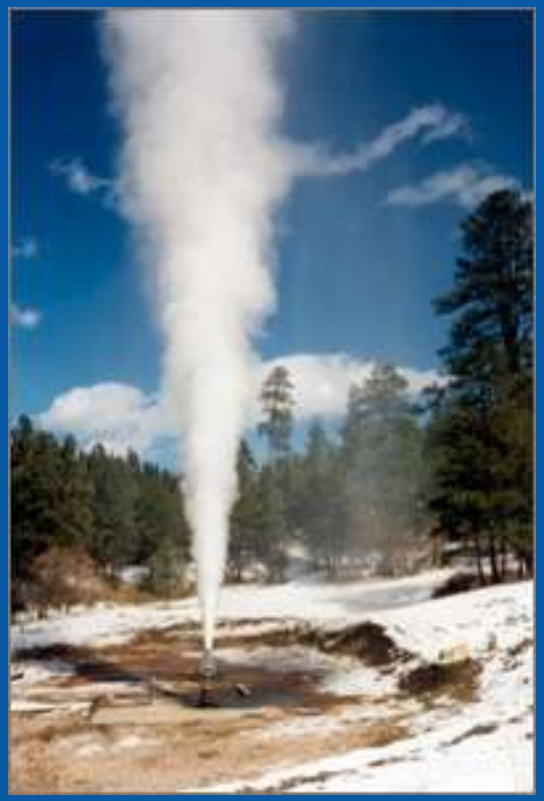
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Geothermal Energy 101: Characteristics, Development, and Utilization of Geothermal Resources



John W. Lund

National Renewable Energy Laboratory

Golden, Colorado

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

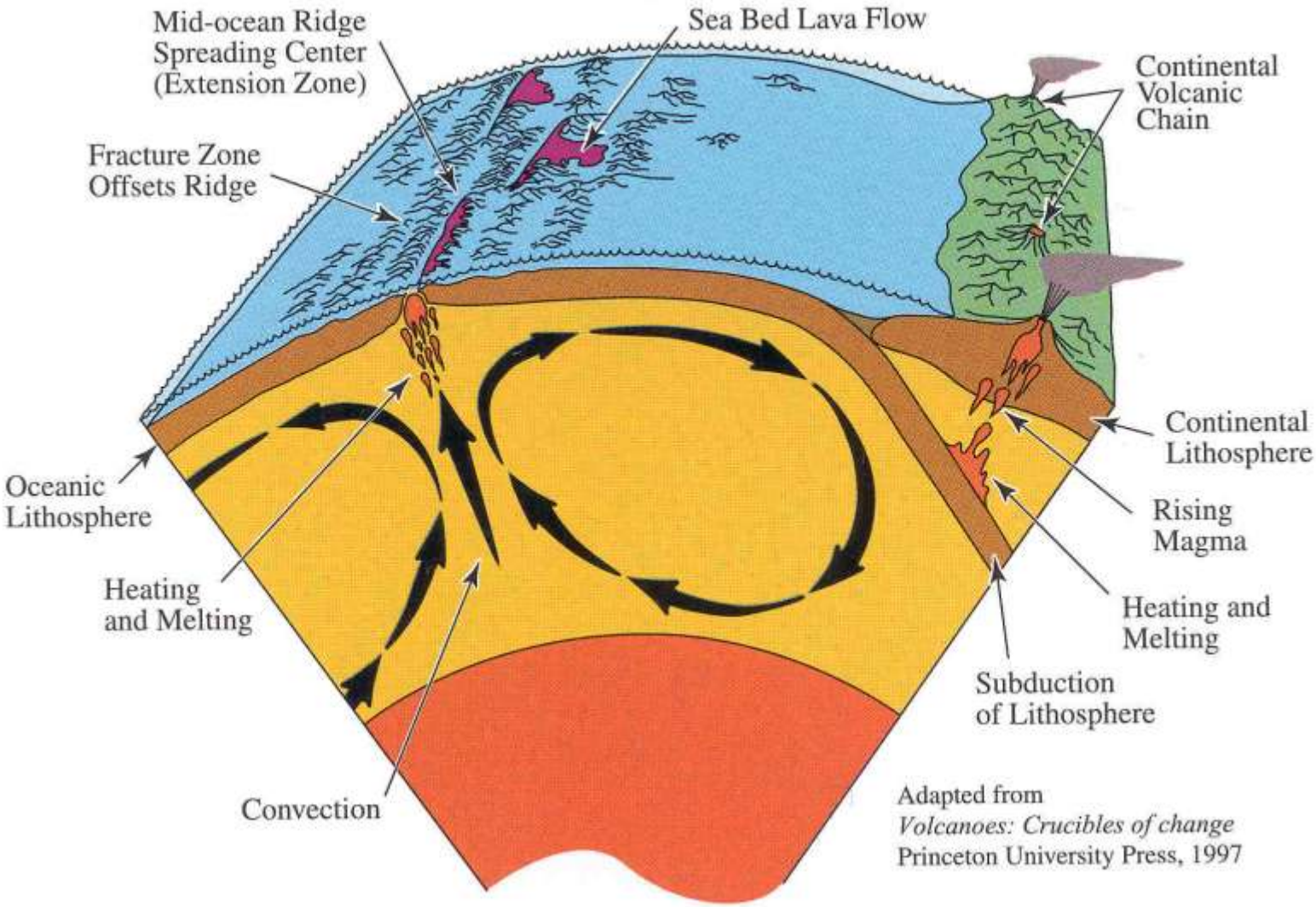
What Is Geothermal Energy?

The internal energy of the earth

- Usually from the radioactive decay of potassium, thorium, and uranium
- Often associated with buried magma bodies
- Characterized on the surface by volcanic activity, hot springs, fumaroles, and geysers
- Found most often along continental plate boundaries

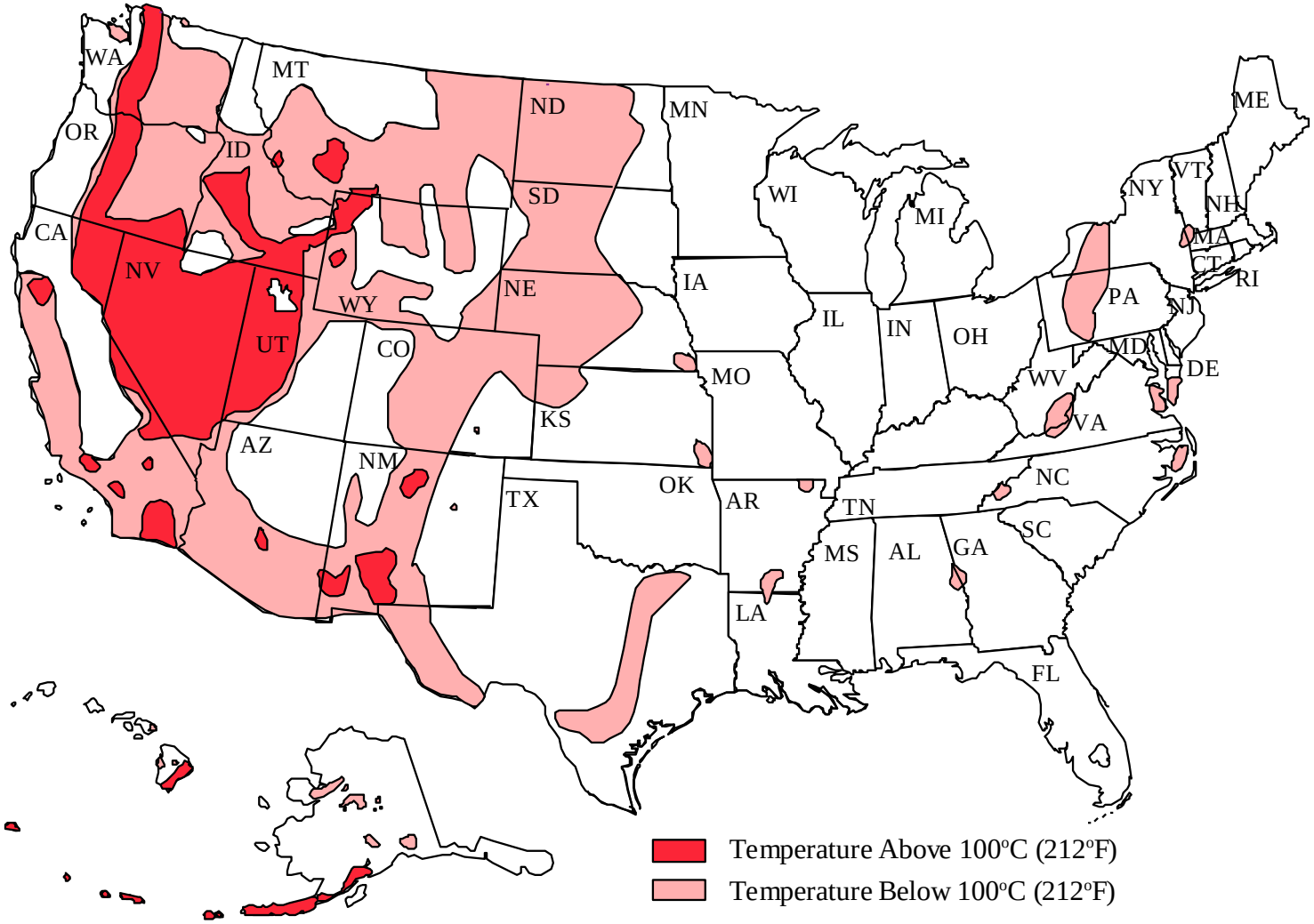
Available to man as heat from heated rocks, water, or steam

