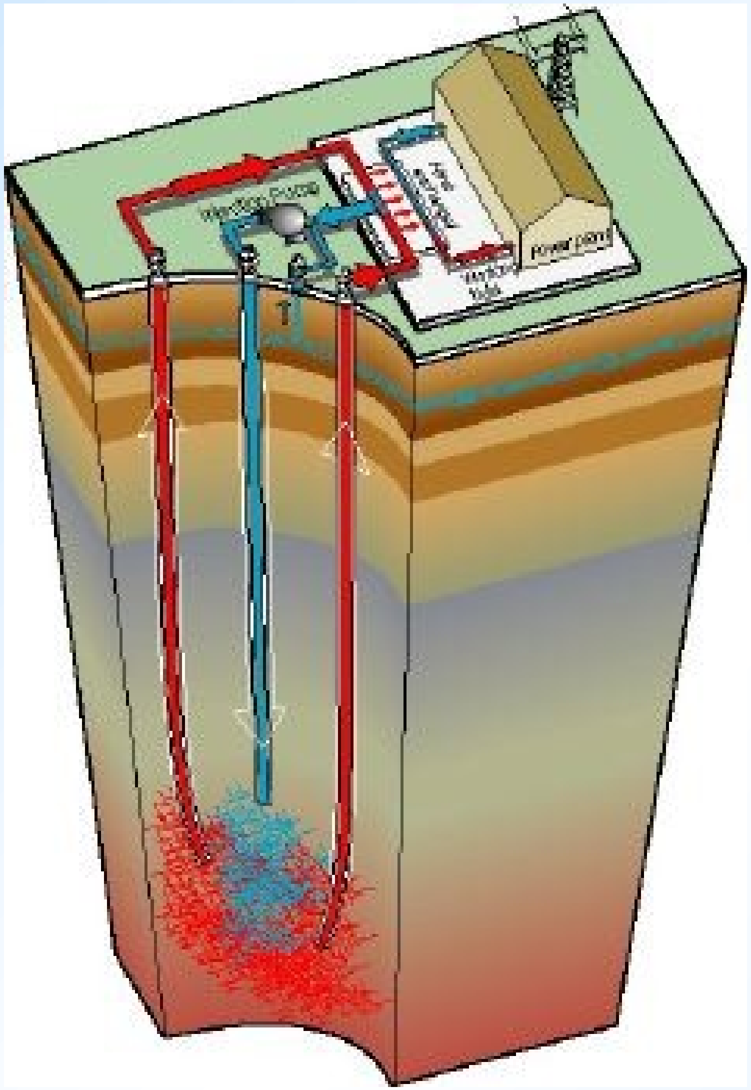

Recharge area
Hot spring or steam vent
Geothermal well
Cold meteoric waters
Impermeable caprock
Hot fluids
Reservoir
Flow of heat (conduction)
Impermeable rocks
Magmatic intrusion

Geothermal resources are characterized by their thermal and compositional characteristics:

i. Enhanced geothermal systems (EGS) (Hot, Dry Rock - HDR)
ii. Hydrothermal or geohydrothermal
iii. Geopressurized
iv. Magma

i - **Hot Dry Rock** (HDR) has the temperature in the excess of 2000 °C. However, as the name implies, contain little amount of liquid. The method for harvesting this resource is to send the water under the rock and reject the heat. This method is also called EGS (Enhanced Geothermal System).





The simplest models have one injection well and two production wells. Pressurized cold water is sent down the injection well where the hot rocks heat the water up. Then pressurized water of temperatures greater than 100 ^{0}C is brought to the surface and passed near a liquid with a lower boiling temperature, such as an organic liquid like butane. The ensuing steam turns the turbines. Then, the cool water is again injected to be heated. This system does not produce any emissions

Some HDR Projects		
Country	**Location**	**Dates**
U.S.A	Fenton Hill, New Mexico	1973 - 1996
	Newberry Volcano, Oregon	2010 - Present
U.K.	Rosemanowes	1977 - 1991
Germany	Bad Urach	1977 - 1990
Japan	Hijiori	1985 - 2003
	Ogachi	1986 - 2008
France	Soultz	1987 - Present
Switzerland	Basel	1996 - 2009
Australia	Hunter Valley	2001 - Present
	Cooper Basin	2002 - Present

ii - **Hydrothermal resources** are the most limited category among the four classes. However they are easiest to harvest.

In hydrothermal resources, water is heated and/or evaporated by direct contact with hot, porous rock. The porous or permeable rock is bounded with rock of low permeability. Water trickles through the porous rock and is heated (and perhaps evaporated) and discharged to the surface.

Hydrothermal systems producing steam are called *vapor dominated*, and if they produce mixture of hot water and steam they are called *liquid dominated.*

iii – **Geo-pressurized resources** include sediment-filled reservoirs and hot water confined under pressures. The fluid temperature is range is 150-1800 °C. The pressure value is up to 600 bars. In many of these systems the fluid contains methane up to 100,000 ppm. This is why the fluid is called “geothermal **brine**” and it is highly corrosive.

iv - **Magma** or molten rock is under active volcanoes at accessible depths. Temperatures excess 650 °C. (No known usage.)

Geothermal Power (Electricity) Production

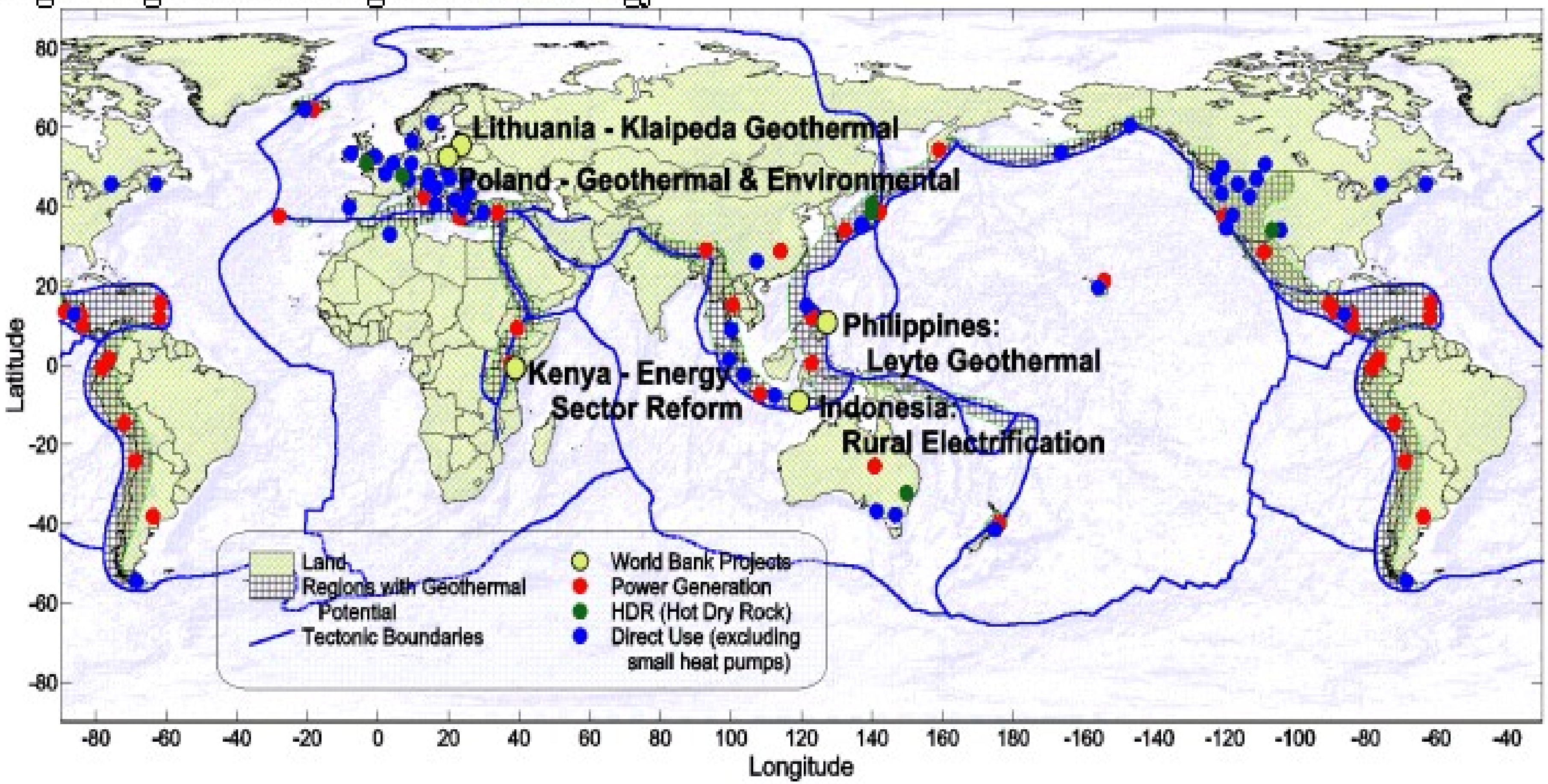
38 years after the invention of the electric power generator by Werner von Siemens and 22 years after the start of the first power station by Thomas A. Edison in New York in 1882, geothermal power production was invented by Prince P. G. Conti in Lardarello, Italy in 1904.

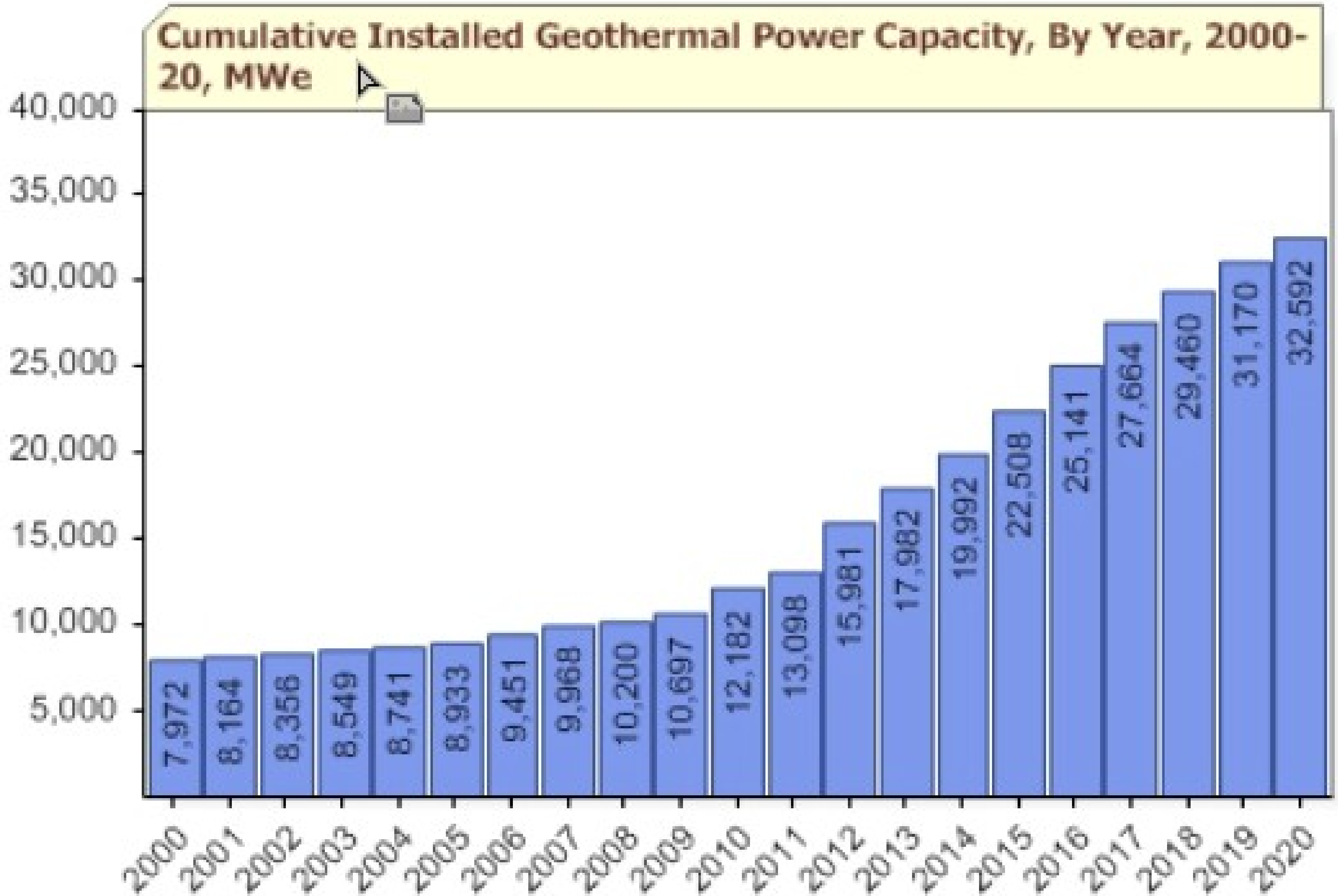
Geothermal power production in Tuscany has continued since then and amounted to 128 MW of installed electrical power in 1942 and to about 790 MW in 2003. In 1958, a small geothermal power plant began operating in New Zealand, in 1959 another in Mexico, and in 1960 commercial production of geothermal power began in the USA within the Geysers Field in California.

