INTRODUCTION

- Direct-use geothermal provides heat and/or cooling to buildings, greenhouses, aquaculture ponds and industrial processes.
- Need to match the resource with the needs of the user to be successful
- Economics and markets are important
- Each project is unique!!!
- Each project needs a leader or champion (“hero”)!!!
INTRODUCTION 2

- Development of a project should be approached in phases to minimize risk.
- Size of the project determines the amount of exploration and development that can be economically justified.
  - For a single home – the risk is high with minimum information economically available.
  - Larger projects can justify more investigations and resource characterization, thus reducing the risk (i.e., district heating and industrial process applications) - a feasibility study is appropriate and may be necessary.
Levels of exploration and reservoir confirmation
INTRODUCTION 3

- PROJECT PHASES:
  - Determine the market or use, and if economically feasible
  - Identify and secure rights to the resource
  - Obtain permits and financing
  - Perform environmental impact studies
  - Carry out exploration (geology, geochemistry, geophysics, drilling & reservoir engineering)
  - Undertake preliminary and conceptual design of the project during exploration
  - Perform drilling and confirmation of the resource (temperature, flow rate and chemistry)
  - Complete production and injection well drilling
  - Once resource is known – Complete the final design
    - Equipment selection
    - Costs
  - Undertake construction and operation
  - Hire people and make money!!!!!
IN SUMMARY: DIRECT-USE HEATING AND COOLING PROJECTS INCLUDES:

- Swimming, bathing and balneology
- Space heating and cooling
  - Including district (heating/cooling) systems
- Agriculture applications
  - Greenhouse and covered ground heating
- Aquaculture applications
  - Fish pond and raceway heating
- Industrial processes
  - Including food and grain drying
  - Mineral extraction and processing
- Geothermal heat pumps
ADVANTAGES OF DIRECT-USE OF GEOTHERMAL ENERGY

- Can use low- to intermediate temperature resources (<150°C)
- These resources are more wide-spread (80+ countries) and are often shallow in depth
- 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
- Quicker return on investment (as compared to power projects)
Frequency vs Reservoir Temperature

Data taken from USGS Circular 790
SELECTING THE USE

“I have this resource, what do I do with it?”

Information needed to answer the question:
- What is the extent and depth of the resource?
- What is the temperature and flow rate?
- What is the chemistry of the resource?
- What are the potential markets and income?
- Do you have the experience or can you hire it?
- Do you have the financing – ROI ok?
- Do you own or can you lease the resource?
Geothermal Energy Uses

Typical uses of geothermal energy at different temperatures

- 700°F: Flash & Dry Steam Geothermal Power Plants
- 400°F: 204°C
- 350°F: 177°C
- 300°F: 149°C
- 250°F: 121°C
- 200°F: 93°C
- 150°F: 66°C
- 100°F: 38°C
- 50°F: 10°C
- 40°F: 4°C

- 95°C: Fruit & Vegetable Drying
- 66°C: Soft Drink Carbonation
- 38°C: Food Processing
- 10°C: Snow Melting & De-icing
- 4°C: Soil Warming

- 204°C: Cement & Aggregate Drying
- 177°C: Onion & Garlic Drying
- 149°C: Lumber Drying
- 121°C: Fabric Drying
- 93°C: Building Heating & Cooling
- 66°C: Blanching, Cooking & Pasteurization
- 38°C: Greenhousing & Soil Sterilization
- 10°C: Aquaculture
- 4°C: Bathing

*Geothermal electricity can be used to produce renewable hydrogen.
**Cool water is added to make the temperature just right for the fish.

Courtesy of the Geothermal Education Office
SPAS AND POOLS

- Use of low temperature resource <60°C
- Temperature and mineral content important
- Drinking the water and using muds also important
- <30°C for pools and <45°C for spas water
- Water used directly desirable – flow through
- May need to be treated (chlorine)
- Secondary water heated through heat exchanger
- Mixing required with higher temperature resource
- Covered and uncovered pools (1:2.5 heat needs)
SPACE AND DISTRICT HEATING