Earth Dynamics



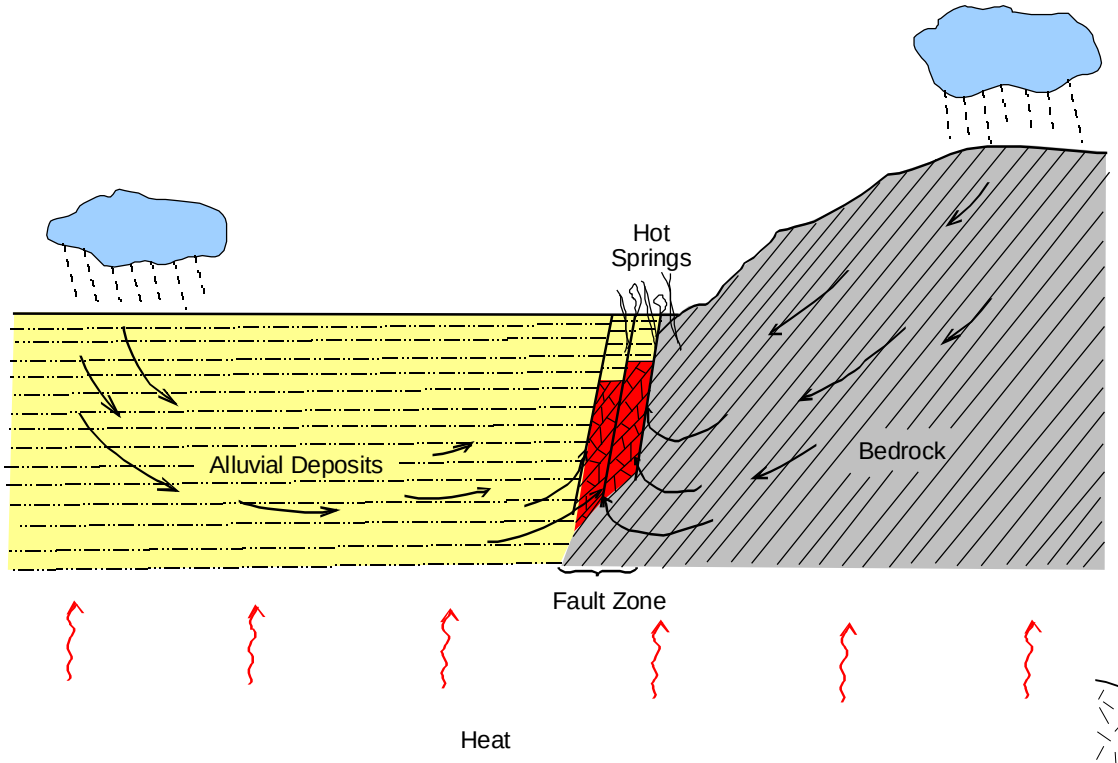
Adapted from
Volcanoes: Crucibles of change
Princeton University Press, 1997

U.S. Geothermal Resources



Geothermal Manifestations

Geysir, Iceland



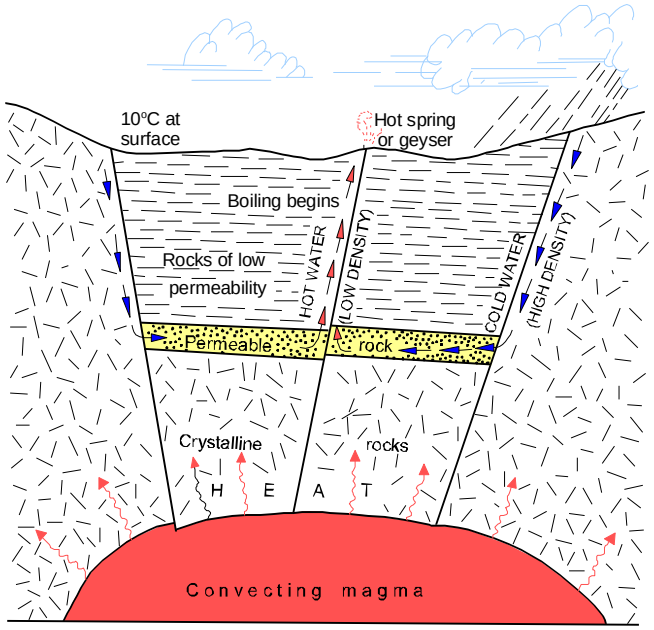
180–600˚F

High silica

High chloride

Self-sealing

100–1,000 ppm

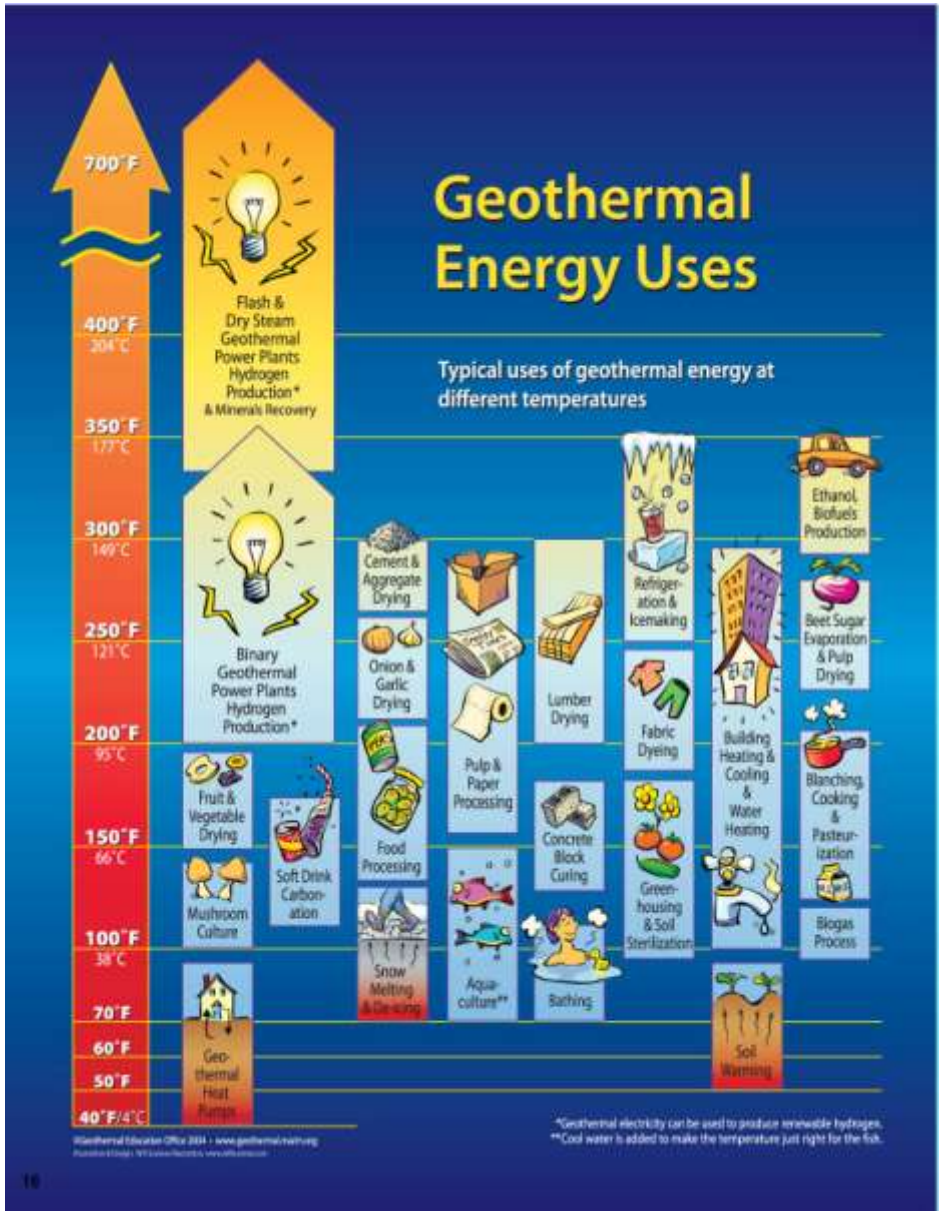


Hydrothermal system

Hot water dominated

“Wet steam”

70–90% water



Electric power generation

Direct use

Heat pumps

Geothermal History

Geothermal electric power used since 1904
- Prince Conti—Larderello, Italy

Geothermal direct-use used for over 10,000 years
- Early inhabitants of the world
- Bathing and cooking

District heating and industrial uses—1700s
- Chaudes-Aiges, France
- Larderello, Italy

Geothermal (ground-source) heat pumps described in 1852 by Lord Kelvin (England)