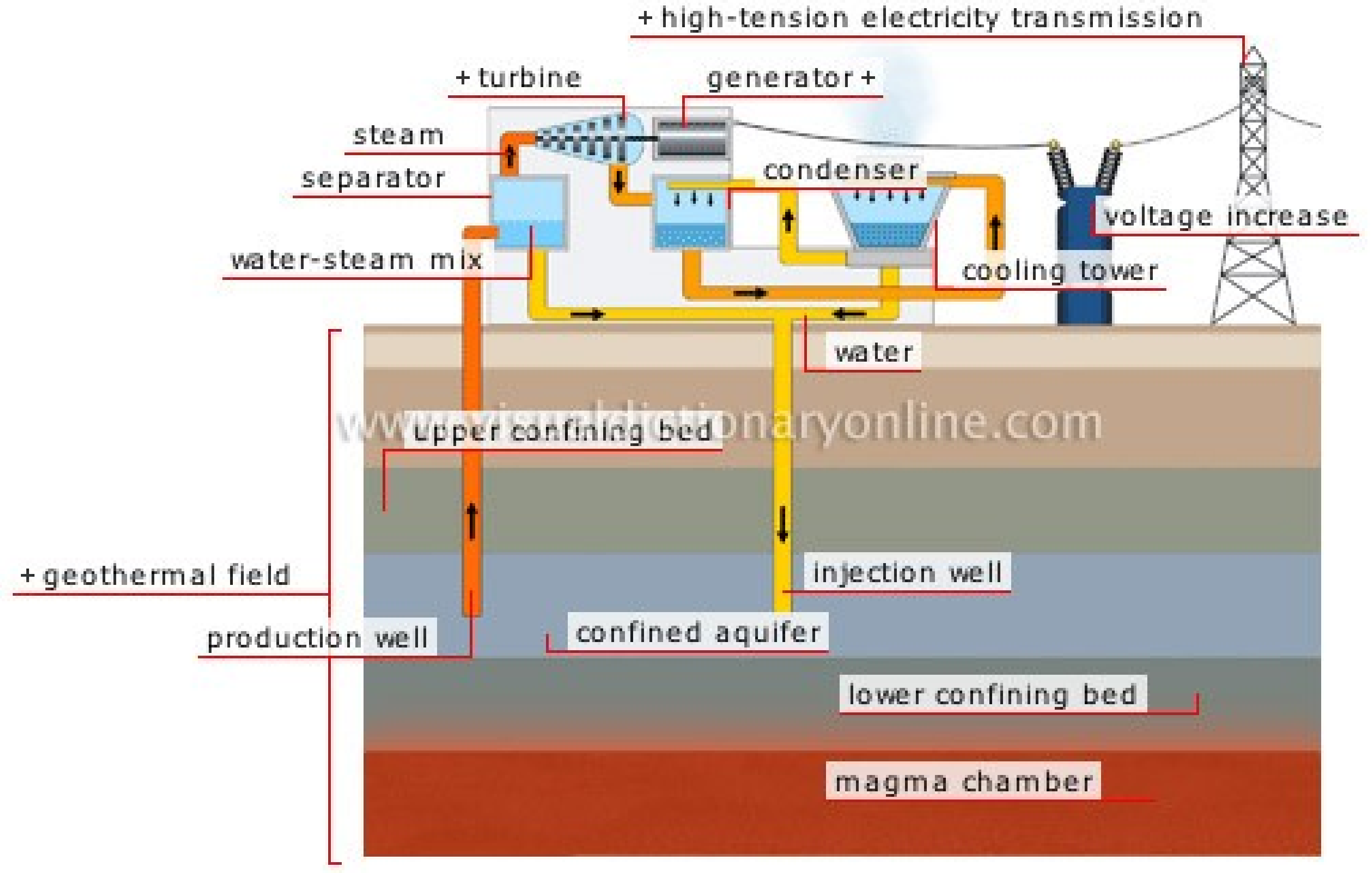
Today, the worldwide geothermal electricity net generation has increased to about 57 billion kWh in the year 2007 which corresponds to 0.3 % of the total electricity net generation whole over the world (www.eia.org). For Turkey, this figure is 0.093 billion kWh which is corresponding to 0.16 % of the world's total geothermal electricity generation. The installed geothermal electric generation capacity has reached to 10.2 GW, worldwide. One of the main reasons for this success is the base load ability of geothermal power generation.

For Turkey, the installed electricity capacity by utilization of the geothermal sources was around 430 MW_e in 2014. The thermal utilization was around 2700 MW_{th}. Today it is close to 2000 MW_e.

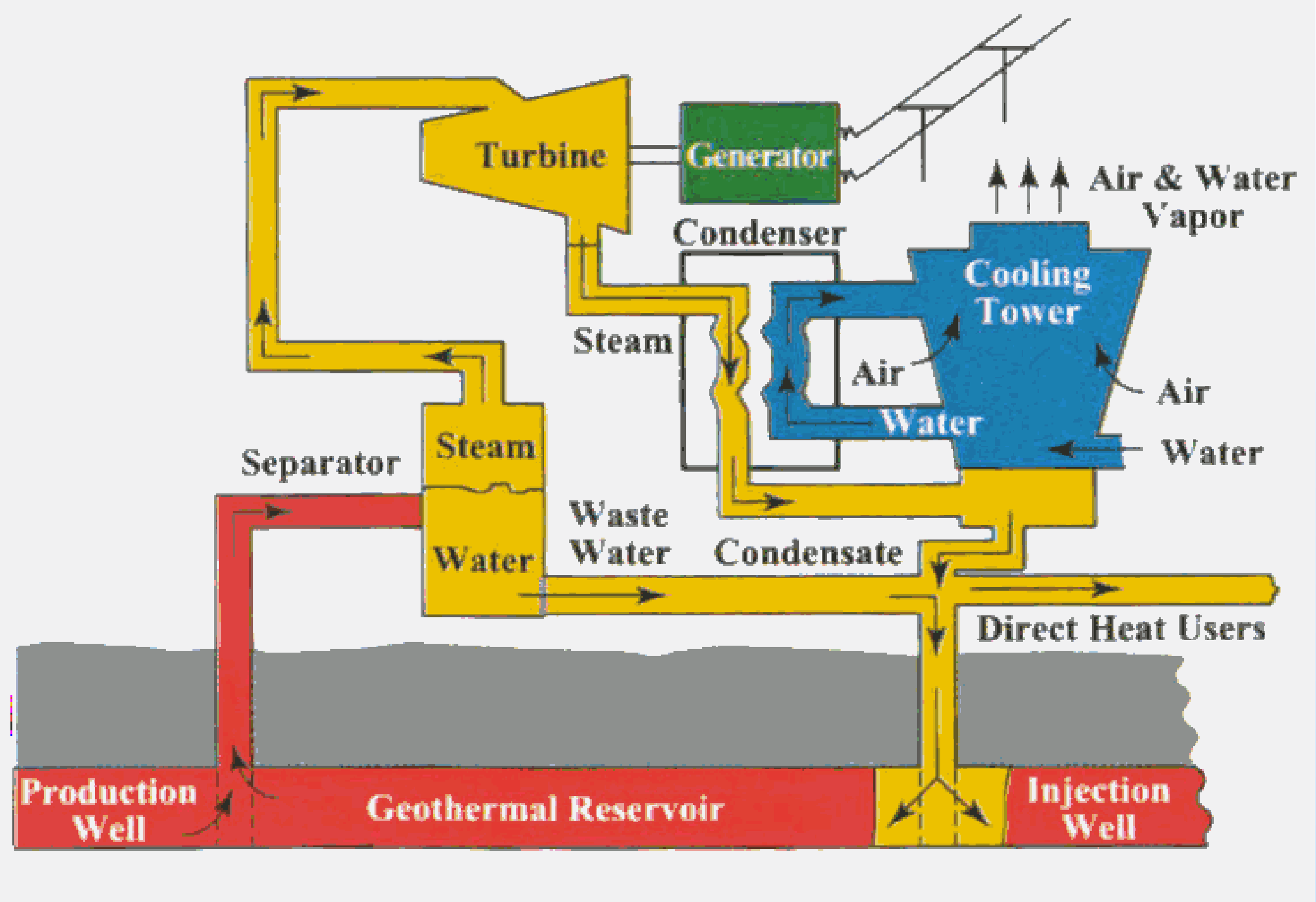
Figure a global view of geothermal energy

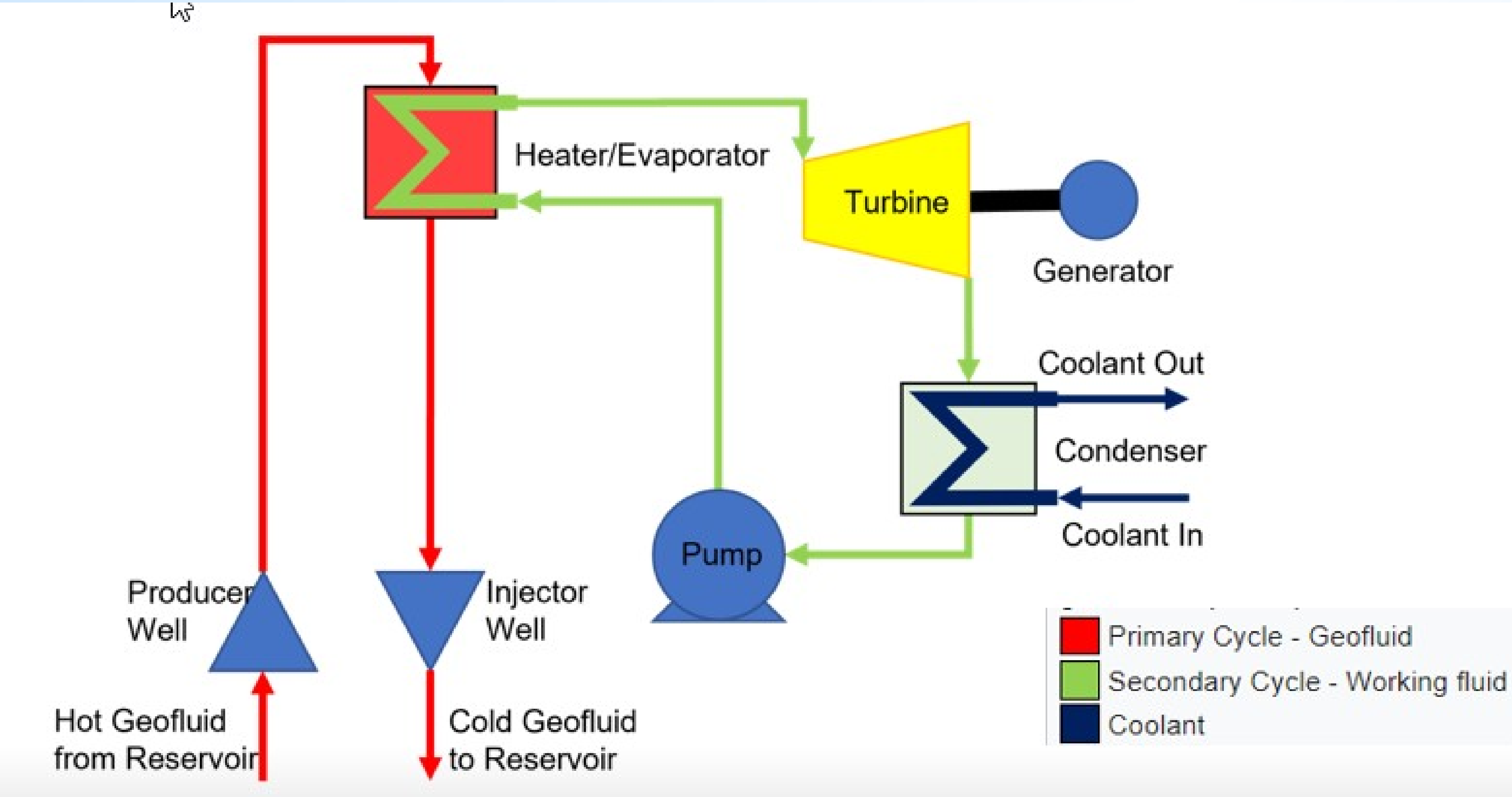



Cumulative Installed Geothermal Power Capacity, By Year, 2000-20, MWe
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
7,972
8,164
8,356
8,549
8,741
8,933
9,451
9,968
10,200
10,697
12,182
13,098
15,981
17,982
19,992
22,508
25,141
27,664
29,460
31,170
32,592
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020



+ high-tension electricity transmission
+ turbine
generator +
steam
separator
condenser
voltage increase
water-steam mix
cooling tower
water
www.visualdictionaryonline.com
upper confining bed
injection well
+ geothermal field
production well
confined aquifer
lower confining bed
magma chamber


Turbine
Generator
Air & Water
Vapor
Condenser
Cooling
Tower
Steam
Air
Air
Water
Water
Separator
Steam
Waste
Water
Water
Condensate
Direct Heat Users
Production
Well
Geothermal Reservoir
Injection
Well

