WORLDWIDE GEOTHERMAL UTILIZATION

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Oregon Institute of Technology
Klamath Falls, Oregon, USA
High Temperature Geothermal Provinces
• Electric power generation
• Direct use
• Heat pumps
## SUMMARY CAPACITY & USE

<table>
<thead>
<tr>
<th>Use</th>
<th>Installed Power (MW)</th>
<th>Energy Use (GWh/yr)</th>
<th>Capacity Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric</td>
<td>11,000</td>
<td>68,000</td>
<td>0.72</td>
</tr>
<tr>
<td>Direct-use</td>
<td>50,000</td>
<td>120,000</td>
<td>0.28</td>
</tr>
</tbody>
</table>
ELECTRIC POWER HISTORY

- Original country – first 50 years: Italy – 350 MWe
- Next 20 years: New Zealand, Mexico, USA, Japan, Russia (1958-1973) - 1,000 MWe
- 1973-1990: 9 more countries – 5,800 MWe
- Growth over the last 20 year (1990-2010):
  - 3.1 %/year (compounded)
  - Increase by about 5,000 MWe
  - New countries: Austria, Australia, Costa Rica, Ethiopia, Germany, Guatemala, Papua New Guinea, Portugal.
  - Argentina, Greece and Taiwan have shut down plants
  - Now at 11,000 MWe
• 1904 – Larderello, Italy – first experimental work by Prince Ginori Conti – 5 light bulbs from 10 kWe dynamo – “indirect cycle”
EARLY DEVELOPMENT II

• 1913 – first commercial geothermal power plant at Larderello – 250 kWe fed into local network – use by villages in the region – resource 200-250°C
EARLY DEVELOPMENT
New Zealand

• 1947 – New Zealand engineers visit Italy
• 1958 – Wairakei “A” station on line in New Zealand – 69 MWe – “wet steam”
• Separators needed - producing HP, IP and LP steam - 230ºC
EARLY DEVELOPMENT
North America

• 1934- first geothermal power plant at The Geysers – 35 kWe - 152ºC
• 1959 – first geothermal power plant in Mexico– Pathé – 3.5 MWe - >250ºC
• 1960 – first modern US plant on line at The Geysers in northern California – 12 MWe - 230ºC
• All are “dry steam” plants
Worldwide Geothermal power production 1904-2012

Production from 1904-1958 entirely from Italian fields
Worldwide Installed Capacity 2010 = 10,715 MWe
## SUMMARY BY REGION

<table>
<thead>
<tr>
<th>Region</th>
<th>%MWe</th>
<th>%GWh/yr</th>
<th>Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>1.6</td>
<td>2.1</td>
<td>2</td>
</tr>
<tr>
<td>Americas</td>
<td>42.6</td>
<td>39.9</td>
<td>6</td>
</tr>
<tr>
<td>Asia</td>
<td>34.9</td>
<td>35.1</td>
<td>6</td>
</tr>
<tr>
<td>Europe</td>
<td>14.5</td>
<td>16.2</td>
<td>7</td>
</tr>
<tr>
<td>Oceania</td>
<td>6.4</td>
<td>6.7</td>
<td>3</td>
</tr>
</tbody>
</table>
Geothermal Electric Power Generation

The Geysers, California, USA

Larderello, Italy
Binary (ORC) Geothermal Power Plants

Kenya

Austria

Nevada

California
CHENA HOT SPRINGS, ALASKA

United Technologies Corporation

200 kWe Carrier converted vapor-compression cycle chiller to a Rankin 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
<table>
<thead>
<tr>
<th>Plant type</th>
<th>%</th>
<th>GWh/unit</th>
<th>MW/unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Steam:</td>
<td>2</td>
<td>260</td>
<td>46</td>
</tr>
<tr>
<td>Single Flash:</td>
<td>41</td>
<td>199</td>
<td>31</td>
</tr>
<tr>
<td>Double Flash:</td>
<td>20</td>
<td>236</td>
<td>34</td>
</tr>
<tr>
<td>Binary/combined cycle/hybrid:</td>
<td>11</td>
<td>27</td>
<td>5</td>
</tr>
<tr>
<td>Back Pressure:</td>
<td>2</td>
<td>26</td>
<td>4</td>
</tr>
</tbody>
</table>

*527 units total with average = 20 MWe
# LEADING COUNTRIES >500 MWe

<table>
<thead>
<tr>
<th>Country</th>
<th>Installed MWe</th>
<th>Running MWe</th>
<th>Capacity Factor</th>
<th>Number Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>3093</td>
<td>2024</td>
<td>0.94</td>
<td>209</td>
</tr>
<tr>
<td>Philippines</td>
<td>1904</td>
<td>1774</td>
<td>0.66</td>
<td>56</td>
</tr>
<tr>
<td>Indonesia</td>
<td>1197</td>
<td>1197</td>
<td>0.92</td>
<td>22</td>
</tr>
<tr>
<td>Mexico</td>
<td>958</td>
<td>958</td>
<td>0.84</td>
<td>37</td>
</tr>
<tr>
<td>Italy</td>
<td>843</td>
<td>843</td>
<td>0.75</td>
<td>33</td>
</tr>
<tr>
<td>New Zealand</td>
<td>628</td>
<td>628</td>
<td>0.74</td>
<td>43</td>
</tr>
<tr>
<td>Iceland</td>
<td>575</td>
<td>575</td>
<td>0.91</td>
<td>25</td>
</tr>
<tr>
<td>Japan</td>
<td>536</td>
<td>422</td>
<td>0.83</td>
<td>20</td>
</tr>
</tbody>
</table>
## GEOTHERMAL POWER CONTRIBUTIONS