First installation: Indianapolis, Indiana in 1945

The Geysers, USA

Larderello, Italy

Electric Power Generation

Types of Utilization

Noncondensing plants

Dry steam plants

Wet steam or flash plants

Binary or organic Rankine cycle plants

Combined cycle plants

Hybrid plants

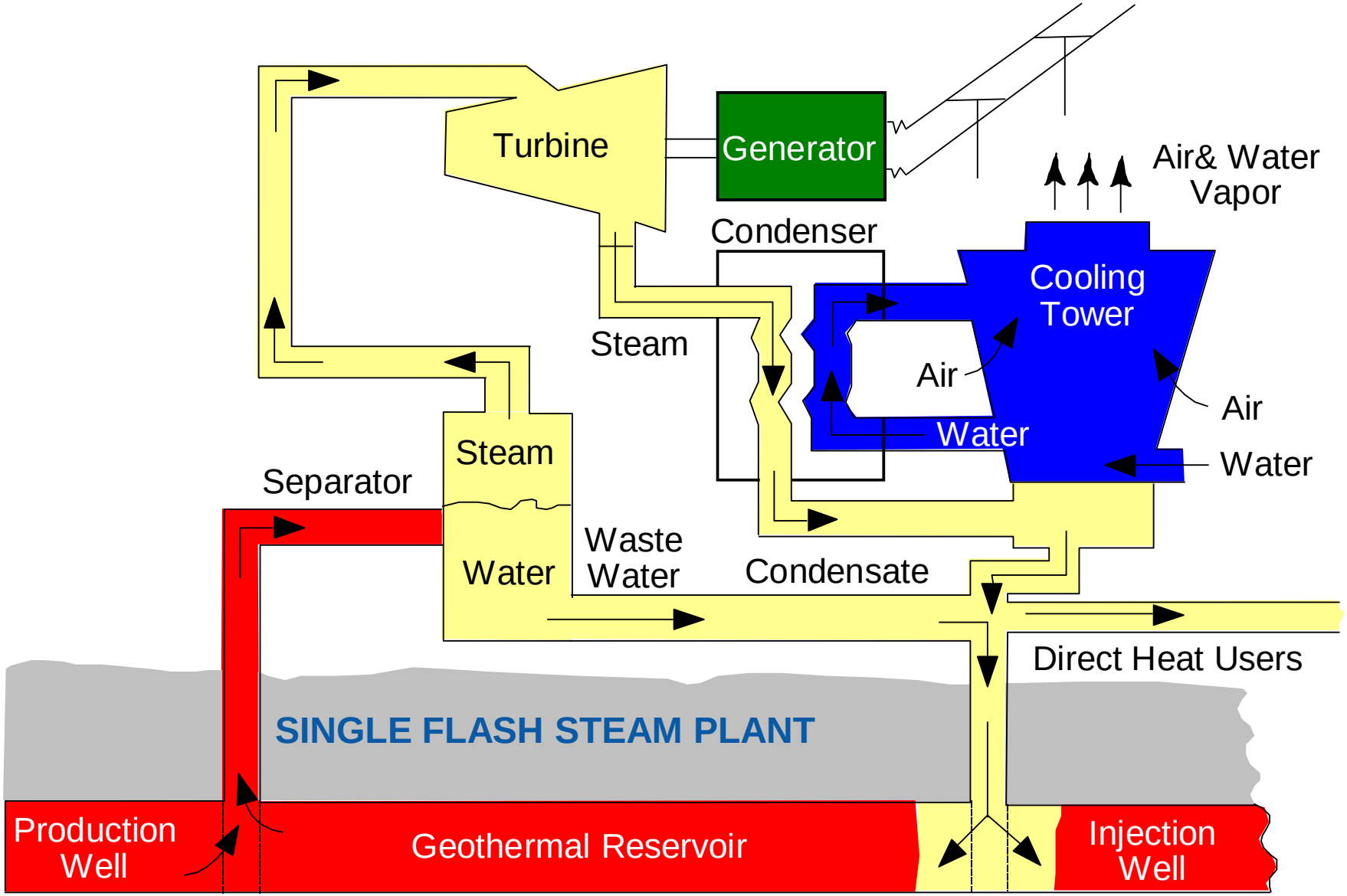
Total flow plants

Drilling at The Geysers
12,000 ft.+

Turbine-generator sets

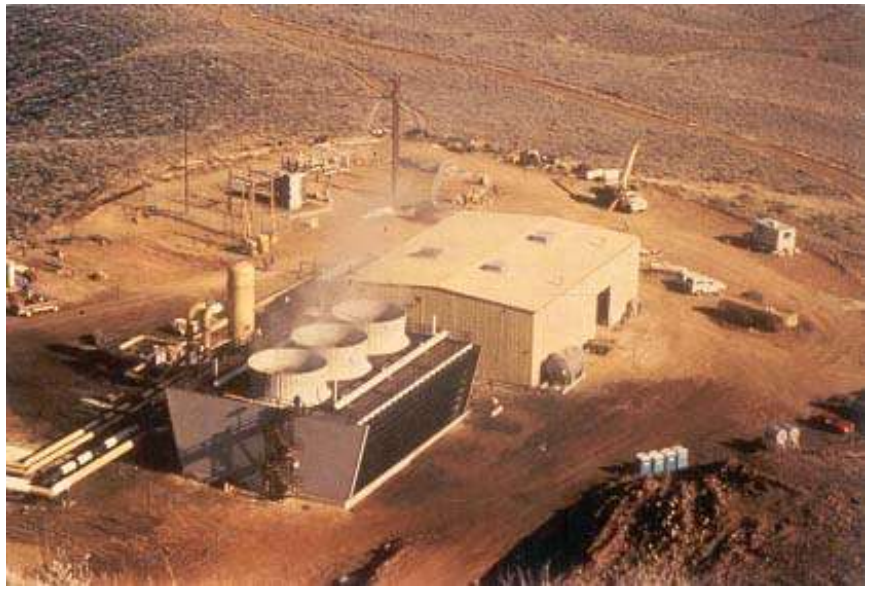
Wet Steam Plants

- Most common type of fields
  - Superheated hot water under pressure
  - Artesian flow
- Single flash plants (most common)
- Double flash plants
  - 15 to 20% more output
  - More common in the USA


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

Flash steam separator

Flash steam plants



Binary Plants

Conventional organic Rankine cycle

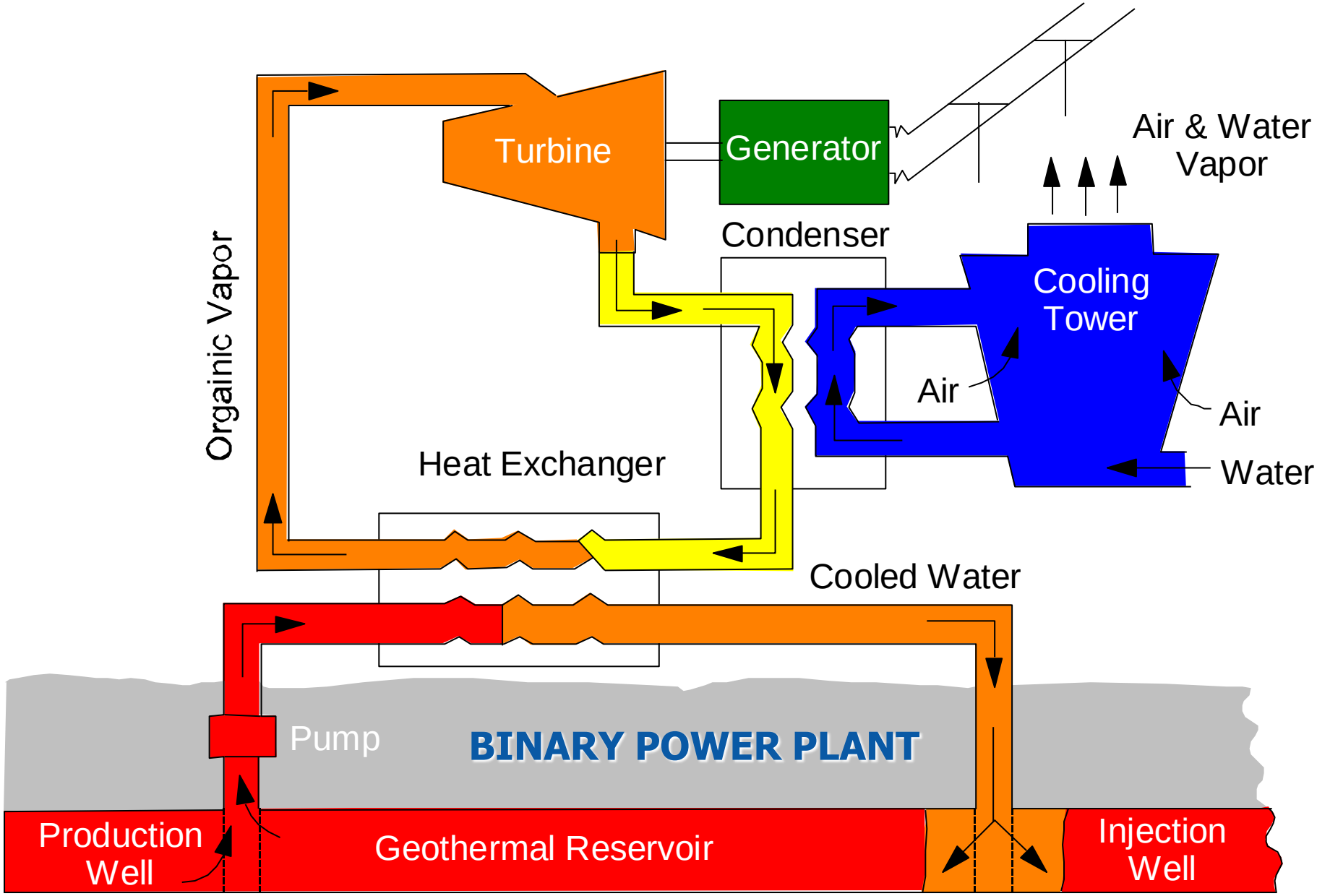
Energy from geothermal fluid transferred through a heat exchanger to a secondary working fluid—hydrocarbon

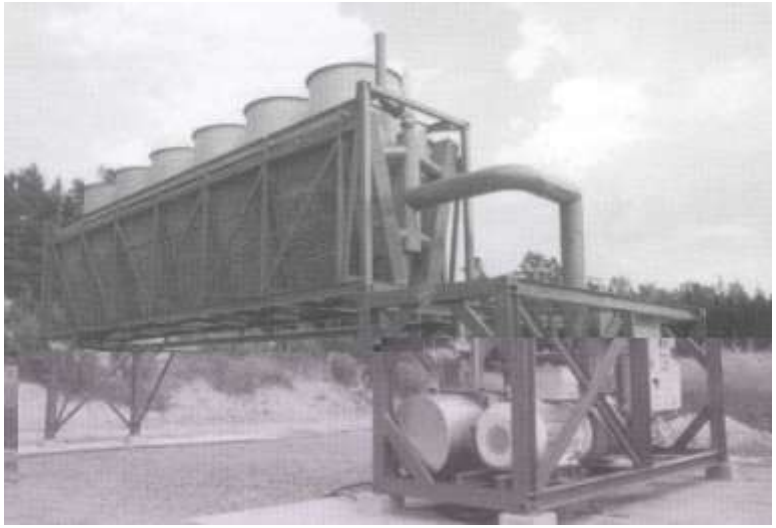
Geothermal fluid does not come in contact with the moving parts of the power plant, thus eliminating corrosion/scaling problems

Wabuska, Nevada

750 kWe

220ºF–855 gpm


Turbine
Generator
Air & Water
Vapor
Condenser
Cooling
Tower
Orgainic Vapor
Air
Air
Water
Heat Exchanger
Cooled Water
Pump
BINARY POWER PLANT
Production
Well
Geothermal Reservoir
Injection
Well



250 kW, Austria

1 MWe, Tibet

Binary Plants

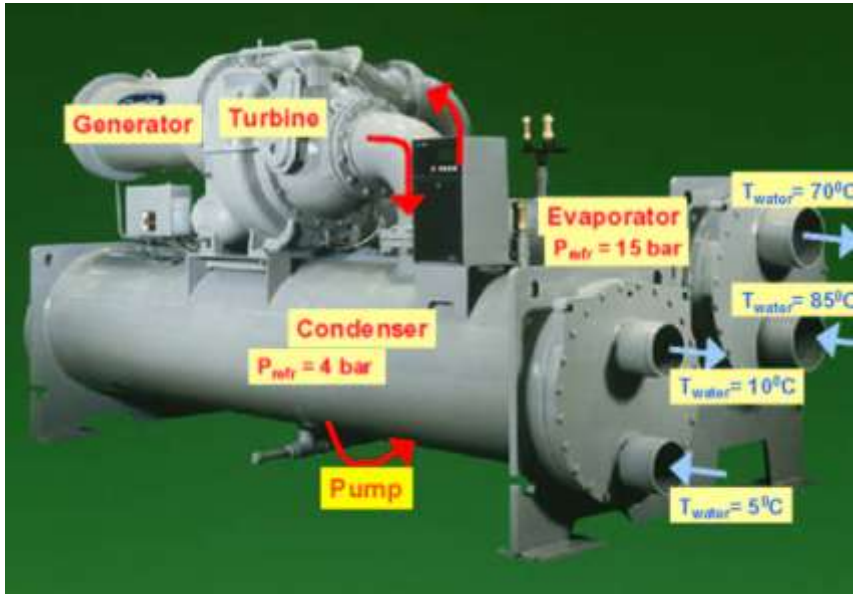
2 x 375 kW, CA

750 kW, NV

Chena Hot Springs, Alaska

United Technologies Corporation – Pratt & Whitney

200 kWe carrier converted vapor-compression cycle chiller to a Rankine cycle that uses R-134a refrigerant



Installed in July 2006

Lowest temperature geothermal use for power generation in the world

165°F resource and 40°F cooling water

What Is Direct Use: Heating and Cooling

- Swimming, bathing and balneology
- Space heating and cooling
  - Including district (heating/cooling) systems
- Agriculture applications
  - Greenhouse heating
- Aquaculture applications
  - Fish pond and raceway heating
- Industrial processes
  - Including food and grain drying
- Geothermal heat pumps

Advantages of Direct Use of Geothermal

Can use low to intermediate temperature resources (<300ºF)

These resources are more widespread (80 countries)

Direct heat use (no conversion, high efficiency)