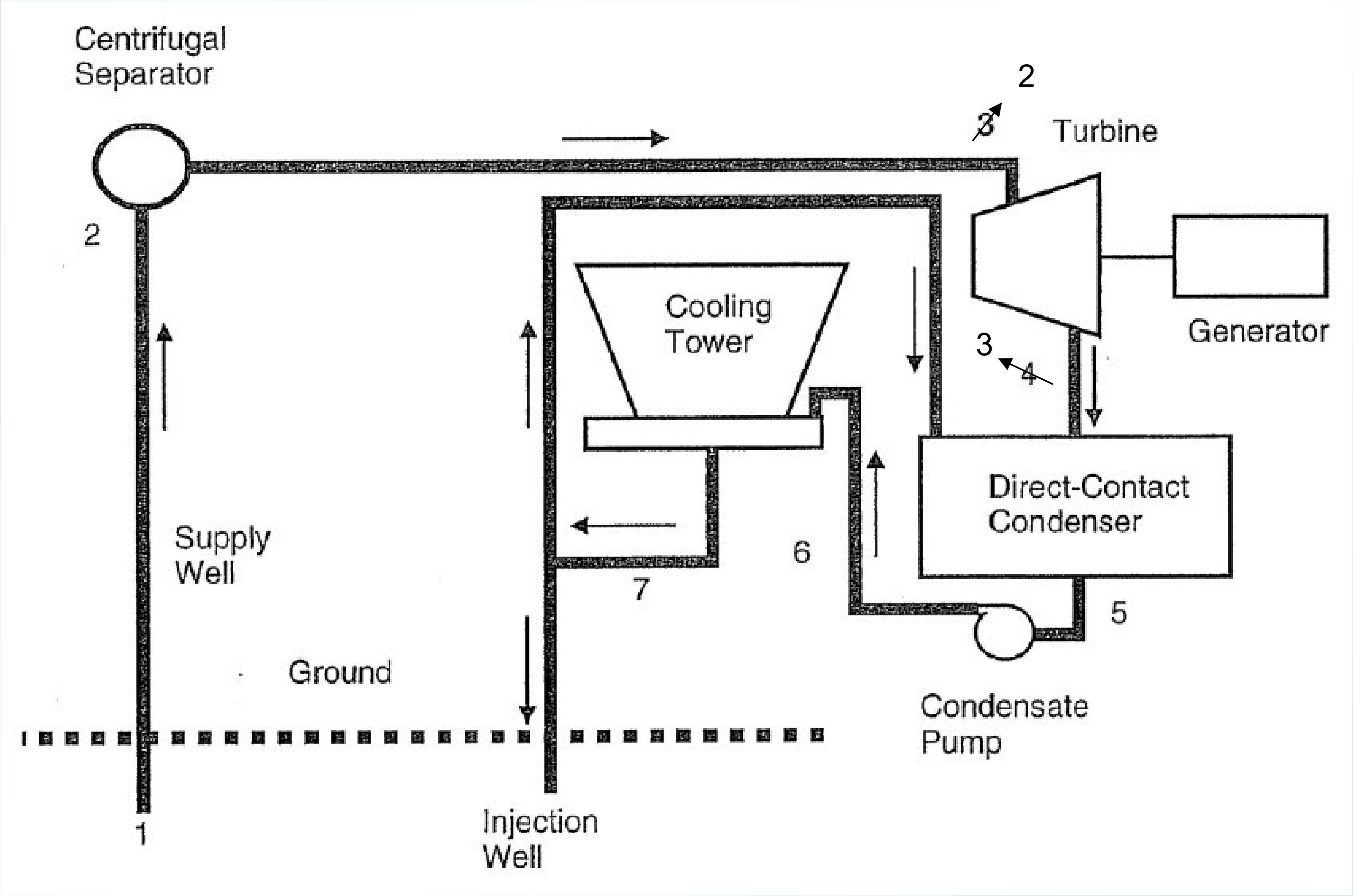


Binary, Liquid-dominated hydrothermal system

Example 1

A vapor-dominated geothermal system is supplied with saturated steam at 3 MPa. The steam enters the turbine at 0.5 MPa and exits at 15 kPa. The turbine isentropic efficiency is 82 %, and the electrical generator is 90 % efficient. If re-injection occurs at the cooling tower, analyze the system performance (find the thermal efficiency and the heat flow rate).

What flow rate of steam is required for a power generation of 10 MW?



Vapor-dominated hydrothermal system

Solution

State 1: Supply Well P_1 = 3 MPa

s_1 = 6.1856 kJ/kg K

h_1 = 2803.2 kJ/kg

State 2: Turbine entrance: P_2 = 0.5 MPa

s_2 = 6.8207 kJ/kg K (turbine inlet entropy s_g at 0.5 MPa)

h_2 = 2748.1 kJ/kg (turbine inlet enthalpy h_g at 0.5 MPa)

State 3: Turbine exit: P_3 = 15 kPa

s_3 = 6.8207 kJ/kg K (isentropic process in turbine) $s_2 = s_3$

State 4: Enthalpy at condenser outlet: $h_4 = h_f$ = 225.94 kJ/kg

Quality at turbine exit: $x_3 = \dfrac{s_3 - s_f}{s_{fg}} = \dfrac{6.8702 - 0.7549}{7.2522} = 0.836$

Enthalpy at turbine exit: $h_3 = h_f + x_3\, h_{fg} = 225.94 + (0.836)\,(2372.3) = 2209.2$ kJ/kg

Specific work out: $w_{out} = h_2 – h_3 = 2748.1 – 2209.2 = 538.9$ kJ/kg

Specific heat out: $q_{out} = h_3 – h_4 = 2209.2 – 225.94 = 1983.26$ kJ/kg

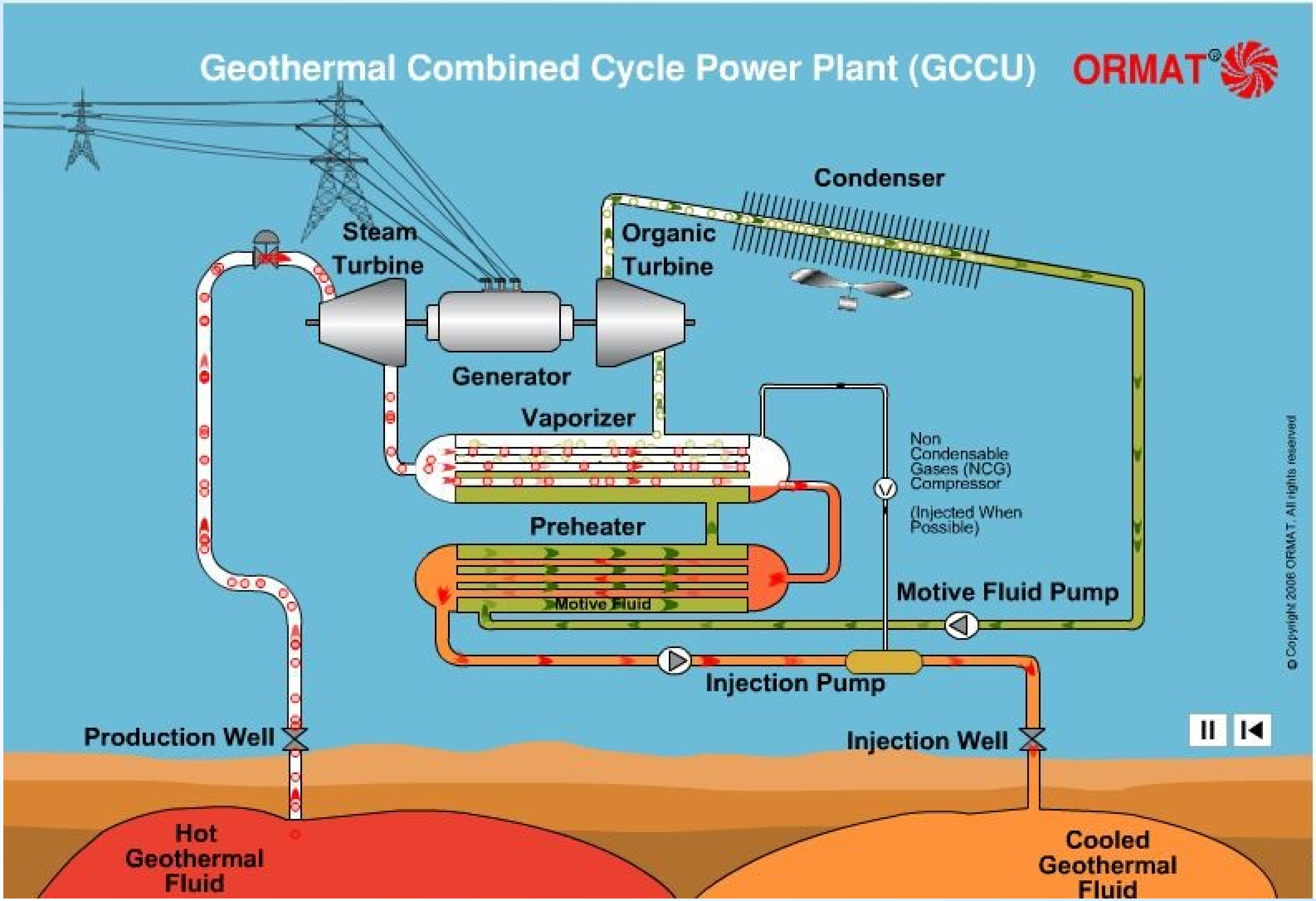
Assuming that the water received by the ground is at P_0 = 15 kPa and T_0 = 25 C

h_0 = 225.94 kJ/kg (condenser outlet enthalpy and ground inlet enthalpy h_f at 15 kPa)

Specific heat in: $q_{in} = h_1 - h_0 = 2803.2 - 225.94 = 2577.26$ kJ/kg

Thermal efficiency: $$\eta_{th} = \frac{w_{out}}{q_{in}} = \frac{558.9}{2577.26} = 0.209$$

Mass flow rate for 10 MW: $$\dot{m} = \frac{\dot{W}_{out}}{w_{out}} = \frac{10000\ \text{kW}}{538.9\ \text{kJ/kg}} = 18.6\ \text{kg/s}$$


Geothermal Combined Cycle Power Plant (GCCU)
ORMAT®
Condenser
Steam Turbine
Organic Turbine
Generator
Vaporizer
Non Condensable Gases (NCG) Compressor
(Injected When Possible)
Preheater
Motive Fluid
Motive Fluid Pump
Injection Pump
Production Well
Injection Well
Hot Geothermal Fluid
Cooled Geothermal Fluid
© Copyright 2006 ORMAT. All rights reserved

