**Figure 6.3 Geothermal Systems Chart**

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| <u>Highest temperature</u><br>Magma environment<br>650-1300° C<br>(~1,200-2,350° F) | Magma is molten rock material in the Earth's crust. Magma is the "highest grade of geothermal ore" because it is the ultimate source of heat for all high-temperature geothermal environments in the crust including both wet and dry systems. | Efforts have been made to tap the magma itself for energy. While tests in the laboratory and the field have shown it is technically feasible, the long-term economics are questionable because of uncertainties in the expectable life span of materials in contact with the magma and problems with accurately locating the magma body before development begins.<br>Experiments were conducted at the Kilauea Iki Crater, Hawaii, in the 1980s, and at Sandia National Laboratories in New Mexico. |
| Hot Dry Rock (HDR)<br>Systems | With decreasing temperature, the magma environment grades into hot solid rock that contains little or no available water. | Rocks at cost-effective drilling depths are hot enough to represent a huge inventory of potential geothermal energy. However, they are not naturally permeable enough to form a producing hydrothermal system.<br>Research on developing ways to increase permeability through fracturing (fracing) may allow the exploitation of "dry rock" environments in the near future. |
| Enhanced Geothermal<br>Systems (EGS) | Similar to the HDR environment, these areas are often shallower and adjacent to producing natural hydrothermal areas but have been considered uneconomic because of low permeability. | Only hydrothermal systems with sufficiently high temperatures and permeable, water-saturated rock have been commercially developed for generating electricity in the past. Research is currently underway to enhance uneconomic areas adjacent to natural hydrothermal areas by stimulating permeability through hydraulic fracturing, directional drilling to intersect favorably oriented fractures, and injecting groundwater or wastewater to replenish fluids and to reverse pressure declines. |
| Hydrothermal<br>Electricity Systems | Distinguished from the categories above because not only hot, but also sufficiently porous and permeable to be saturated with fluids that mobilize the heat to generate electricity. | Approximately twenty geothermal fields in the United States generate electricity.<br>The three subcategories of hydrothermal electricity systems vary based on what turns the turbines:<br>[a] steam (vapor dominated systems),<br>[b] liquid hot water, or<br>[c] a secondary fluid (using moderate-temperature water in a binary process). |

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| a. Steam or vapor-dominated | When a potent heat source intersects with a restricted source of water, the pore spaces of rocks in a high-temperature hydrothermal system are saturated with steam, rather than liquid water, and only steam is produced through the wells and directly routed into turbine generators. | Vapor-dominated systems do not require the separation of steam from water, so the energy they contain is relatively simple and efficient to harness, making these systems the most desirable for electric power production. Vapor-dominated systems are rare compared with valuable, but less-simple-to-develop, hot-water systems. The largest vapor-dominated system developed in the world is at The Geysers in northern California. |
| b. Hot Water /212-700°F | These systems are in porous and permeable rock naturally saturated with enough water to drive electric turbines. The water partly "flashes" into steam when it rises up production wells. | The hotter the hydrothermal fluids are, the more capable they are of producing steam and correspondingly generating electricity. To extract the most energy from the fluid, it sometimes can be "flashed" two or three times to drive additional turbine generators. Examples of hot-water systems are Coso and Imperial Valley in southern California. |
| c. Binary Systems Below 212°F | Moderate-temperature hydrothermal systems are incapable of producing steam at high enough pressure to directly drive a turbine generator. They are, however, hot enough to produce a high-pressure vapor through heat transfer to a secondary working fluid. | A binary cycle generates power by transferring the heat from the geothermal fluid to another fluid whose boiling temperature is lower than that of water (for example, isobutene). Binary systems producing electricity include California plants at Mammoth Lakes, east of the Sierra Nevadas, and a plant in the Imperial Valley. By taking advantage of the more widespread distribution of moderate-temperature geothermal water, binary systems may contribute significantly to the overall generation of electricity from geothermal sources. |
| Direct Use Systems | >1,300 direct-use sites worldwide include Boise, Idaho; Klamath Falls, Oregon; Aquitaine Basin in SW France, and Iceland. | Some direct-use applications include heating for homes, businesses, greenhouses, fish farms, and dairies; industrial processing; domestic hot water heating; driveway and sidewalk snow melting; and recreational hot springs. |
| Low temperature Geothermal Heat Pumps (GHP) | GHP, also called Groundsource Heat Pumps or Geoexchange, employs normal ground temperatures in ordinary, relatively shallow surface rock and soil. | Not related to hotter-than-average magma systems, but instead based on solar isolation on the surface of the earth and retained because of the ground's thermal mass. Because this source of thermal energy is virtually everywhere, it represents a huge potential alternative energy source for heating and cooling individual buildings. |