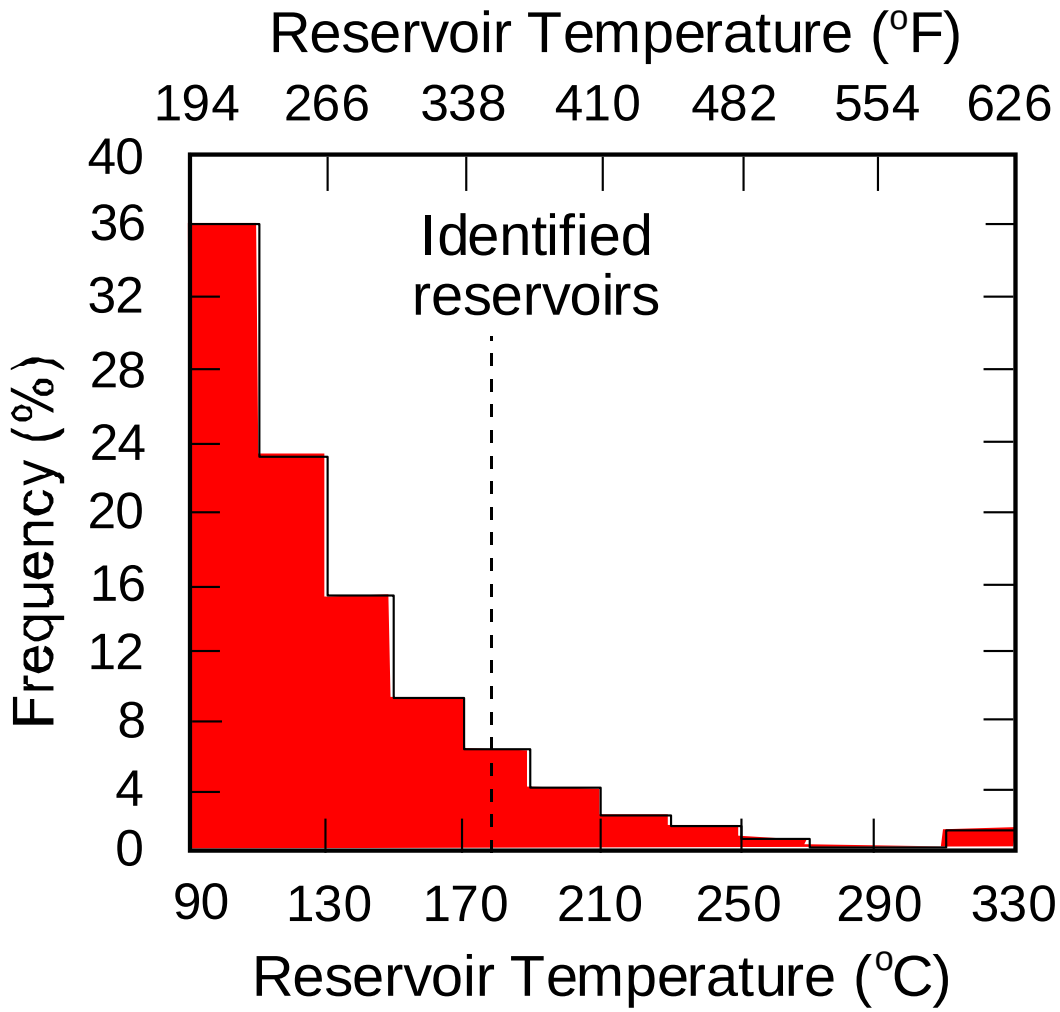
Use conventional water-well drilling equipment

Use conventional, off-the-shelf equipment

(allow for temperature and chemistry of fluid)

Minimum start-up time

Frequency vs Reservoir Temperature



Data taken from USGS Circular 790

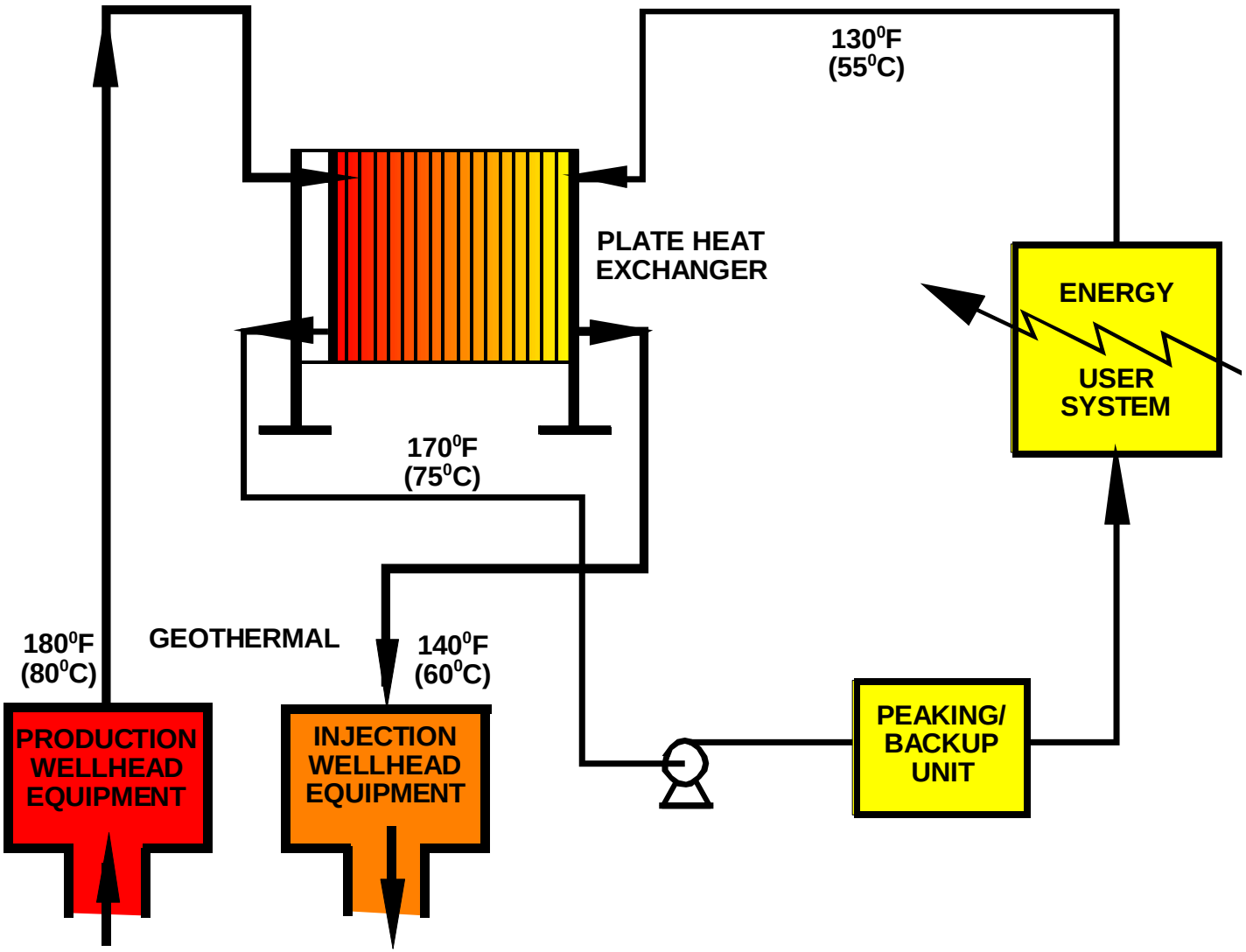
Advantages of Direct Use of Geothermal

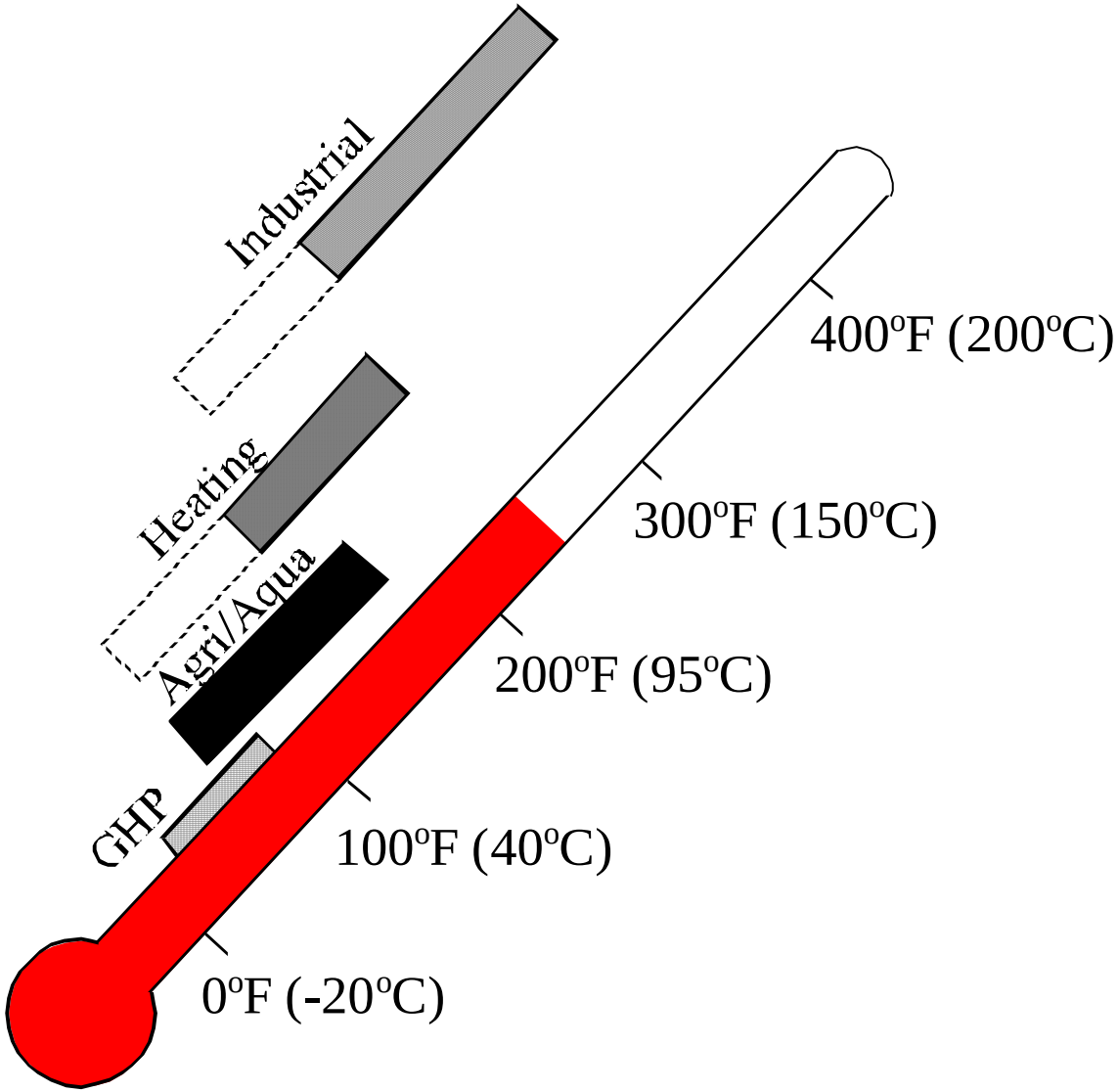
Can be used on a small scale (“mom and pop operation”)