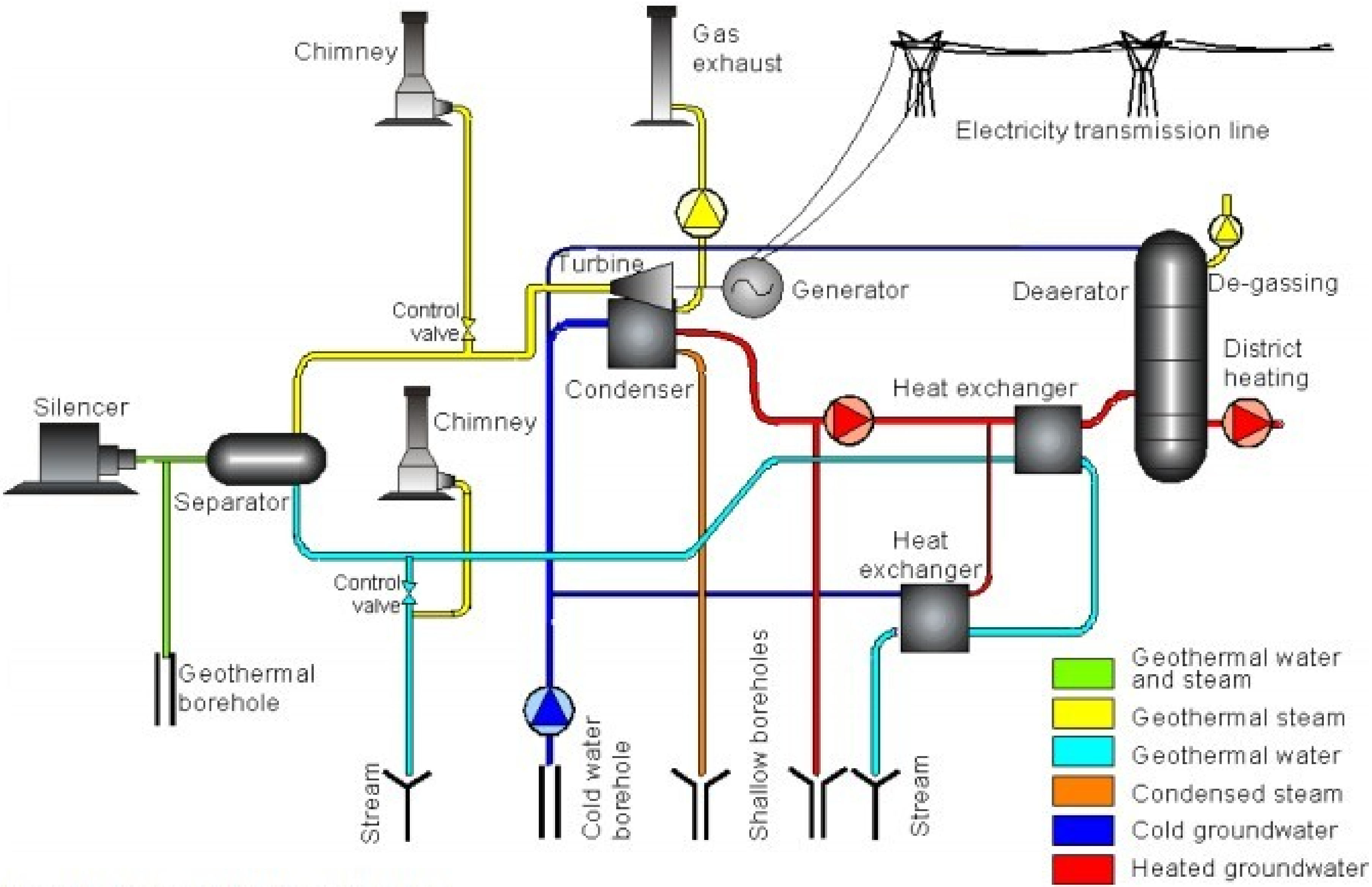
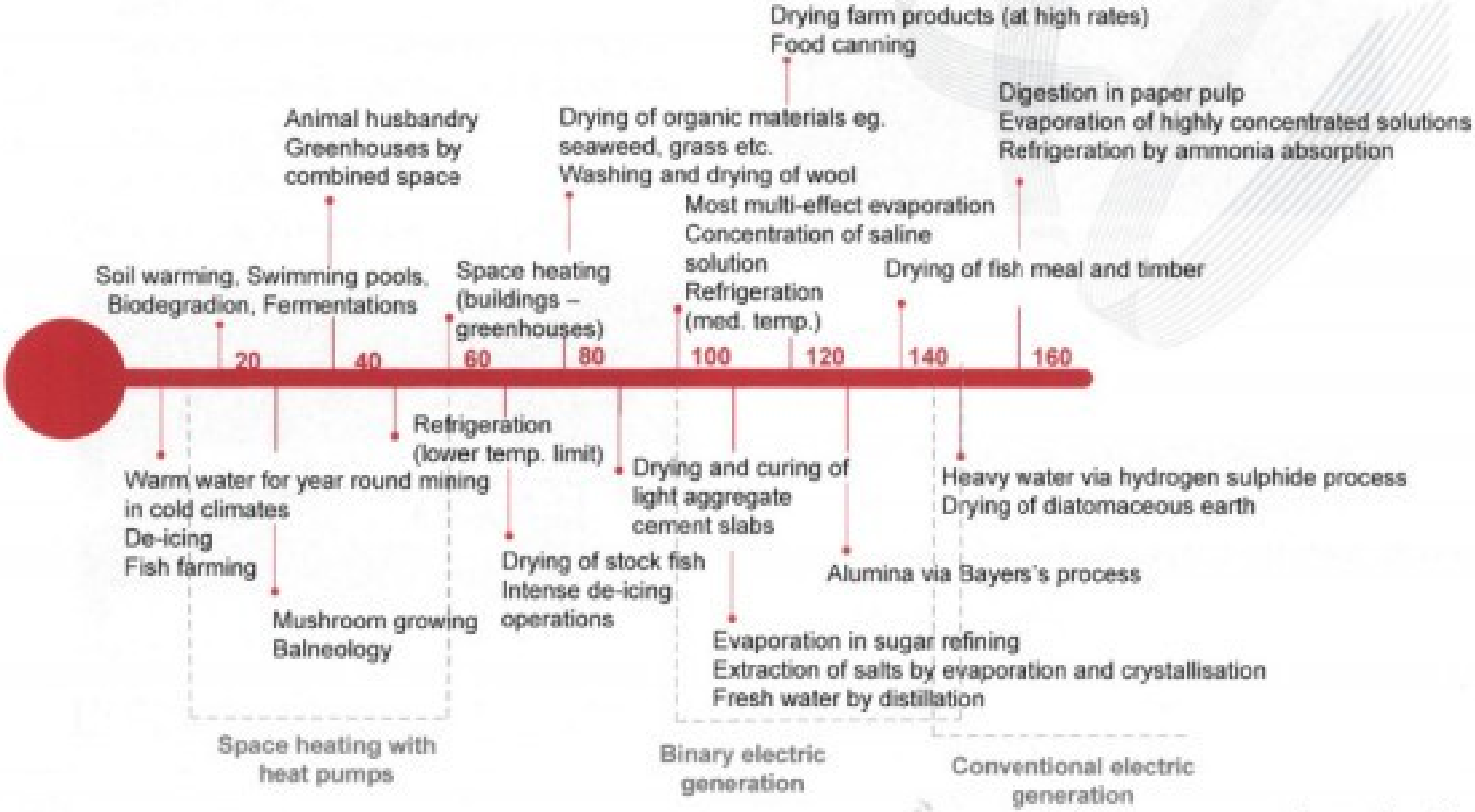
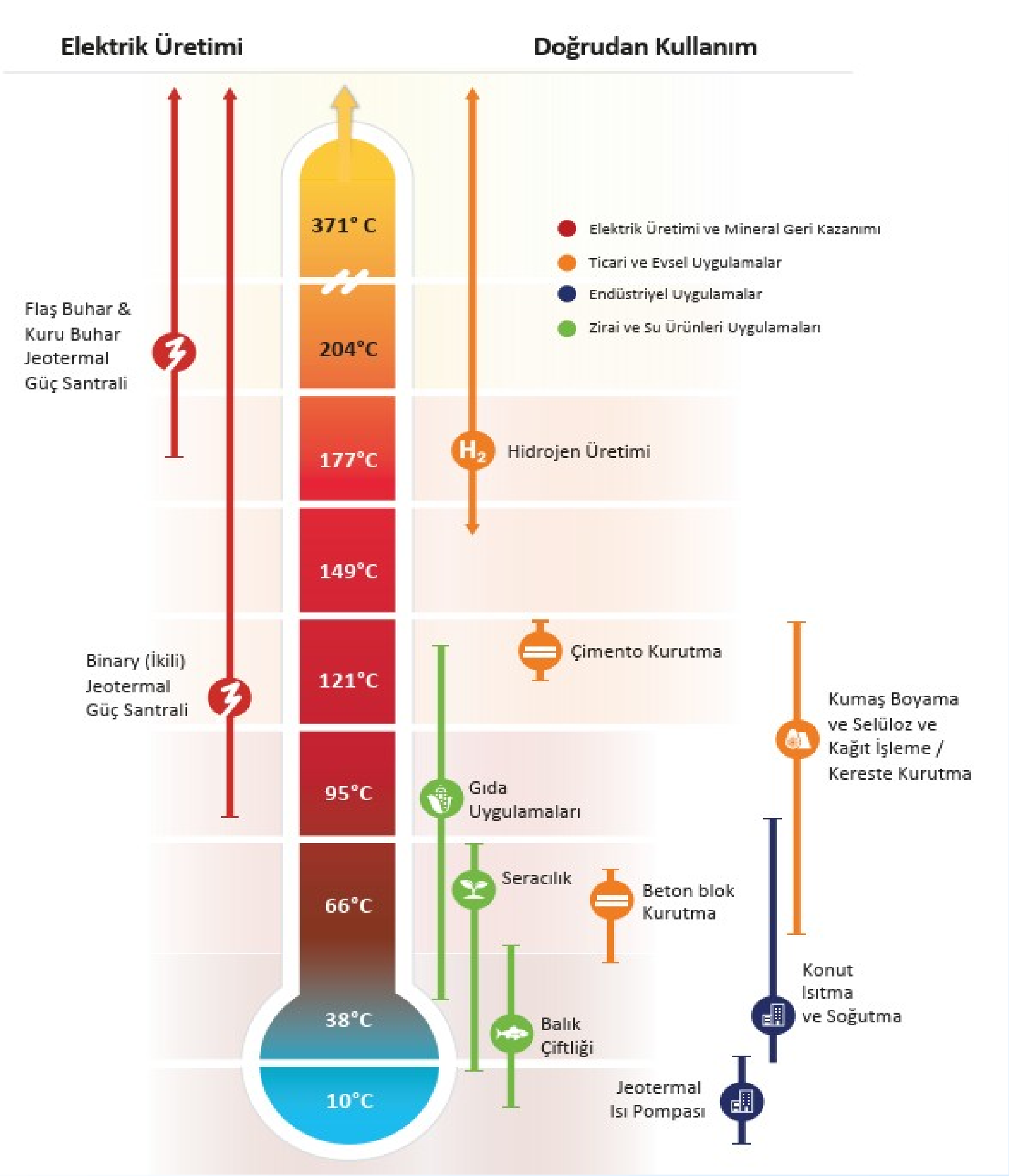


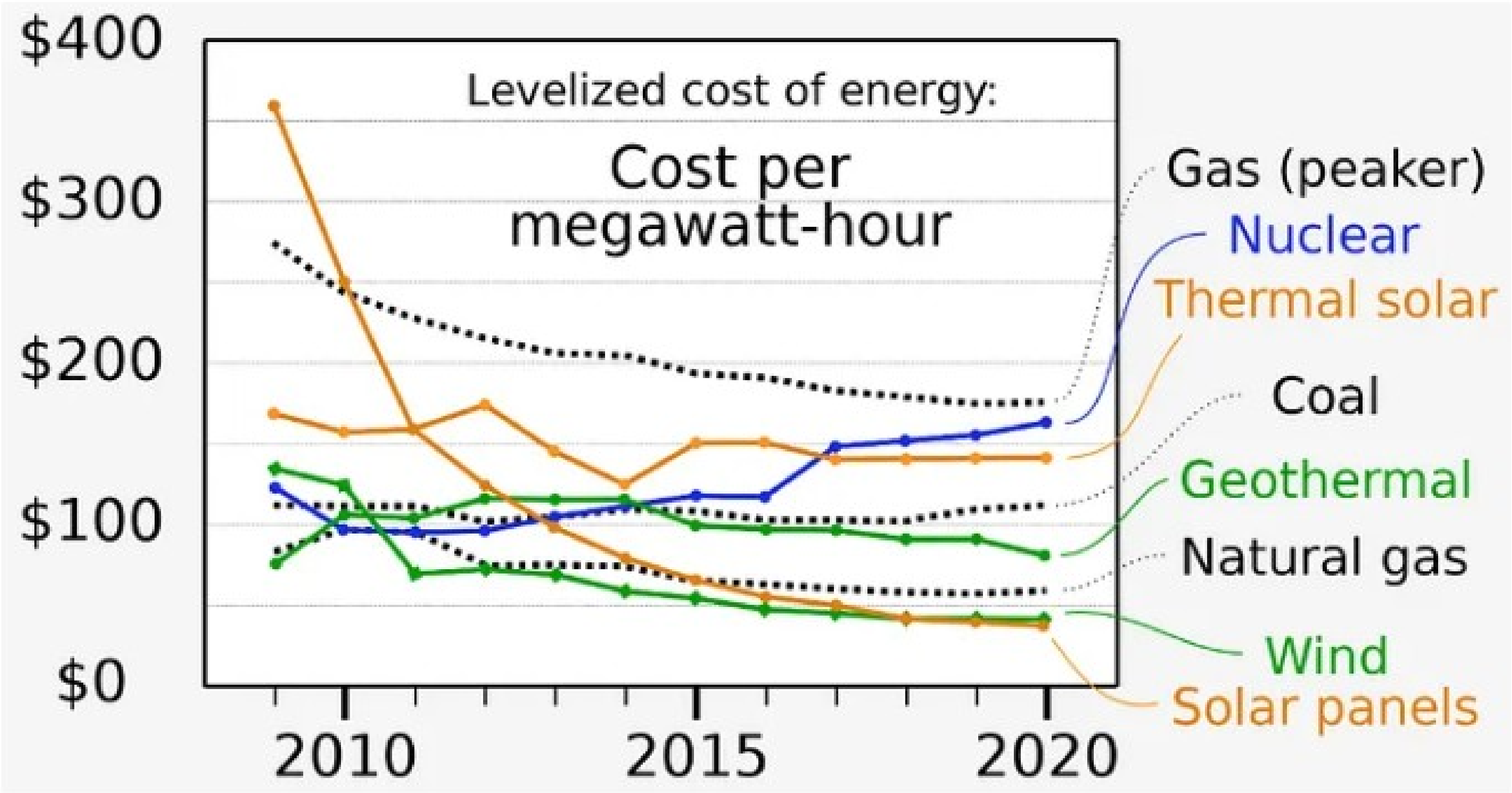
Figure 1. Design of the Nesjavellir plant