- Heating (and cooling) of individual buildings or a group of buildings
- District heating requires a high thermal load density >1.8 GJ/hr/ha (50 MWth/km²) or a favorability ratio of 2.5 (heat load available/heat load on system).
- Peaking with fossil fuel often economically viable as geothermal can provide 50% of the load 80 to 90% of the time.
- However, district heating is capital intensive – especially the distribution network (pipelines) – 35 to 75% of total
- Typical savings of 30 to 50% compared to natural gas, and higher when compared to electricity
Meeting peak demand with fossil fuel
DOWNHOLE HEAT EXCHANGERS

- Used by homes – individual or shared in:
  - Klamath Falls, Oregon
  - Rotorua and Taupo, New Zealand
  - Cesme, Turkey
- Closed loop of pipe in well (coil or DHE)
- Clean secondary water used
- Only heat extracted from well
- Wells 25 to 30 cm in diameter
- Casing 5 cm smaller - clearance
DOWNHOLE HEAT EXCHANGER DESIGN

DHE with promoter pipe

DHE with perforated casing
Downhole heat exchangers – 600 in KF

Black iron DHE vs. PEX pipe
KLAMATH FALLS, OREGON DISTRICT HEATING SYSTEM

- Completed 1983 – $2.33 million – DOE-PON
- Two wells – 112/274 m deep
  - 104/100°C
  - 45/49 L/s – max
- Pipeline: 1,231 m – 20 cm steel
  - Preinsulated – direct buried & sidewalk utilidor
- Heat Exchanger building – 2 plate heat exchangers - each 10.5 GJ/h
- Injection well – 376 m deep
  - 763 m from production zone
Klamath Falls district heating system
Klamath Falls district heating system
BENEFITS

- Reduced costs to customers – 60 to 80% of natural gas
- Attracted industry
  - Greenhouses
  - Brewery
- Snow melting – cost and safety issue benefits
- 24 buildings heated
- Tourist attraction – three swimming pools now heated with geothermal energy – spa in the future?
OTHER KLAMATH FALLS GEOTHERMAL USES ON THE DISTRICT HEATING SYSTEM

IFA Nursery – 1.6 ha (4 acres) – trees seedlings
GREENHOUSES

- A variety of crops can be raised: vegetables, flowers, house plants, trees
- Various heating systems can be used
- Geothermal reduces costs and allows operation in colder climates
- Temperate climate zone: 1.0 MJ/m²
- 2 ha facility: 20 GJ/hr (5.5 MWt) peak
- Annual requirement with LF of 0.45 = 80 TJ/yr (22 million kWh/yr)
Greenhouse heating systems
AQUACULTURE

- Raising catfish, bass, tilapia, shrimp and tropical fish and even alligators
- Temperature of water from 13 to 30°C
- Increase growth rate by 50 to 100%
- Water quality and disease control important when using the geothermal water directly
- Outdoor pond in temperate climate zone:
  - 2.5 MJ/hr/m²
  - 2 ha facility: 50 GJ/hr (14 MWt) peak
  - With LF of 0.60 = 260 TJ/yr (73 million kWh/yr)
The graph illustrates the relationship between temperature and percent of optimum growth for various species.

- **Cows**: The percent of optimum growth increases with temperature, reaching a peak around 50°C before decreasing sharply.
- **Chickens**: Shows a similar pattern to cows, with the peak at a slightly lower temperature.
- **Trout**: The percent of optimum growth increases rapidly at lower temperatures, peaking sharply near 20°C before declining.
- **Shrimp**: Demonstrates a sharp increase in percent of optimum growth at lower temperatures, peaking around 20°C.
- **Catfish**: Displays a moderate increase in percent of optimum growth with temperature, peaking around 30°C.

The x-axis represents temperature in °C, and the y-axis represents percent of optimum growth. The graph provides a visual representation of how different species respond to temperature changes in terms of their growth rates.
Typical aquaculture facilities
“Gone Fishing” – African Cichlids
Giant freshwater prawns – *Macrobrachium rosenbergii* 
New Zealand
INDUSTRIAL

- Generally require higher temperatures as compared to space heating - $>100\,^\circ C$.
- High energy consumption
- Year-around operation
- Drying of timber, extracting minerals, concrete block curing, leather tanning, milk pasteurization, borate and boric acid production, and dehydration of vegetables and fruit are examples
- They also tend to have high load factors in the range of 0.4 to 0.7 – which reduce the unit cost of energy.
Cost of Energy