- Individual home
- Single greenhouse
- Single aquaculture pond

Can also be a large-scale operation

- District heating
- Food, lumber, and mineral ore drying


130⁰F
(55⁰C)
PLATE HEAT
EXCHANGER
ENERGY
USER
SYSTEM
170⁰F
(75⁰C)
180⁰F
(80⁰C)
GEOTHERMAL
140⁰F
(60⁰C)
PRODUCTION
WELLHEAD
EQUIPMENT
INJECTION
WELLHEAD
EQUIPMENT
PEAKING/
BACKUP
UNIT



Temperatures for Direct-Use Applications

Swimming, Bathing, & Balneology (Spas)

These are normally provided for:

- Exercise and fitness
- Medical reasons/health
- Relief from stress; relaxation

Typical temperature range: 75ºF–104ºF

Geothermal resource: 15ºF–25ºF above pool temperature

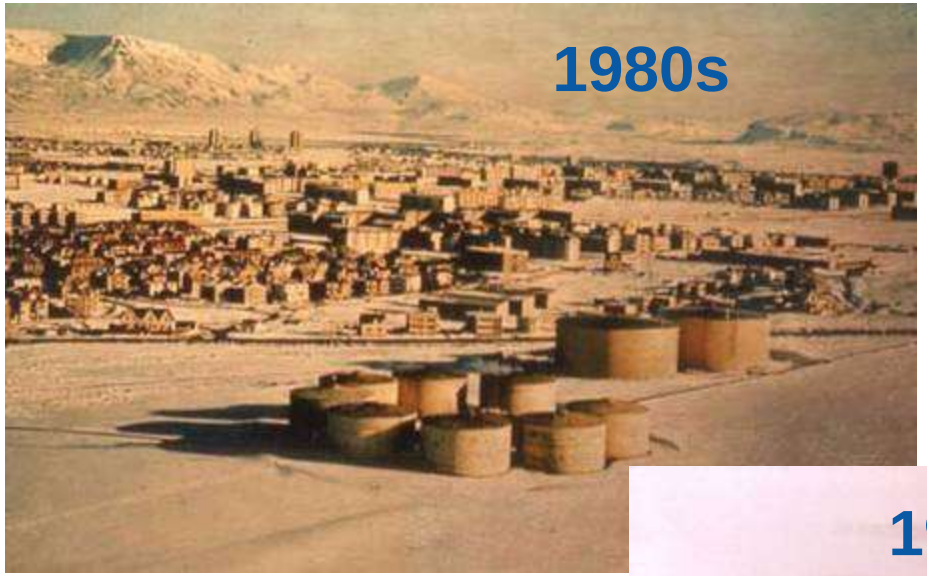
Soaking & Swimming in Geothermal Waters

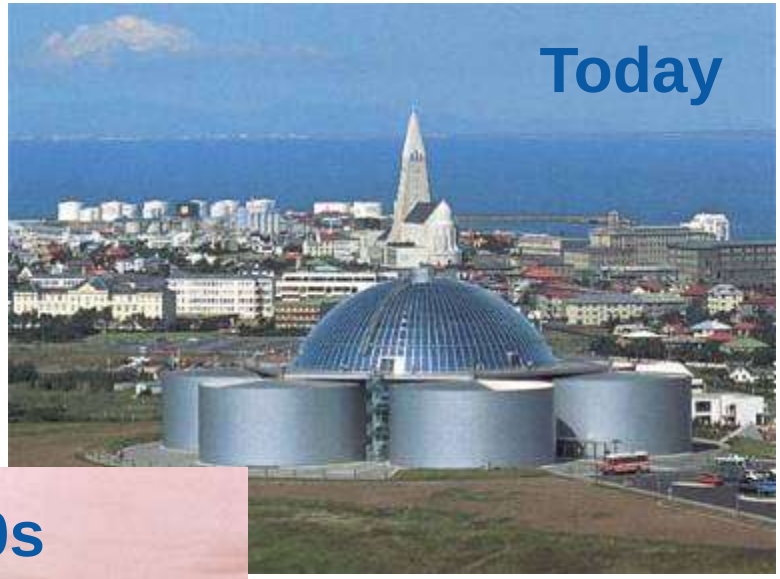
Space Heating and Cooling

District Heating Example

Reykjavik, Iceland

- Started 1930
- 200,000 people
- 190° to 260°F water—supplied at 175°F
- Adequate to 15°F
- 925 MWt (peak)
- 62 wells
- Large storage tanks for peaking
- Oil-fired booster station


1980s


Today

1930s

Agribusiness Applications

- Greenhouse heating (flowers, vegetables, tree seedlings)
  - Up to 35% savings due to heating costs
- Animal pen heating and cleaning
- Soil warming
- Crop irrigation
- Mushroom raising
- Soil and mulch sterilization
- Aquaculture
  - 50% increase in growth rate
  - Catfish, shrimp, tilapia, eels, tropical fish

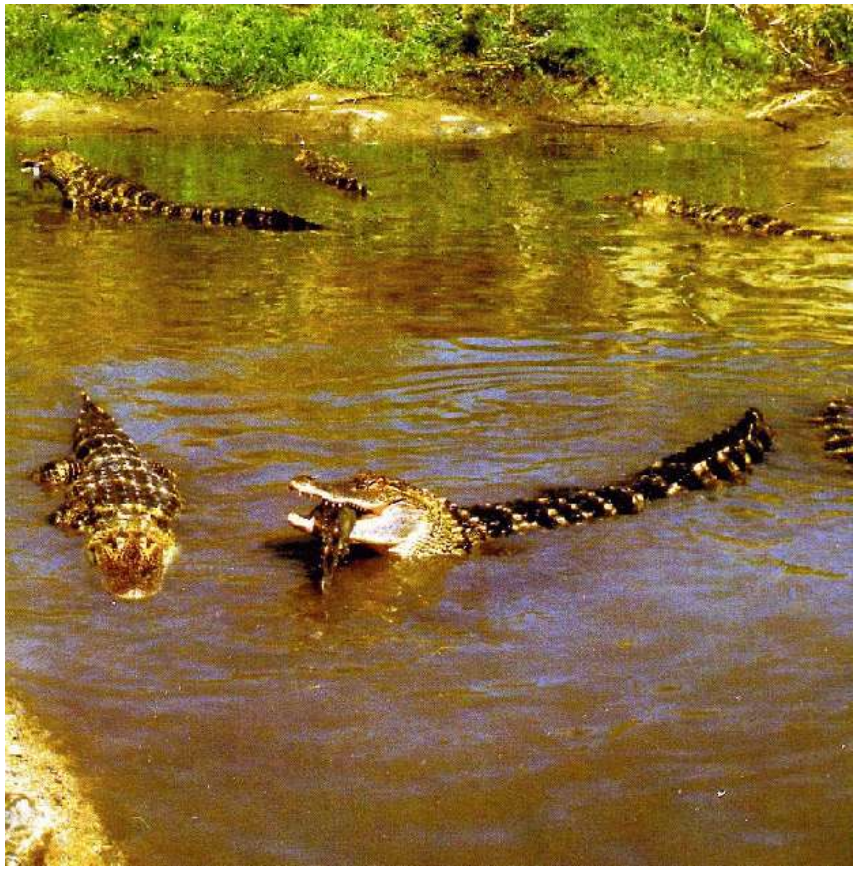
Agribusiness Applications (cont'd)

Must consider heavy metals, fluorides, chlorides, arsenic, and boron in fluid

Can produce CO_2 for greenhouses to improve growth

- Iceland
- New Zealand

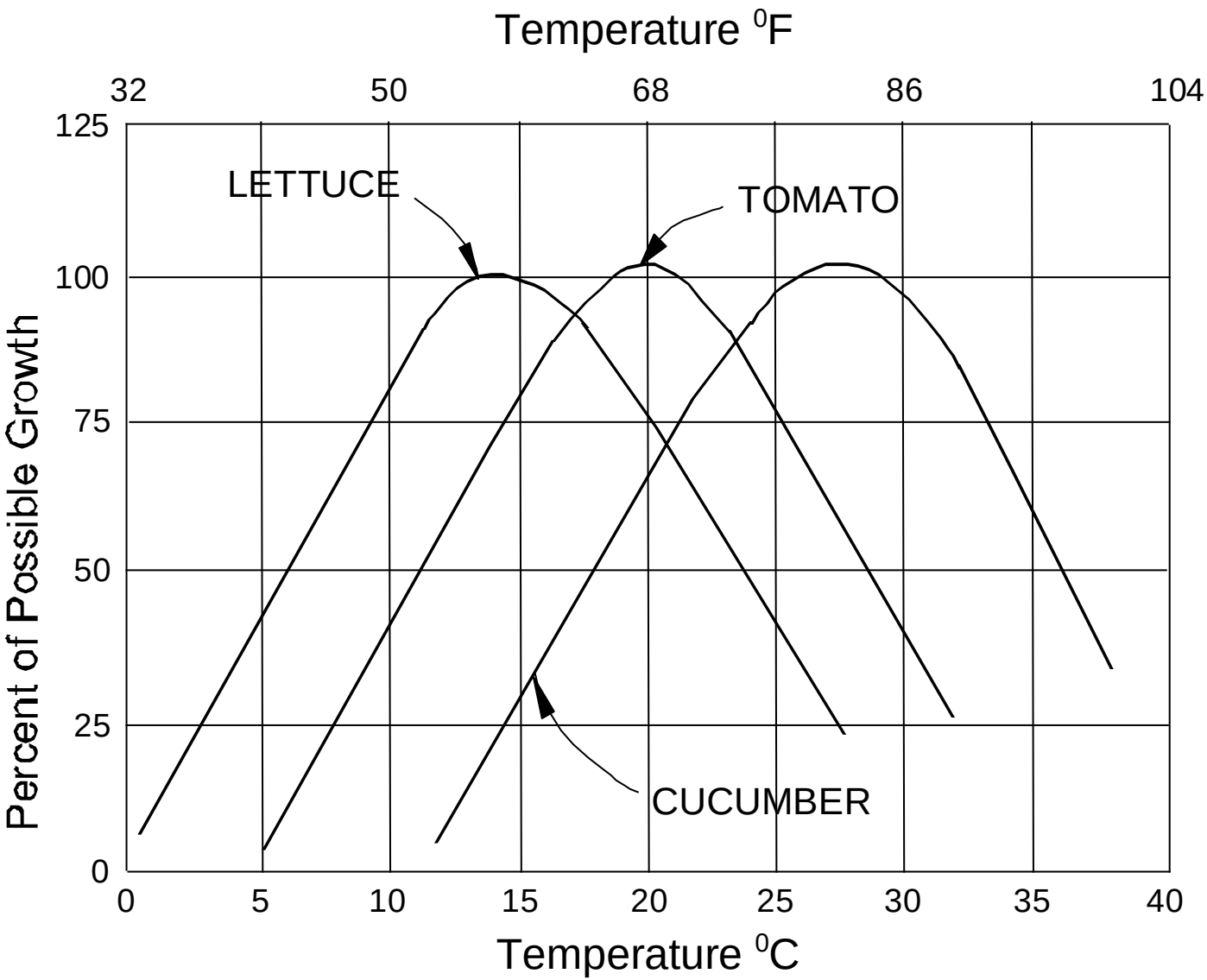
Only low geothermal temperature needed (>105°F)



59ºC
geo.