<table>
<thead>
<tr>
<th>Region</th>
<th>% of National or Regional Capacity (%MWe)</th>
<th>% of National or Regional Energy (%GWh/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibet</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Tuscany (Italy)</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Iceland</td>
<td>22</td>
<td>27</td>
</tr>
<tr>
<td>El Salvador</td>
<td>15</td>
<td>26</td>
</tr>
<tr>
<td>Kenya</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>Philippines</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>Hawaii (Big Island)</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Nicaragua</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>Guadeloupe (Caribbean)</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Costa Rica</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>New Zealand</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>California</td>
<td>4</td>
<td>7</td>
</tr>
</tbody>
</table>
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
Soaking and swimming in geothermal waters
SPACE HEATING AND COOLING
REYKJAVIK, ICELAND

1930s

1980s

Today

1930s
INDUSTRIAL APPLICATION EXAMPLES
HEAT PUMPS

- Ground source and geothermal heat pumps (GSHP or GHP) – uses 5 to 30°C ground temperature – COP = 4
- 50 to 100% more efficient than air source, since uses constant temperature resource
- Ground coupled
  - Horizontal in trenches 1 – 3 m deep
  - Vertical in 10-cm diameter 50 – 100 m deep drill holes
  - Coils ("Slinky")
- Ground water
  - Using well water or lake water
Worldwide direct-use installed capacity (MWt)- 2010

- Geothermal heat pumps: 69.7%
- Bathing and swimming: 13.2%
- Greenhouse Heating: 3.1%
- Space Heating: 10.7%
- Aquaculture pond heating: 1.3%
- Agricultural drying: 0.3%
- Industrial uses: 1.1%
- Cooling / snow melting: 0.7%
- Others: 0.1%
Worldwide direct-use annual use (TJ/yr)- 2010
### LEADING COUNTRIES >1,000 MWt

<table>
<thead>
<tr>
<th>Country</th>
<th>GWh/yr</th>
<th>MWt</th>
<th>Main Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>20,932</td>
<td>8,898</td>
<td>bathing/dist. heating</td>
</tr>
<tr>
<td>USA</td>
<td>15,710</td>
<td>12,611</td>
<td>GHP</td>
</tr>
<tr>
<td>Sweden</td>
<td>12,585</td>
<td>4,460</td>
<td>GHP</td>
</tr>
<tr>
<td>Turkey</td>
<td>10,247</td>
<td>2,084</td>
<td>district heating</td>
</tr>
<tr>
<td>Japan</td>
<td>7,139</td>
<td>2,100</td>
<td>bathing (onsens)</td>
</tr>
<tr>
<td>Iceland</td>
<td>6,768</td>
<td>1,826</td>
<td>district heating</td>
</tr>
<tr>
<td>France</td>
<td>3,592</td>
<td>1,345</td>
<td>district heating</td>
</tr>
<tr>
<td>Germany</td>
<td>3,546</td>
<td>2,485</td>
<td>bathing/dist. heating</td>
</tr>
<tr>
<td>Norway</td>
<td>3,000</td>
<td>1,000</td>
<td>GHP</td>
</tr>
<tr>
<td>Netherlands</td>
<td>2,972</td>
<td>1,410</td>
<td>GHP</td>
</tr>
<tr>
<td>Canada</td>
<td>2,465</td>
<td>1,126</td>
<td>GHP</td>
</tr>
<tr>
<td>Switzerland</td>
<td>2,143</td>
<td>1,061</td>
<td>GHP</td>
</tr>
</tbody>
</table>
## DIRECT-USE SUMMARY BY REGION

<table>
<thead>
<tr>
<th>Region</th>
<th>%MWt</th>
<th>%GWh/yr</th>
<th>Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>0.3</td>
<td>0.7</td>
<td>7</td>
</tr>
<tr>
<td>Americas</td>
<td>30.1</td>
<td>19.0</td>
<td>15</td>
</tr>
<tr>
<td>Asia</td>
<td>28.7</td>
<td>34.9</td>
<td>16</td>
</tr>
<tr>
<td>Europe</td>
<td>40.0</td>
<td>43.1</td>
<td>37</td>
</tr>
<tr>
<td>Oceania</td>
<td>0.9</td>
<td>2.3</td>
<td>3</td>
</tr>
</tbody>
</table>
NATION DIRECT-USE CONTRIBUTIONS