Applications for low temp. geothermal resources

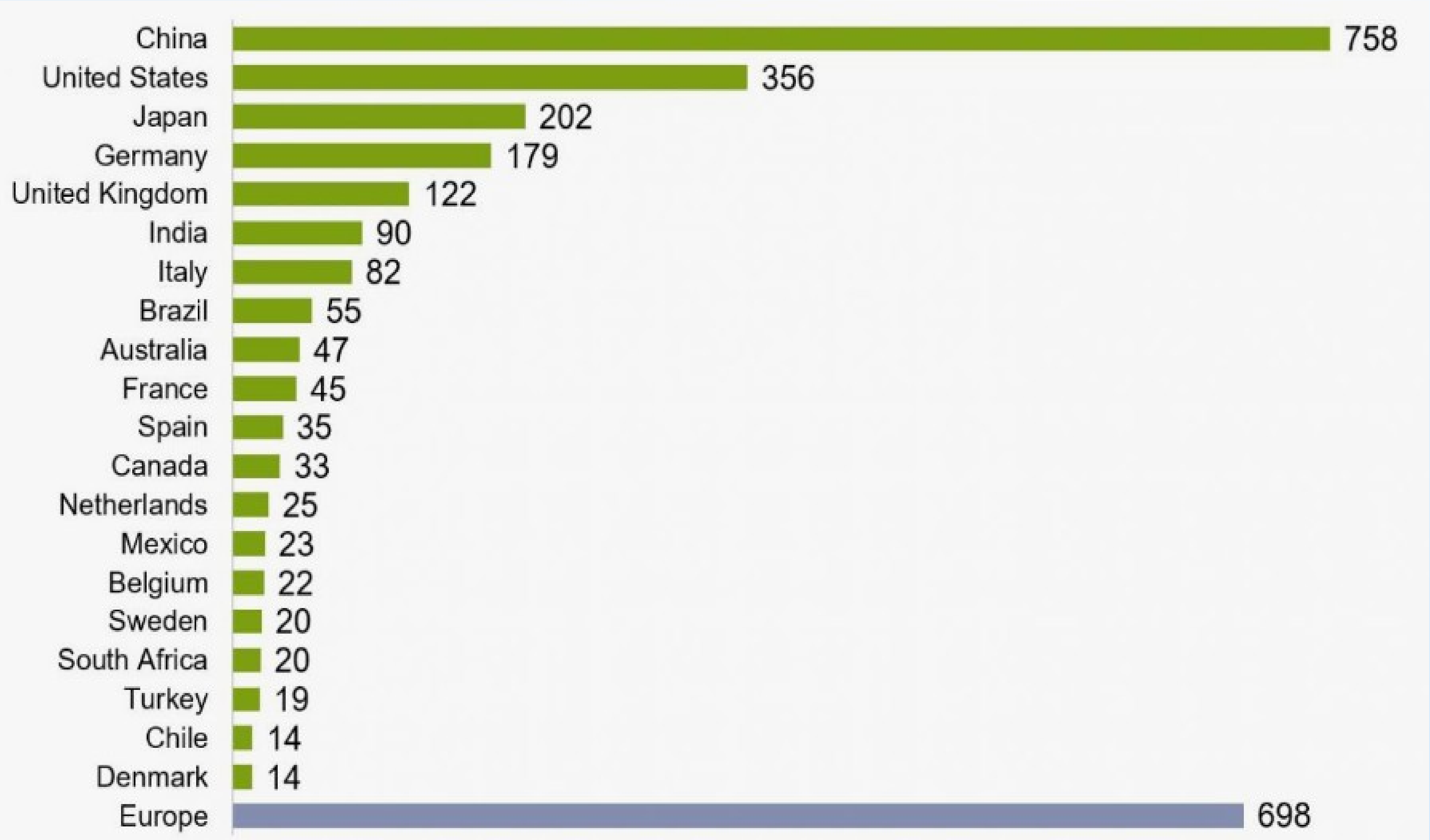


Source: Geo - Heat


Elektrik Üretimi
Doğrudan Kullanım
371° C
204°C
177°C
149°C
121°C
95°C
66°C
38°C
10°C
Elektrik Üretimi ve Mineral Geri Kazanımı
Ticari ve Evsel Uygulamalar
Endüstriyel Uygulamalar
Zirai ve Su Ürünleri Uygulamaları
Flaş Buhar & Kuru Buhar Jeotermal Güç Santrali
Hidrojen Üretimi
Binary (İkili) Jeotermal Güç Santrali
Çimento Kurutma
Kumaş Boyama ve Selüloz ve Kağıt İşleme / Kereste Kurutma
Gıda Uygulamaları
Seracılık
Beton blok Kurutma
Konut Isıtma ve Soğutma
Balık Çiftliği
Jeotermal Isı Pompası


$400
$300
$200
$100
$0
Levelized cost of energy:
Cost per megawatt-hour
2010
2015
2020
Gas (peaker)
Nuclear
Thermal solar
Coal
Geothermal
Natural gas
Wind
Solar panels

Global Renewable Energy Capacity Investment 2010 to 2019 $bn – Top 20 Countries



Geothermal

Key Facts

1. It is the energy obtained from the earth(geo), hot rocks and water/steam reservoirs present inside the earth.
2. It is produced due to the fission of radioactive materials in the earth’s core and some places inside the earth become very hot.
3. They cause water deep inside the earth to form steam. As more steam is formed, it gets compressed at high pressure and comes out in the form of hot springs which produces geothermal power.

Geothermal

Advantages

1. It is a renewable source of energy.
2. It is non-polluting and environment friendly.
3. There is no wastage or generation of by-products.
4. Geothermal energy can be used directly. In ancient times, people used this source of energy for heating homes, cooking, etc.
5. Maintenance cost of geothermal power plants is rather small.
6. Geothermal power plants don't occupy too much space and thus help in protecting natural environment.
7. Unlike solar and wind energy, it is not dependent on the weather conditions.

Geothermal

Disadvantages

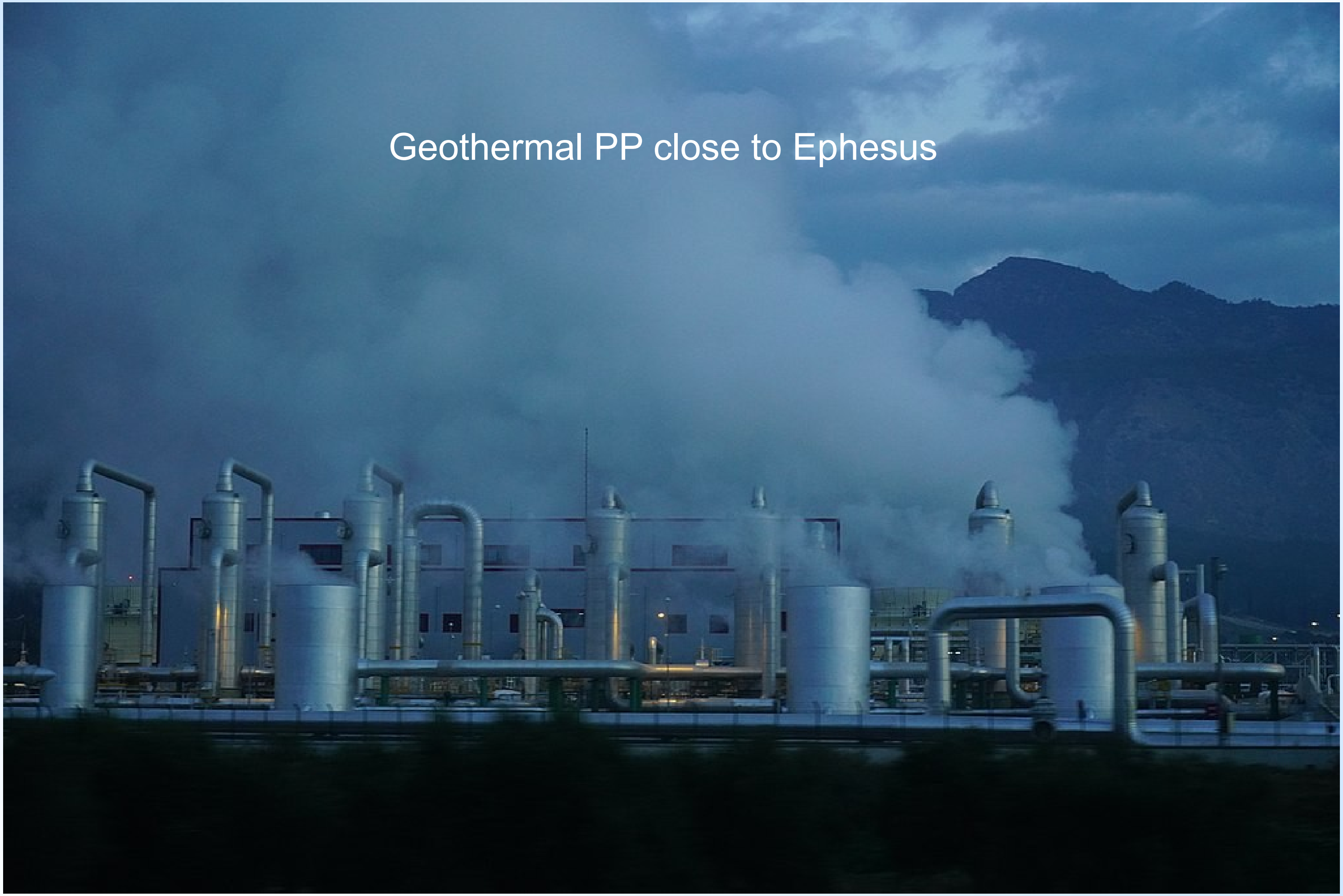
1. Only few sites have the potential of Geothermal Energy.
2. Most of the sites, where geothermal energy is produced, are far from markets or cities, where it needs to be consumed.
3. Total generation potential of this source is rather small.
4. Installation cost of steam power plant is quite high.
5. There is no guarantee that the amount of energy which is produced will justify the capital expenditure and operations costs.
6. It may release some harmful, poisonous gases that can escape through the holes drilled during construction.
7. Geothermal fluid can be poisonous to the environment due to dissolved minerals and gasses it contains.

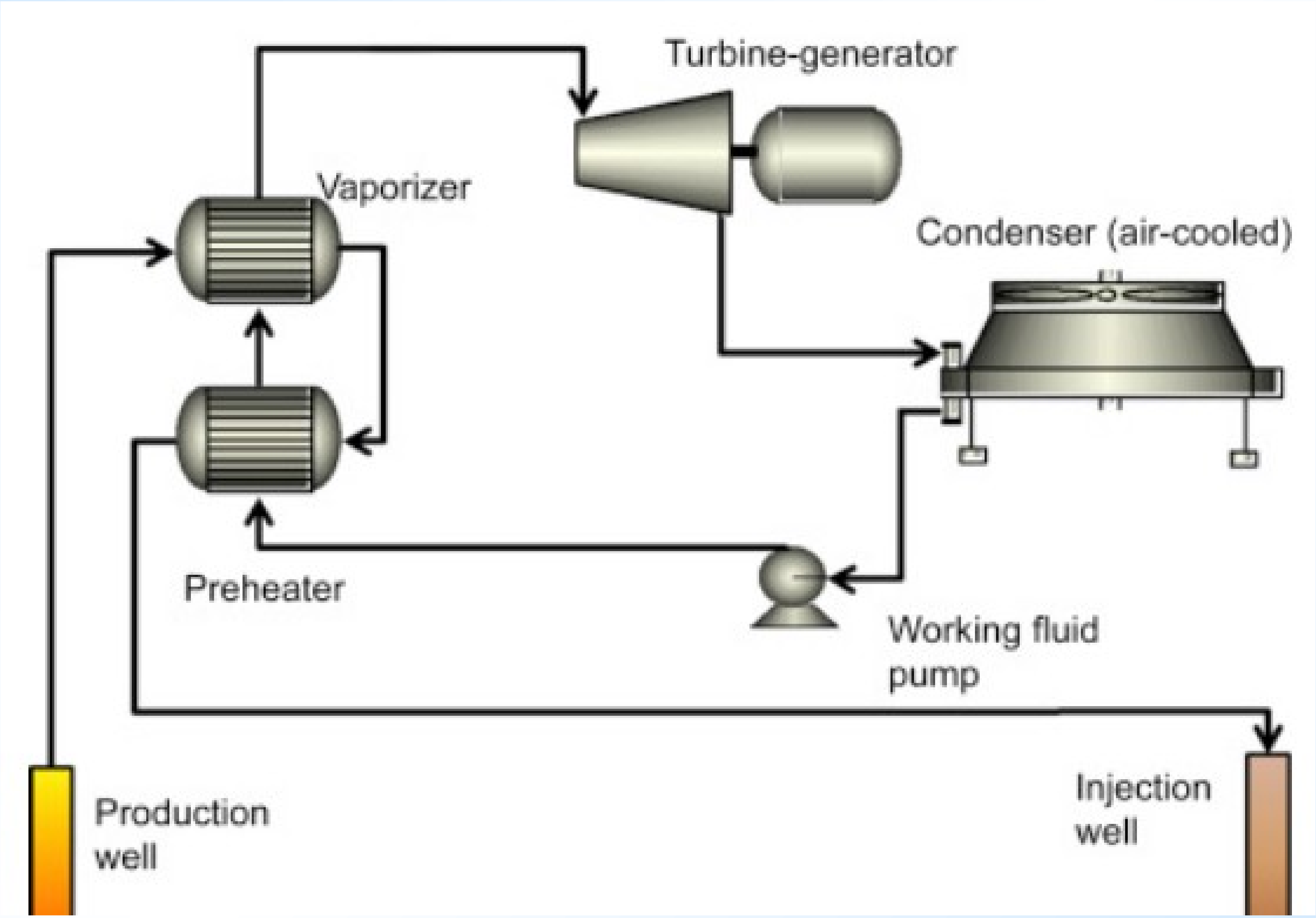
Geothermal Power Plant Environmental Concerns

Possible Impact	Details	Abatement Techniquies
Air Pollution	H_2S emissions	Several effective commercial systems in use
Water Pollution	Surface discharge of waste brine; groundwater contamination	Reinjection
Noise Pollution	Drilling; well testing	Rock mufflers; silencers
Visual Pollution	Unsightly pipes and buildings in pristine areas	Use low-level structures; paint equipment in blending colors
Land Usage	Well pads, pipe routes, powerhouse, and substation	Much lower impact than conventional plants
Water Usage	Cooling tower makeup (for binary plants only)	Use air-cooled condensers

Possible Impact	Details	Abatement Techniquies
Land Subsidence	Liquid removal from subsurface can lead to surface depressions	Rare, most dramatic at Wairakei, New Zealand
Greenhouse Gases	CO_2 emissions	Very low emissions relative to conventional fossil plants
Loss of Natural Wonders	Thermal manifestations may disappear (geysers)	Do not develop resources in or adjacent to national parks