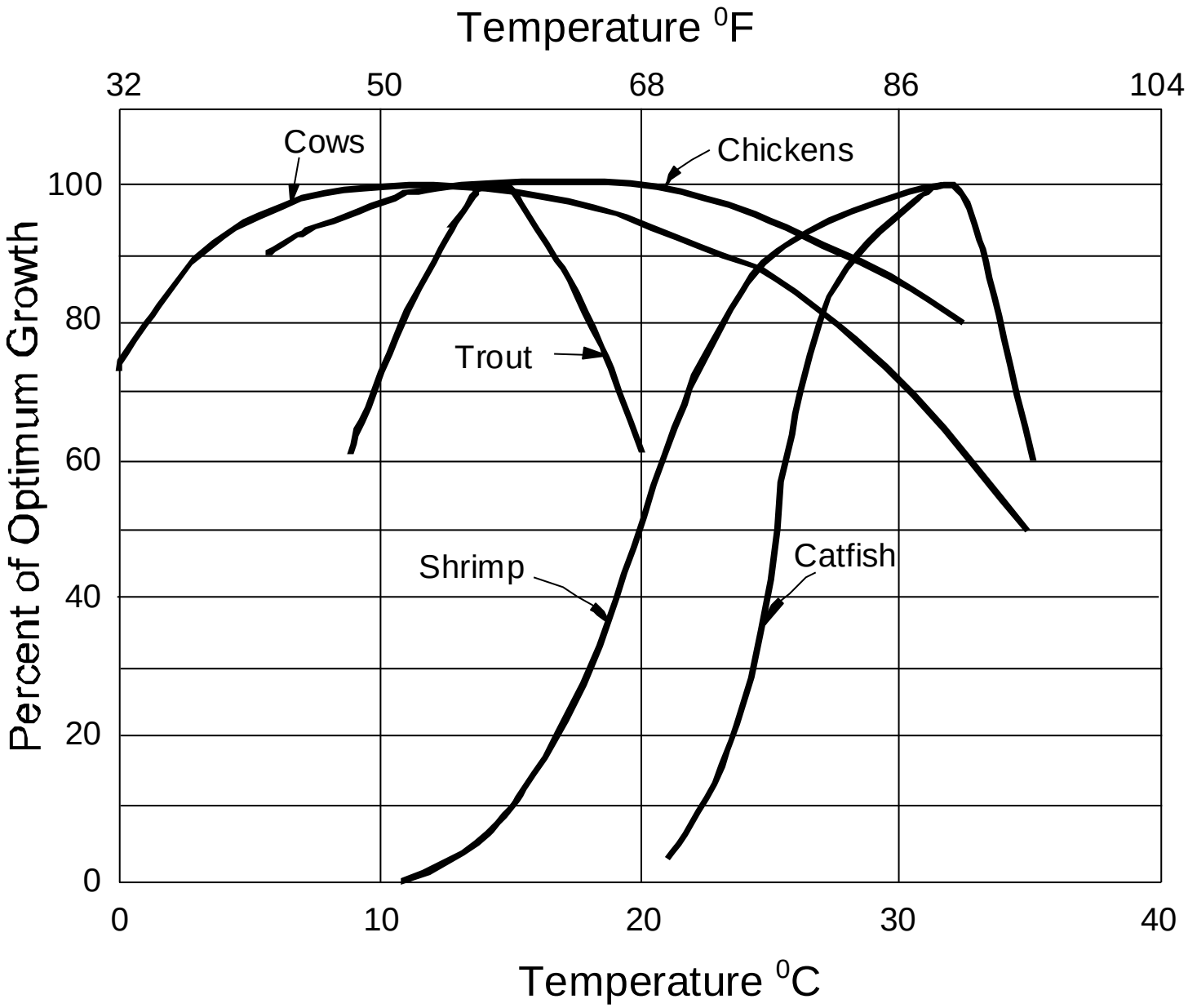
14 kg/h
4t/yr
dried

Tomato drying—Greece


Temperature 0F
32
50
68
86
104
125
100
75
50
25
0
Percent of Possible Growth
LETTUCE
TOMATO
CUCUMBER
0
5
10
15
20
25
30
35
40
Temperature 0C

Iceland

Hungary


Temperature 0F
32
50
68
86
104
Cows
Chickens
Trout
Shrimp
Catfish
100
80
60
40
20
0
Percent of Optimum Growth
0
10
20
30
40
Temperature 0C

Aquaculture Examples

New Zealand

Giant freshwater prawns—*Macrobrachium rosenbergii*

Refrigeration

Lithium bromide system (most common—uses water as the refrigerant)

- Supplies chilled water for space and process cooling—above the freezing point
- The higher the temperature, the more efficient (can use geothermal fluids below 212°F; however, >240°F is better for 100% efficiency)

Ammonia absorption used for refrigeration below freezing
Normally large capacity and requires geothermal temperatures above 250°F

Oregon Institute of Technology—Chiller

192ºF producing 45ºF chilled water @ 600 gpm

1 MWt installed—500 kWt net

Alaska

Aurora Ice Museum—
Chena Hot Springs

33 kW absorption chiller using 86 gpm of 165ºF geothermal water and 40ºF river water at 80 gpm producing 25ºF inside

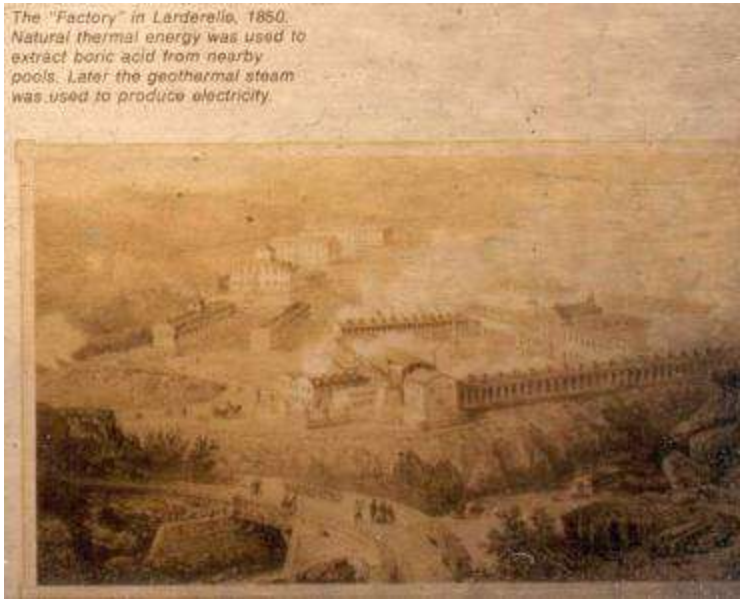
Industrial Applications

Larderello, Italy: (oldest) boric acid and borate compounds processed since 1790

Kawerau, New Zealand: pulp, paper, and wood processing

Myvatn, Iceland: Diatomaceous earth drying

Nevada, USA: Vegetable dehydration (onion) and gold extraction (heap leaching)



Industrial Application Examples

More Industrial Applications

Heat Pumps

Used for both heating and cooling

Heated capacity of 3 kWt to 1,500 kWt (1 to 430 tons)

- Typical home: 3–4 tons

43 countries

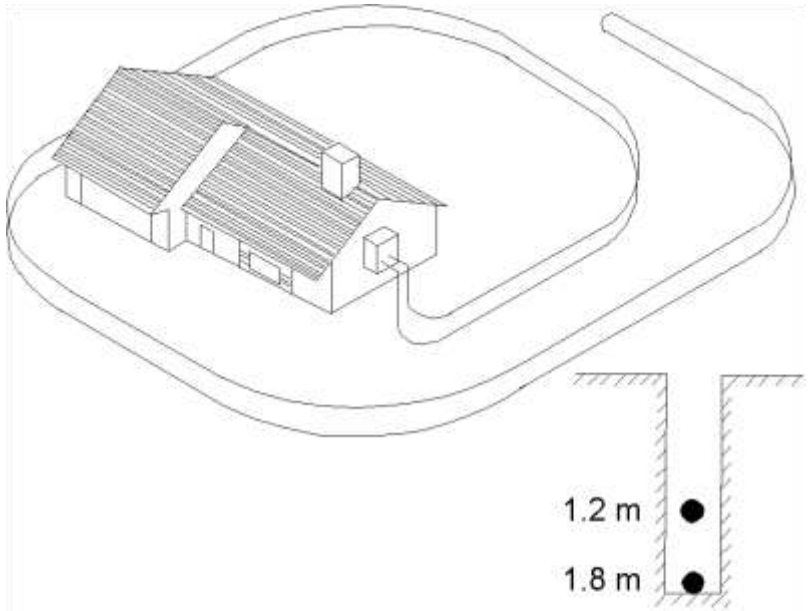
>2.7 million units installed worldwide (1 million in the U.S.)