After Rafferty, 2003
Heap leaching, milk pasteurization, onion dehydration, timber drying
Studies of grain, corn and tea drying in Kenya
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 temperature, the more efficient (can use geothermal fluids below 100°C – however, >115°C better for 100% efficiency)
  - Units are now available down to 80°C @ 100% efficiency
- Ammonia absorption used for refrigeration below freezing normally large capacity and require geothermal temperatures above 120°C – only one in operation worldwide (Alaska)
Oregon Institute of Technology – chiller
89°C producing 7°C chilled water @ 38 l/s
1 MWt installed – 500 kWt net
HEAT PUMPS (2)

- Ground source or geothermal heat pumps (GSHP or GHP) – uses 5 to 30 °C ground or ground-water
- COP = 4 = energy output kWt/energy input kWhe
- 50 to 100% more efficient than air source, since uses constant temperature resource: COP = <2
- Ground coupled
  - Horizontal in trenches 1 – 3 m deep
  - Vertical in 10 cm diameter 50 – 60 m deep drill holes
    - One hole produces approximately 3.5 kW
  - Coils (“Slinky”)
- Ground water
  - Using well water or lake water
  - 0.2 l/s will produce approximately 3.5 kW
SELECTING THE EQUIPMENT FOR DIRECT-USE PROJECTS

- Geothermal fluids often must be isolated to prevent corrosion and scaling
- Normally need a plate HE to isolate the fluid
- Care to prevent oxygen from entering the system
- Dissolved gases and species such as boron and arsenic can be harmful to plants and fish.
- Hydrogen sulfide attacks copper and solder.
- Carbon dioxide can be used in greenhouses.
- Peaking or backup fossil fuel plants often used
Typical direct-use system equipment
HEAT EXCHANGERS

Plate type HE
Flow requirement proportional to $T_{ge} - T_{go}$
- At $40^\circ C$, flow = $2x$
- At $35^\circ C$, flow = $4x$
- At $32.5^\circ C$, flow = $8x$

Direct pools and aquaculture pond heating
(modified from Rafferty, 2004)
NEW TRENDS

• COMBINED HEAT AND POWER PLANTS
  • Low temperature resources used for binary power production and cascaded for direct use
  • Temperatures as low as 98°C are being used
  • Makes efficient use of the resources
  • Improves economics
  • Increases employment
Altheim, Austria – combined heat and power plant
CHENA HOT SPRINGS, ALASKA

United Technologies Corporation

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

Installed in July of 2006

Lowest temperature geothermal use for power generation in the world

74°C resource and 5°C cooling water
OREGON INSTITUTE OF TECHNOLOGY

BINARY POWER PLANT

- 280 kW electric
- 92°C geothermal water
- Cost: $1,000,000
- Provides 10% of campus electricity
- 2nd power plant planned @ 1.75 kW
- With solar array - 100% of campus electrical energy supplied.
- Water cascaded to heat all of campus at 80°C
FANG GEOTHERMAL PLANT, EGAT, THAILAND

- Artesian well at 116°C (240°F) and 8.3 L/s (130 gpm).
- 300 kWe binary (ORMAT) power plant
- Net power varies from 150 to 250 kWe producing 1.2 GWh/yr
- Water then cascaded:
  - Refrigeration (cold storage)
  - Crop drying
  - Spa
- Direct-use: 480 kWt producing 0.92 TJ/yr
- Power cost: 6 to 8¢/kWh vs 22 to 25 for diesel
Process schematic of Fang power and heating system
Fang geothermal binary power plant (250 kW)
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 even in mild climates
- GHP for both heating and cooling
- Combined heat and power projects – cascading
- Mineral extraction (silica, zinc, gold, etc.)
CONCLUSIONS

- Many possible direct-uses of geothermal fluids
- Number of parameters will limit choices:
  - Temperature, flow rate, chemistry and land availability
  - Market available, and do you have the expertise to provide the product (i.e. heat and/or flowers/fish, etc.)
  - Can you get the product to the user economically – (i.e. pipelines or truck/rail/airline transportation)
  - Availability of capital, income and ROI/payback
  - Can you attract investors (i.e. minimize the risk)
- Alternative to consider – combined heat and power project – to better utilize the resource and help the bottom line
THANK YOU