Krafla, a geothermal power station in Iceland


Geothermal PP close to Ephesus



Binary Liquid-dominated hydrothermal system

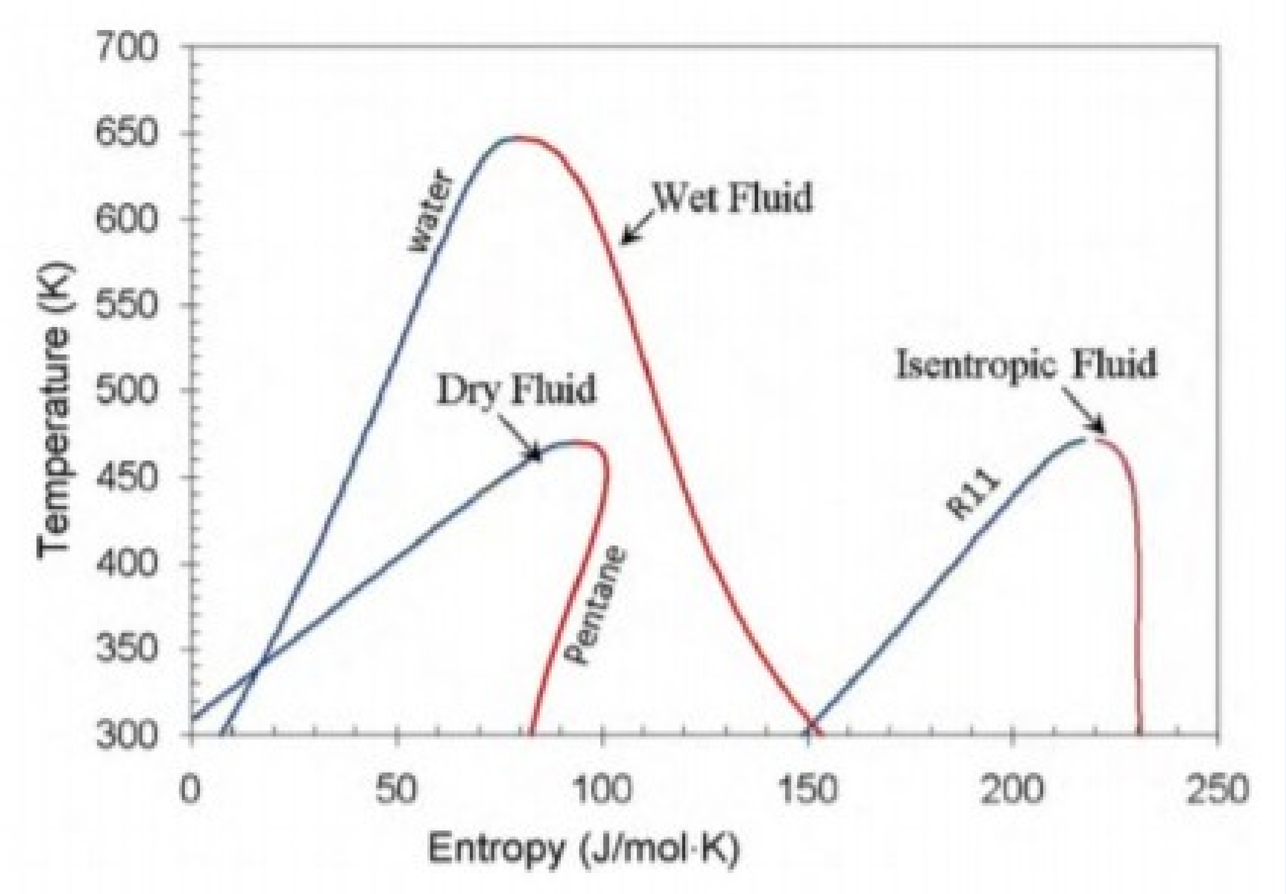
Properties of an optimal working fluid:

- A high critical temperature and maximum pressure
- Low triple-point temperature
- A condenser pressure that is not too low (a substance with a saturation pressure at the ambient temperature is too low)
- A high enthalpy of vaporization (h_{fg})
- A saturation dome that resembles an inverted U
- High thermal conductivity (good heat transfer characteristics)
- Other properties: nontoxic, inert, inexpensive, and readily available

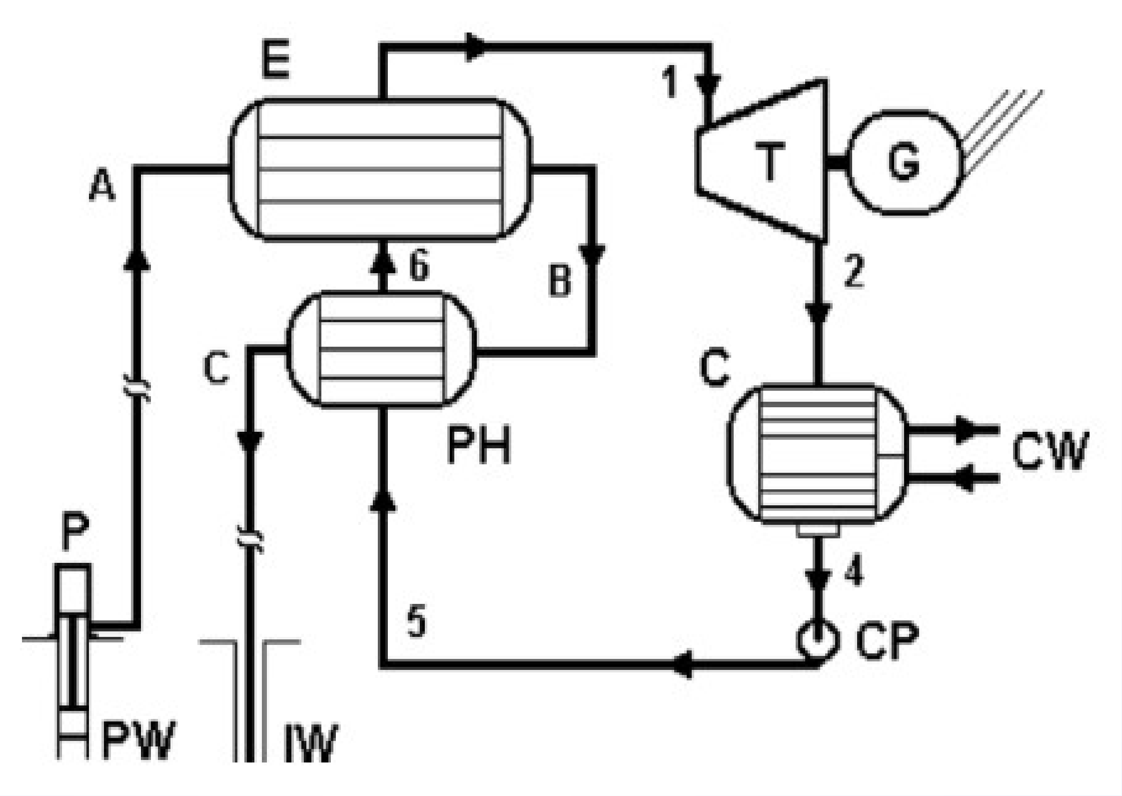
Fluids: Refrigerants, hydrocarbons, isobutane and propane based mixtures, etc.

Name	Tcr [C]	Pcr [MPa]	Type
Propyen	129.23	5.62	Wet
R-152a	113.26	4.52	Wet
R-32	78	5.78	Wet
HC-270	125.15	5.58	Wet
R-134a	101.06	4.06	Wet
R-142b	137.42	4.06	Isentropic
R-21	178.33	5.18	Isentropic
Isobutane	134.66	3.63	Dry
Butane	151.89	3.8	Dry
FC-4-1-12	147.41	2.05	Dry

Depending on the slope of saturated vapor line in the T-s diagram, fluids can be classified as dry, isentropic and wet (with positive, infinite and negative slopes respectively).



Example 2



A basic binary-cycle geothermal power plant is shown in the figure. the working fluid is isopentane, i-C_5H_{12}, and that the cycle has a subcritical boiler pressure. The net cycle power is 1,200 kW, a typical value for this type of plant. Pressure losses in all heat exchangers and piping will be assumed negligible.

The cycle specifications are as follows:

- Brine inlet temperature, T_A = 440 K
- Brine specific heat, c_b = 4.19 kJ/kg.K = constant
- Brine density 900 kg/m^3
- Pinch-point temperature difference = 5 K
- Preheater-evaporator pressure, $P_5 = P_6 = P_1$ = 2.0 MPa
- Condensing temperature, T_4 = 320 K
- Turbine isentropic efficiency = 85 %
- Feed pump isentropic efficiency = 75 %.

Determine the following:

a) Specific work of the turbine: w_T

b) Heat rejected to the cooling water: q_c

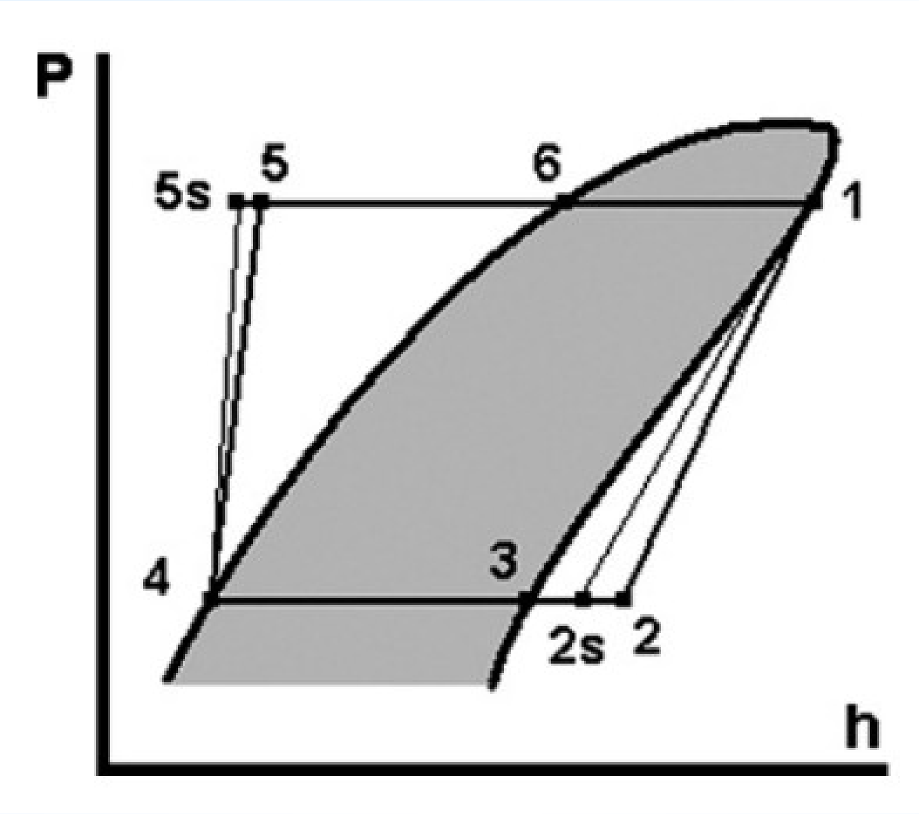
c) Specific work of the feed pump: w_P

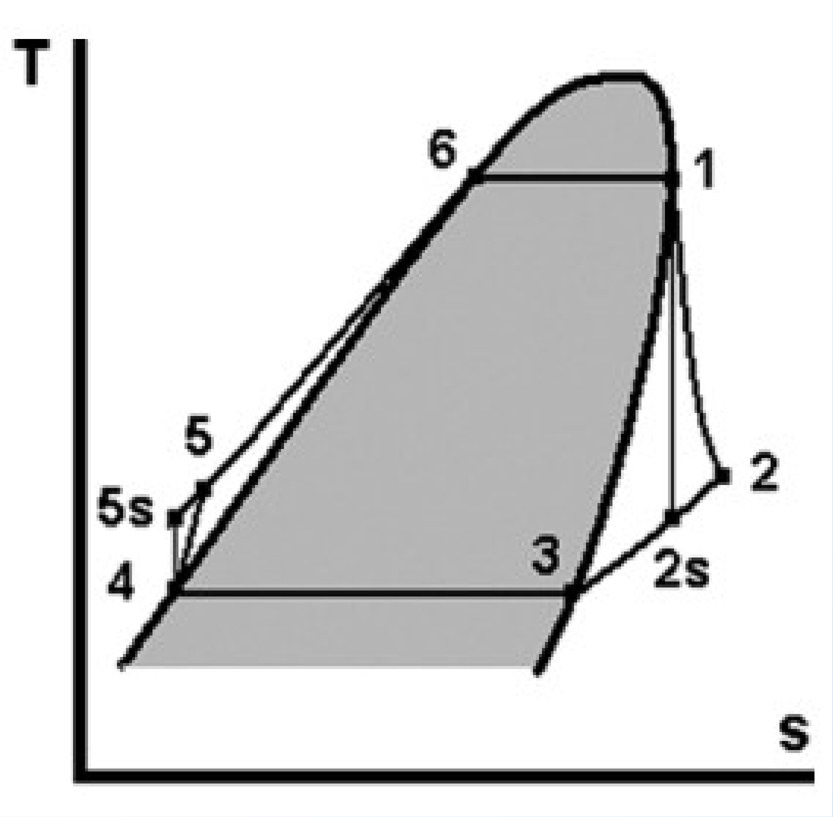
d) Heat transferred to the working fluid: q_{IN}

e) Cycle thermal efficiency: η_{th}

f) Mass flow rate of i-C_5H_{12}: $m_{i\text{-}C5}$

Reference: Reynolds, W.C., Thermodynamic Properties in SI: Graphs, Tables and Computational Equations for 40 Substances, Dept. of Mechanical Engineering, Stanford University, Stanford, CA, 1979.


P
h
5s
5
6
1
4
3
2s
2


T
s
6
1
5
5s
4
3
2
2s

The enthalpy values at the six state points in the cycle must be found:

State	P, MPa	T, K	v, m³/kg	s, kJ/kg.K	h, kJ/kg	Comments for h
1	2.0	427.1		2.2022	741.08	From Table
2	0.1866				663.38	From η_t
2s	0.1866			2.2022	649.66	Interpolation
3	0.1866	320		1.9887	578.16	From Table
4	0.1866	320	0.001686		249.50	From Table
5	2.0				253.58	From η_p
5s	2.0				252.56	From (v) (ΔP)
6	2.0				545.73	From Table

Some of the properties of isopentane:

- State 1: Saturated vapor at 2 MPa: s_1 = 2.2022 kJ/kg.K , h_1 = 741.08 kJ/kg.
- State 2: Actual turbine outlet state; must find isentropic outlet state first.
- State 2s: Isentropic turbine outlet state;

  $s_{2s} = s_1$, $P_2 = P_{sat}$ = 186.6 kPa for T_3 = 320 K.

  By interpolation, h_{2s} = 649.66 kJ/kg.