- Iceland: 89% of space heating
- Turkey: space heating approaching 30%
- Tunisia: 200 ha of greenhouses
- Japan: 2,000 onsens; 5,000 public baths; 1,500 hotels – 15 million guests/yr
- Switzerland: 60,000 GHP (≈1/km²)
- United States: 1 million GHP – 12.5% growth/yr
- Sweden: 12% of space heating/thermal storage
HOT DRY ROCKS (ENHANCED GEOTHERMAL SYSTEM) : >200°C HYDRO-FACTURED ROCK – 3 TO 6 KM DEEP
Soultz-sous-Forêts – Rhein graben
Hot dry rock project – “Heat Mining”
European Economic Interest Group
4 countries including ENEL
Commercial electricity production

- Inject cold water at 5 km
- Obtain 200°C water/steam
- Produce 1.5 MWe by 2010
- Suitable European sites
  potential = 110 000 MWe
Hot Fractured Rock (HFR)  
Australia’s Cooper Basin  
(source: Geodynamics Ltd.)

Two wells drilled: 4900 & 4572 m  
270 and 250°C into granite rock  
2013: 3-5 MWe binary plant  
275 kV powerline – 60 million €
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
Cascading to maximize use of geothermal energy
NEUSTADT GLEWE, GERMANY
combined heat and power plant

98°C – 1,700 L/s
210 kWe & 6 MWt
KLAMATH FALLS

- 600± geothermal wells
- 30 to 600 m deep
- 40 to 105°C
- Majority use downhole heat exchangers
- City district heating system – 24 buildings
- Pavement snow melting systems
- Oregon Institute of Technology
- 50 MWt capacity, 116 GWh/yr (418 TJ/yr)
- 50,000 bbl equivalent fuel oil saved per year
Klamath Falls snow melting system
IFA Nursery – 1.6 ha
– commercial trees seedlings

KLAMATH FALLS
GEOTHERMAL USES ON THE DISTRICT HEATING SYSTEM
“Gone Fishing” – African Cichlids
91°C water
3 wells: 400 – 600 m
6 MWt – 14 GWh/yr
Saving $1mil/yr

Oregon Institute of Technology
OREGON INSTITUTE OF TECHNOLOGY SMALL SCALE POWER PLANT

- Uses existing wells at 91°C
- 280 kWe
- Uses 38 l/s
- Taking 17°C off the top
- Remainder used to heat campus
- Started operation in February 2010
- Supplies 10% of campus electric needs and provides energy to pump wells on campus
## WORLDWIDE ENERGY SAVINGS

Compared to fuel oil:

<table>
<thead>
<tr>
<th></th>
<th>(10^6) Barrels</th>
<th>(10^6) Tonnes</th>
<th>C (10^6)t</th>
<th>CO(_2) (10^6)t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric</td>
<td>114</td>
<td>17</td>
<td>15</td>
<td>49</td>
</tr>
<tr>
<td>Direct-use</td>
<td>125</td>
<td>19</td>
<td>17</td>
<td>53</td>
</tr>
<tr>
<td>Total</td>
<td>239</td>
<td>36</td>
<td>32</td>
<td>102</td>
</tr>
</tbody>
</table>

Savings: \(\approx 3\) days of world’s consumption of oil
Emissions From Power Plants

\[ \text{SO}_x \] lbs/MW-hr

- Coal
- Oil
- Methane
- Geothermal - Maximum
- Geothermal - with gas injection

\[ \text{CO}_2 \] lbs/MW-hr

- Coal
- Oil
- Methane
- Geothermal - Maximum
- Geothermal - with gas injection

After Goddard & Goddard, GRC Transactions, 14, 643-649 (1 lb = 0.4536 kg)
WORLDWIDE SUMMARY

• Electricity generation increased 11%/yr over the past 40 years; dropping to 3%/yr in last 10 years.
• Direct-use remained steady at 10%/yr over the past 40 years.
• Majority of direct-use growth due to GHP at 24%/yr over the past 10 years.
• Only 10 countries reported geothermal use 40 years ago; 78 now; 10 more developing use.
FUTURE PREDICTIONS

• Emphasis on combined heat and power plants such as those in Germany and Austria
• Low temperature, small scale binary power plants providing distributed power as at Chena Hot Springs in Alaska
• Agricultural crop drying especially in tropical climates
• Largest growth will be in geothermal heat pumps growing at a rate of 10 to 20%/year
FUTURE POWER GENERATION

• By 2015 new countries on line: Argentina, Canada, Chile, Greece, Honduras, Hungary, Netherlands, Nevis, Romania, Spain, Slovakia and Taiwan

• Total of 18,500 MWe (increase of 8,000 MWe)

• By 2050, 70,000 MWe (without EGS)
  – 4.8%/yr growth from 2010
  – 3.9%/yr growth from 2015
FUTURE DIRECT-USE

• By 2015 increasing direct-use from 78 to 100 countries and GHP from 43 to 60 countries
• Then by 2015 assuming an average increase of 7%/yr for direct-use and 22%/yr for GHP
  – Total: 111,000 MWt and 855,000 TJ/yr
• By 2050 assuming an average increase of 3.1%/yr for direct-use and 7.5%/yr for GHP
  – Total: 650,000 MWt and 4,370,000 TJ/yr
Thank you