Growing at the rate 15%–20%/year

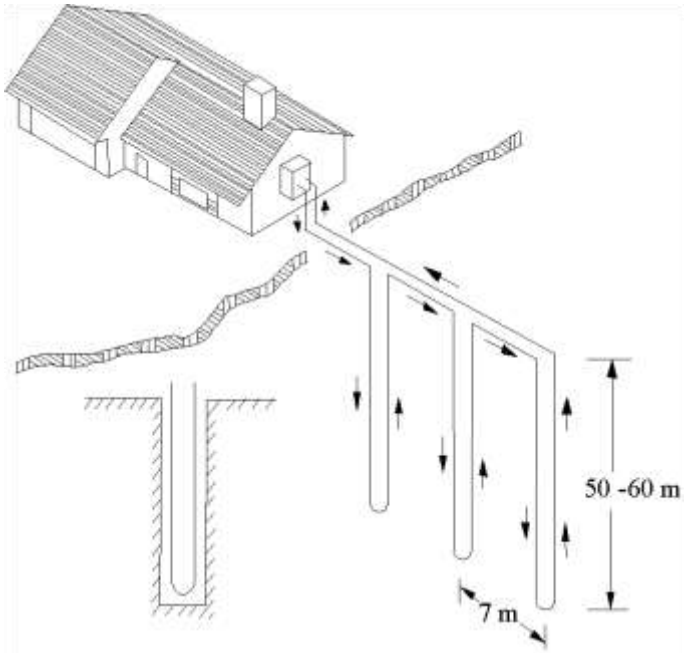
COP of 4 (75% savings in electricity)

Heat Pumps (Cont'd)

- Ground source and geothermal heat pumps (GSHP or GHP)
  - Uses 40–90°F ground temperature
- 50%–100% more efficient than air source, since it uses a constant temperature resource
- Ground coupled
  - Horizontal in trenches 3 – 10 ft. deep
  - Vertical in 4-inch diameter 100 – 300 ft. deep drillholes
  - Coils ("Slinky")
- Ground water
  - Using well water or lake water



Earth Coil Type:	Horizontal -Two-Layer
Water Flow:	Series
Typical Pipe Size:	3.5 to 5.0 cm
Practical Length:	18 to 26 m/kW (double)
	36 to 52 m/kW (single)
Burial Depth:	1.2 to 1.8 m

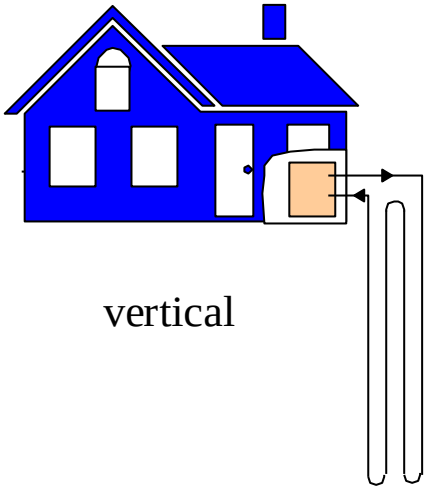


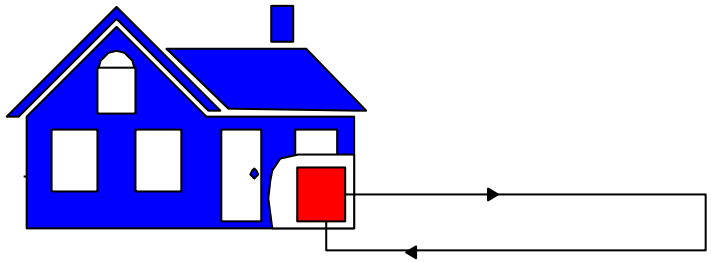
Earth Coil Type:	Vertical - Single U-Bend
Water Flow:	Series
Pipe Sizes:	2.5 to 5.0 cm
Bore Length:	14 to 17 m/kW
Pipe Length:	28 to 34 m/kW

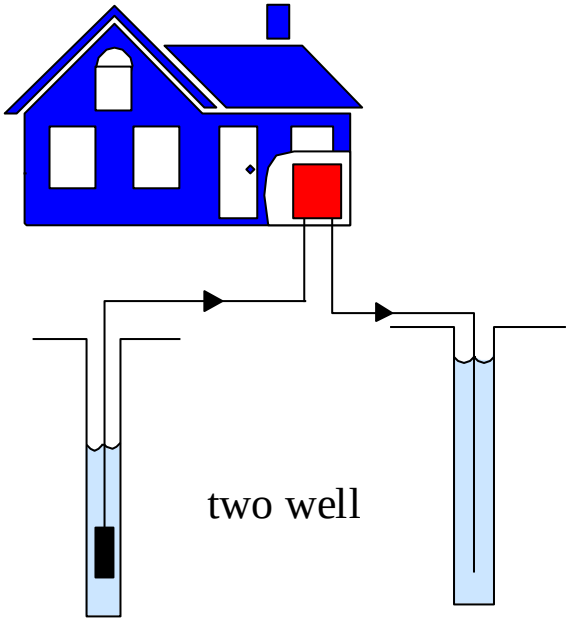
Residential Closed-Loop Installations

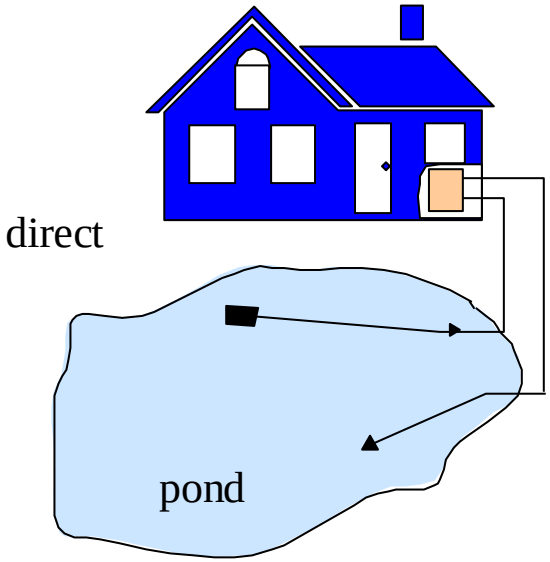
Examples of Water-Source Heat Pumps

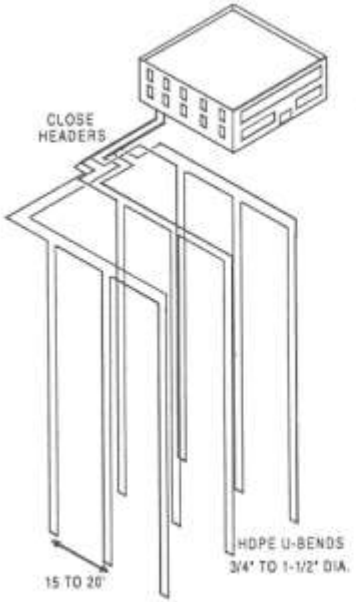
Most common: ¾ to 10 tons (2.5 to 35 kW)


vertical

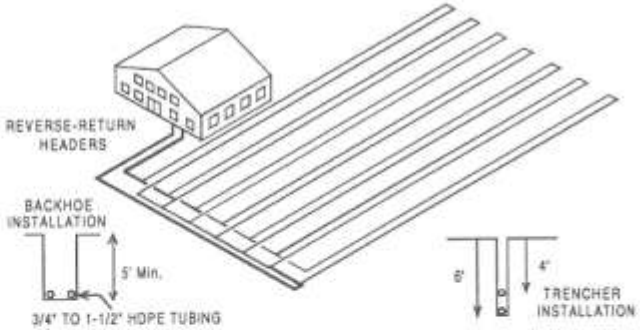

horizontal


two well

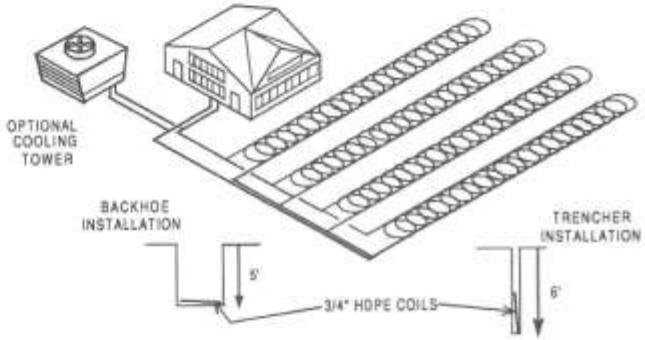

direct
pond



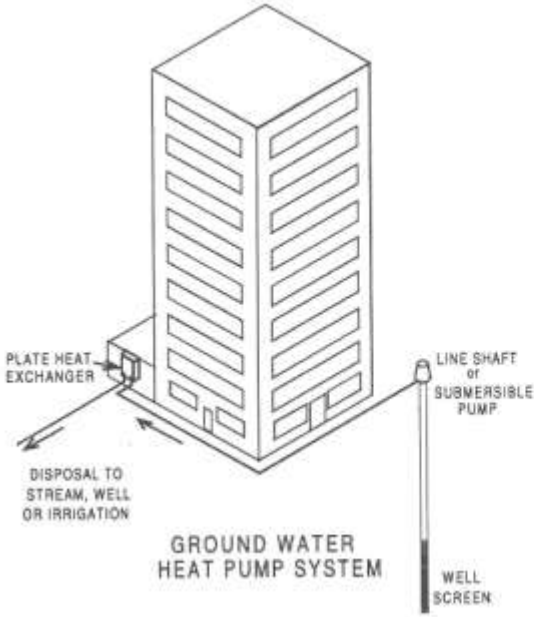
VERTICAL GROUND-COUPLED HEAT PUMP SYSTEM



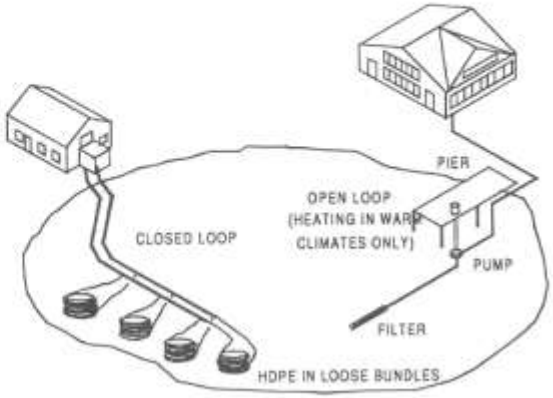
CONVENTIONAL HORIZONTAL GROUND-COUPLED HEAT PUMP SYSTEM



SLINKY COIL GROUND-COUPLED HEAT PUMP SYSTEM



GROUND WATER HEAT PUMP SYSTEM



SURFACE WATER HEAT PUMP SYSTEM

Estimate of Annual Energy Consumption 1

Denver (Stapleton): 924°F—days cooling (>65°F), 6,282°F-days heating <65°C)

System	Cooling (kWh)	Heating (kWh)	DHW (kWh)	Total (kWh)
Electric	3,910	17,640	4,120	25,670
ASHP	1,960	8,820	4,120	14,900
GHP	1,220	4,650	2,510	8,380

For a 2,000 ft² home, newly constructed with desuperheater: est. annual savings @ 8¢/kWh = $1,385 (electric vs. GHP), and $522 (ASHP vs. GHP)

Contacts (USA)

Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, Oregon: http://geoheat.oit.edu

American Society of Heating, Refrigeration and Air-Conditioning Engineers, Atlanta, Georgia: www.ashrae.org