- State 2: Using the definition of the turbine efficiency, we can find h2:

  $$h_2 = h_1 - \eta_t (h_1 - h_{2s}) = 663.38 \text{ kJ/kg}$$

- State 3: Saturated vapor at T_3 = 320 K: s_3 = 1.9887 kJ/kg.K, h_3 = 578.16 kJ/kg.
- State 4: Saturated liquid at T_3 = 320 K: v_4 = 0.001686 m^3/kg, h_4 = 249.50 kJ/kg.

  The specific volume v4 is recorded because we can use a very good approximation to find the enthalpy at state 5s.

Some of the properties of isopentane:

- State 5: Actual pump outlet state; must find isentropic outlet state first.
- State 5s: Isentropic pump outlet state: P_{5s} = 2 MPa. Because the liquid is very nearly incompressible (i.e., constant density), to a high degree of accuracy, the value of h_{5s} can be found from: $h_{5s} \approx h_4 + v_4 (P_{5s} - P_4)$ = 252.56 kJ/kg.
- State 5: The definition of the pump efficiency is similar to that for the turbine but the numerator is the isentropic work and the denominator is the actual work; thus, we can find h_5: $h_5 = h_4 + (h_{5s} - h_4)/\eta_p$ = 253.38 kJ/kg.
- State 6: Saturated liquid at 2 MPa: h_6 = 545.73 kJ/kg.

With all the enthalpy values in hand, we can easily find the first six of our objectives:

a) Specific work of the turbine: $w_t = h_1 - h_2 = 77.70$ kJ/kg

b) Heat rejected to the cooling water: $q_c = h_2 - h_4 = 413.88$ kJ/kg

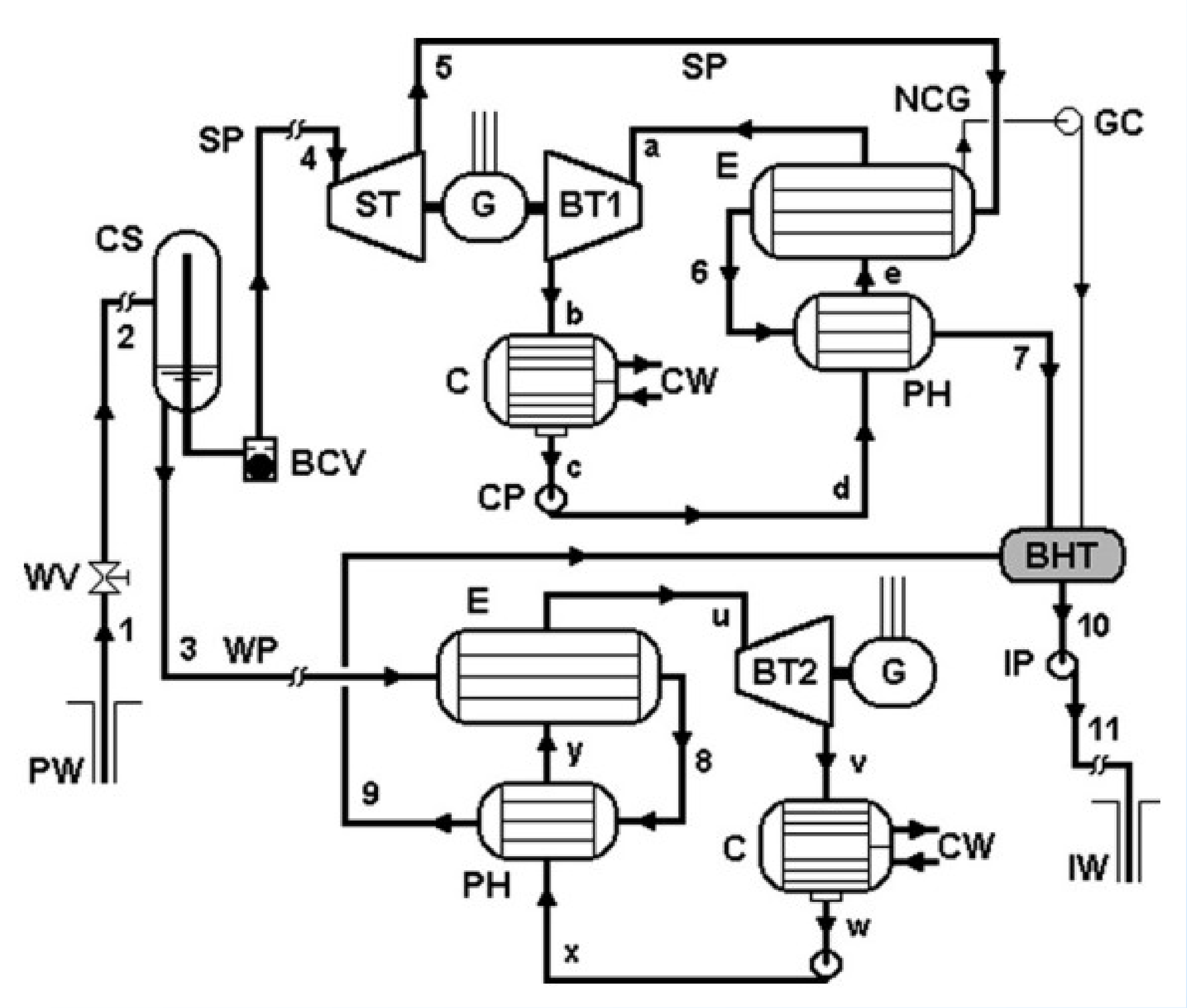
c) Specific work of the feed pump: $w_p = h_5 - h_4 = 3.06$ kJ/kg

d) Heat transferred to the working fluid: $q_{IN} = h_1 - h_5 = 487.50$ kJ/kg

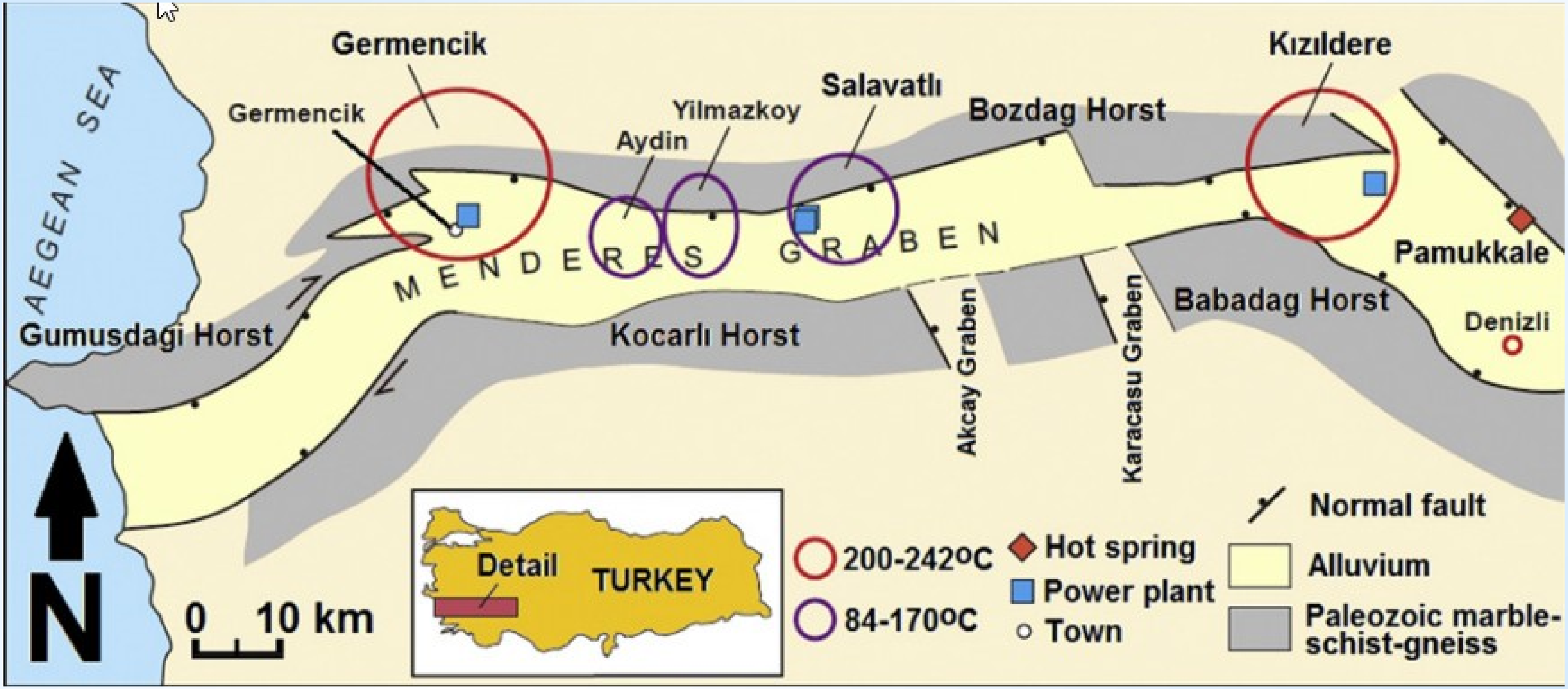
e) Cycle thermal efficiency: $\eta_{th} = (w_t - w_p)/q_{IN} = 1 - (q_C/q_{IN}) = 15.1$ %.

f) Mass flow rate of i-C5H12: $m_{i\text{-}C5} = W_{net} / (w_t - w_p) = 1200 / 73.62 = 16.3$ kg/s

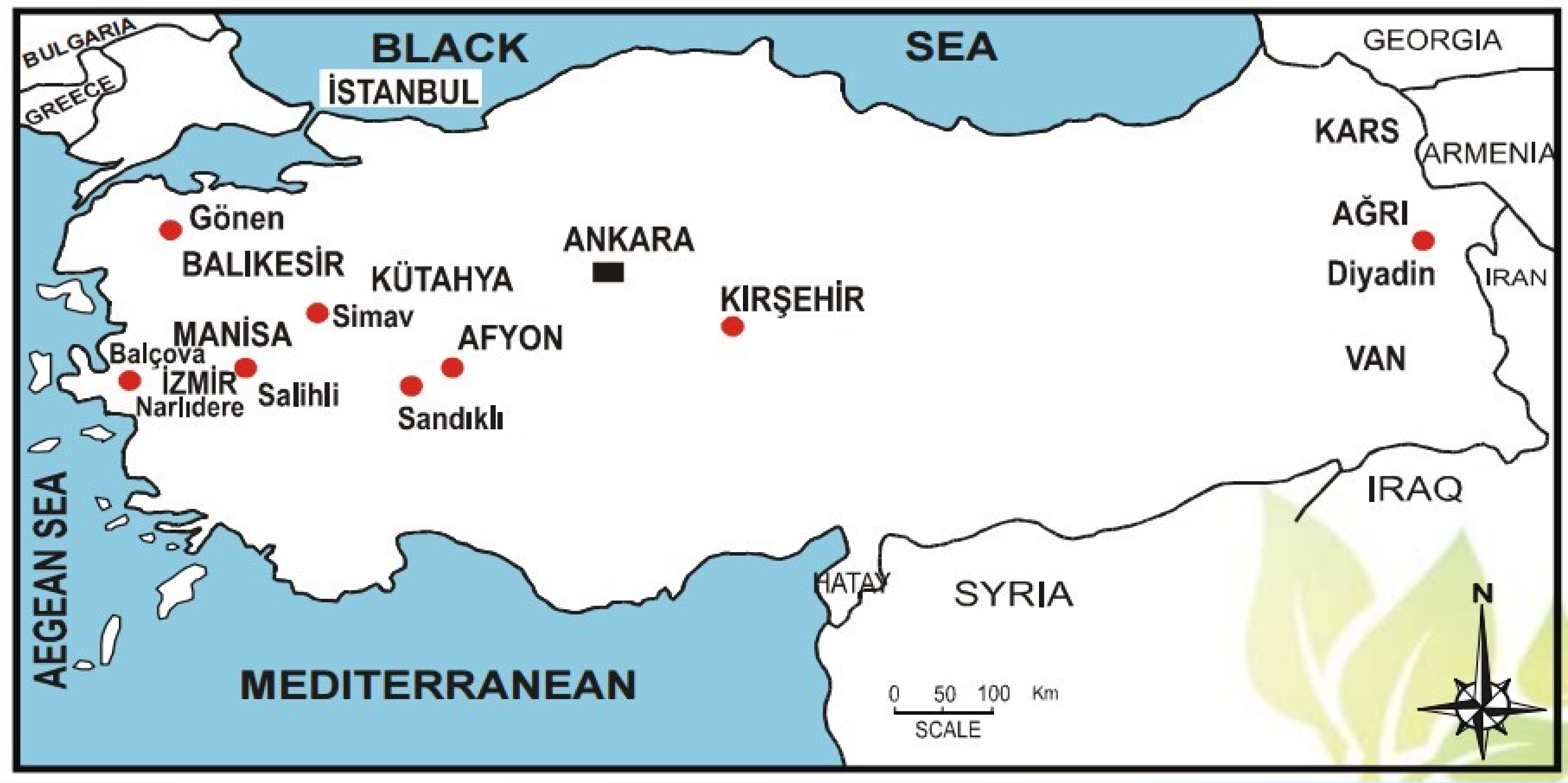
Integrated Single-flash / Binary PP



Upper Mahiao integrated flash-binary 125 MW power plant, Leyte Island, Philippines



A horst is a raised block of the Earth's crust that has lifted or stayed stationary while the land around it (graben) has sunk.



BULGARIA
GREECE
BLACK
SEA
İSTANBUL
GEORGIA
KARS
ARMENIA
AĞRI
Diyadin
IRAN
Gönen
BALIKESİR
KÜTAHYA
ANKARA
KIRŞEHİR
Simav
MANİSA
AFYON
Balçova
İZMİR
Narlıdere
Salihli
Sandıklı
VAN
IRAQ
AEGEAN SEA
HATAY
SYRIA
N
0 50 100 Km
SCALE
MEDITERRANEAN

District heating in Turkey started in 1987 heating 1500 households. Later the system was expanded to 2500 subscribers. By 2007, Turkey had 20 district heating systems working with geothermal energy. Of these district heating systems, the one in Sarayköy is heated by the waste heat coming from bottoming binary power plant at Kızıldere.

Next table shows that low temperature geothermal resources are mostly used in district heating with the exception of Balçova and Simav, which have medium grade resources that could also have been used for power generation purpose. About 6 million square meter space are heated by district heating with a capacity of 395 MW_{th}.

District heating	Year	Capacity, MW_t
Gönen, Balıkesir	1987	18.4
Simav, Kütahya	1991	36.6
Kırşehir	1994	5.6
Kızılcahamam, Ank.	1995	17.6
Balçova, İzmir	1996	77.7
Afyon	1996	33.9
Kozaklı, Nevşehir	1996	19.2
Sandıklı, Afyon	1998	29.3
Diyadin, Ağrı	1998	8.4
Salihli, Manisa	2002	25.1

District heating	Year	Capacity, MW_t
Dikili, İzmir	2008	10.0
Sarayköy, Denizli	2002	27.2
Edremit, Çanakkale	2004	16.9
Bigadiç, Balıkesir	2006	10.0
Bergama, İzmir	2006	10.0
Kuzuluk, Sakarya	1994	11.2
Armutlu, Yalova	2000	4.8
Güre, Balıkesir	2006	8.5
Sorgun, Yozgat	2007	20.9
Yerköy, Yozgat	2007	3.3

Çizelge 2. Yenilenebilir enerjide Türkiye-dünya kurulu güçlerinin karşılaştırılması.

Teknoloji	Dünya Kurulu Kapasite 2014 (GW_e)	Türkiye Kurulu Kapasite 2014 (MW_e)	Türkiye/Dünya Oranı, %	2025
Rüzgar	318	3424	1.1	13391 MWe
Güneş PV	139	120	0.9	22760 MWe
Jeotermal	12.0	410	3.4	1734 MWe

Çizelge 3. Türkiye'nin dünya jeotermal kurulu gücündeki payı.

	Yıllar	Türkiye	Dünya	Türkiye/Dünya, %
Kurulu Jeotermal Elektrik Gücü, MW_e	2000	17.8	7972	0.2
	2005	17.8	8933	0.2
	2006	25	9 000	0.3
	2010	99	10 715	0.9
	2014	410	12 bin	3.4

YEKDEM: Renewable energy support scheme, in effect since 2011, ending in 2020

Under the YEKDEM program, renewable energy plants get feed-in tariffs. The stimulus is available for wind, hydro, geothermal, biomass, and solar.

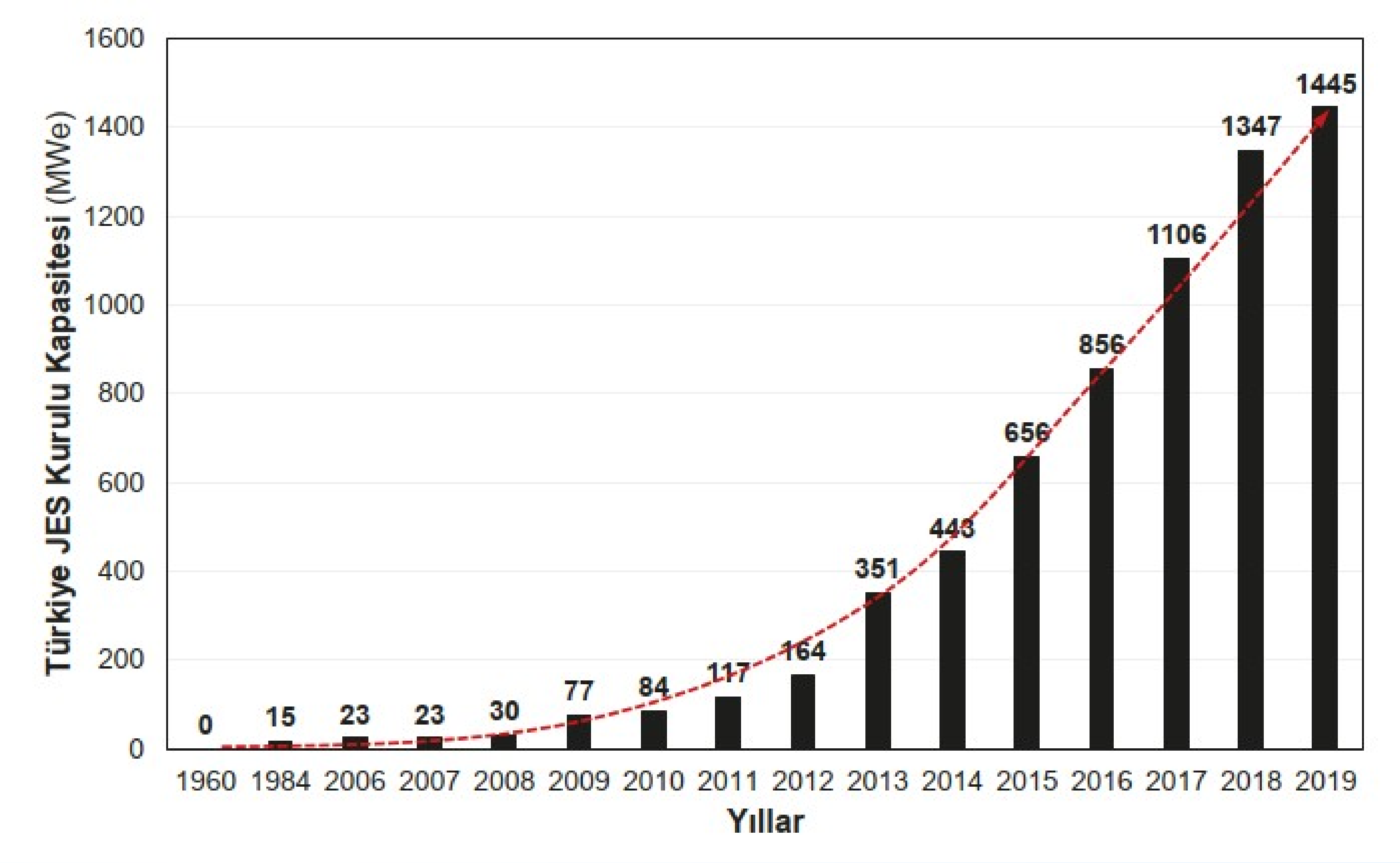
A total of 777 facilities (as of 2019) with an installed capacity of 20.92 GW received financial backing under YEKDEM and produced 76.67 TWh of electricity.

The scheme launched in 2011 envisages support of USD 0.073 per kWh for wind parks and hydropower plants, USD 0.105 per kWh for geothermal facilities and USD 0.133 per kWh for solar power and biomass-fueled plants.

Turkey has another incentives mechanism, called YEKA (Renewable Energy Resource Zones), launched in 2016. It encourage the development and use of domestic manufacture of equipment.

Feed-in Tariff:

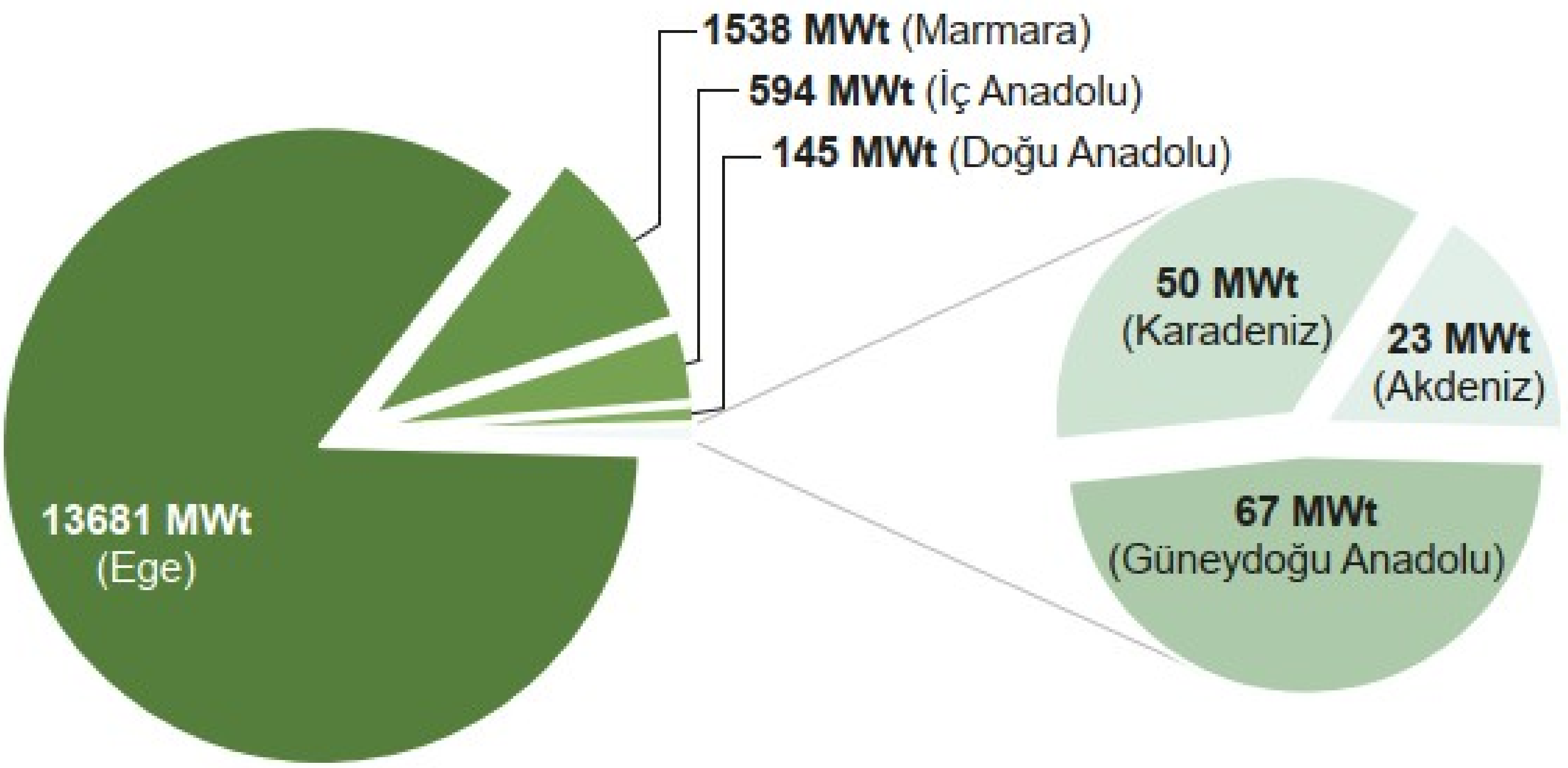
- Guaranteed grid access, meaning energy producers will have access to the national grid of electricity distribution in the country.
- Offer of long-term contracts, typically in the range of 15 to 25 years.
- Offer guaranteed, cost-based purchase prices, meaning that energy producers are paid in proportion to the resources and capital expended in order to produce the energy.


Türkiye JES Kurulu Kapasitesi (MWe)
1600
1400
1200
1000
800
600
400
200
0
0
15
23
23
30
77
84
117
164
351
443
656
856
1106
1347
1445
1960
1984
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Yıllar

Jeotermal Kaynakların Değerlendirilmesi		
Elektrik üretimi	1557,71	MWe
Merkezi ısıtma (Şehir, Konut)	137650(*)	Konut Eşdeğeri (1223 MWt)
Kaplıca, termal oteller, devre mülk ısıtılması	46400(**)	Konut Eşdeğeri (420 MWt)
Sera ısıtması	4350	Dönüm (820 MWt)
Jeotermal ısı pompası	7,6(**)	MWt
Tarımsal kurutma	1,5(**)	MWt
Soğutma	0,35	MWt
Toplam jeotermal ısı kullanımı	3487,1	MWt
Kaplıca, termal tesis ve spada balneolojik kullanım	450(**)	Adet (1205 MWt)
Karbondioksit üretimi	400000(**)	Ton/Yıl

Kaynak: (*) Enerji Kentleri Birliği, (**) Türkiye Jeotermal Derneği

Geothermal Potential



Notes from the Geothermal Seminar, İzmir, 18 - 19 April 2019

Total installed capacity of electricity generation in Turkey is approximately 80000 MW_e, as of the end of 2018.

The installed capacity of electricity generation from geothermal energy in Turkey is over 1300 MW_e, as of the end of 2018.

This is up from about 800 MW_e two years ago. This may be a world record high increase.

One reason is that the government incentive will be over in 2020, and the companies are hurrying up to meet the deadline.

There are 57 geothermal power plants producing electricity and using more than 50000 tons per hour geothermal fluid (brine).

By the year 2020, the installed capacity is expected to reach about 2200 MW_e, maximum being about 2600 MW_e.

The actual electricity production is 70 % of the installed capacity, on the average.

The cost of a 25 MW_e geothermal power plant is 80-100 million US dollars.

Geothermal energy is not as «green» as claimed if it is not used properly in all stages of planning, drilling, construction, operation, and accident handling.

Features of geothermal installations in Turkey, producing electricity or hot water for direct use:

* Water dominated

* Binary cycle is used in the power plants

* Unusually high CO_2 content

* CO_2 is released to the atmosphere causing

- pressure drop in the reservoir, which means power drop
- Soil becomes acidic, effecting crops (figs)

* Dissolved CO_2 in the brine could have been used to produce CO_2 ice