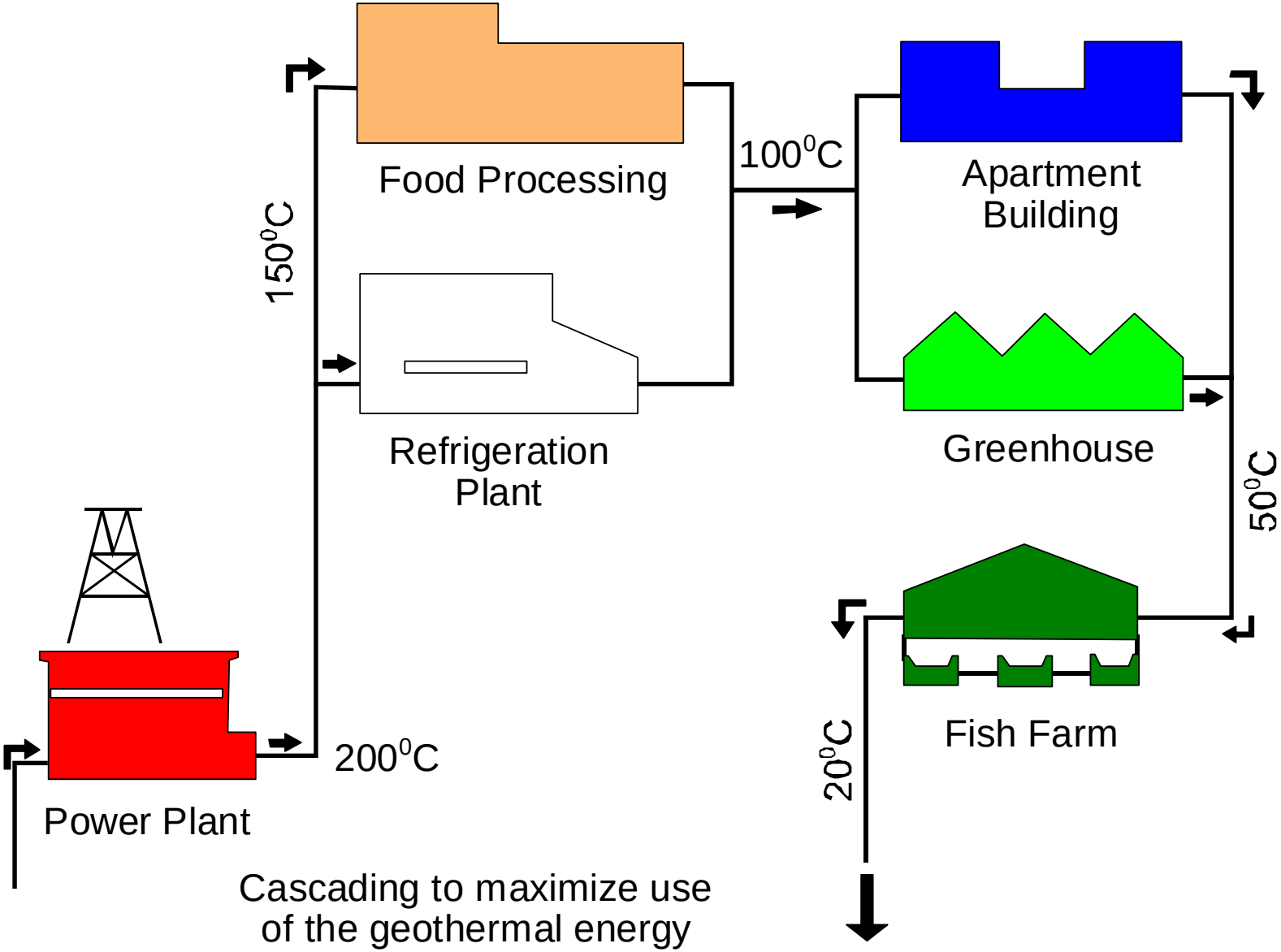
International Ground Source Heat Pump Association, Oklahoma State University, Stillwater, Oklahoma: www.igshpa.okstate.edu

Geothermal Heat Pumps Consortium, Washington, D.C.: www.geoexchange.org.

New Trends

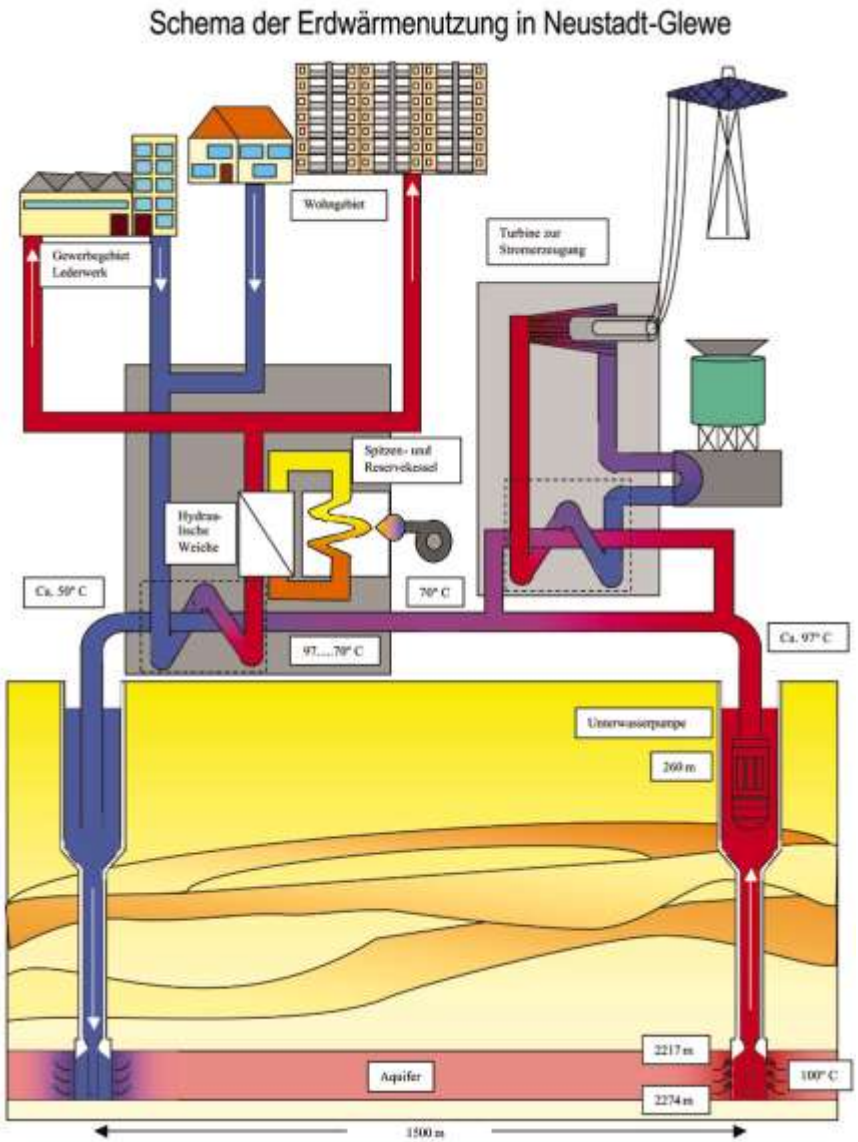
Combined heat and power plants

- Low temperature resources used for binary power production and cascaded for direct use
- Temperatures as low as 210°F are being used
- Makes efficient use of the resources
- Improves economics
- Increases employment



Cascading to maximize use of the geothermal energy

Neustadt Glewe, Germany



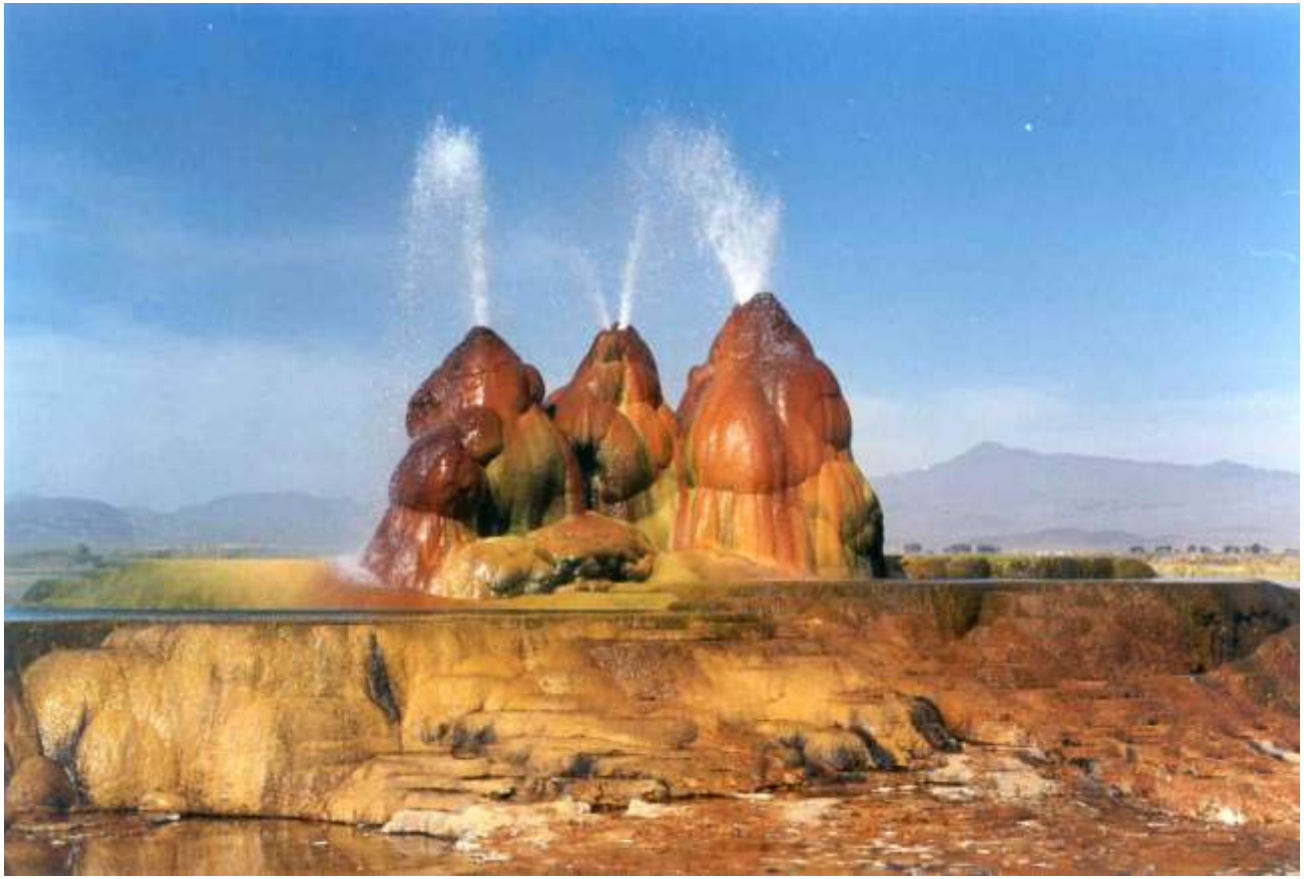
Combined heat and power plant

210ºF–27,000 gpm

210 kWe & 6 MWt

Future Developments

- Collocated resources and use
  - Within 8 km apart
- Sites with high heat and cooling load density
  - >37 MWt/km2
- Food and grain dehydration
  - Especially in tropical areas where spoilage is common
- Greenhouses in colder climates
- Aquaculture—to optimize growth
- GHP for both heating and cooling
- Combined heat and power projects—cascading
- Mineral extraction (silica, zinc, gold, etc.)



Thank You