GRID-CONNECTED RENEWABLE ENERGY:

GEOTHERMAL POWER

Geothermal Energy

- **Origins and Uses**
- Global Status
- Geothermal Power Generation Technologies
- Environmental Impacts And Climate Change
- Project Development Issues
- Barriers To Market Penetration
- Best Practices

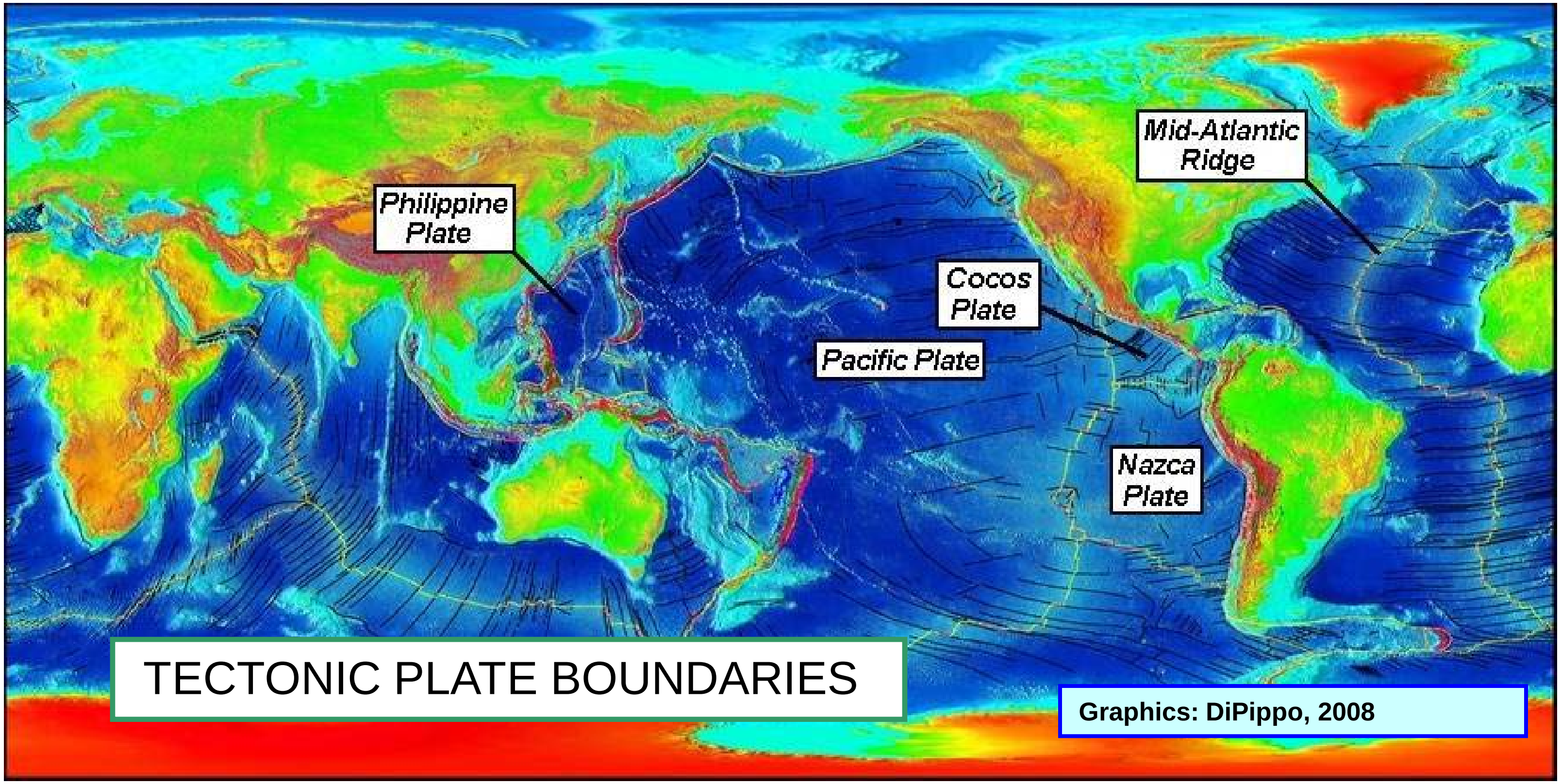
ORIGINS OF GEOTHERMAL ENERGY

HEAT STORED IN THE EARTH'S CRUST CAN BE USED TO GENERATE ELECTRICITY. RADIOACTIVE ELEMENTS IN ROCK CREATE HIGH HEAT CONCENTRATIONS.

PLATE TECTONICS – ACTIVE BOUNDARIES GIVE RISE TO VOLCANOES.

VOLCANIC HEAT CREATES HIGH-TEMPERATURE RESERVOIRS.

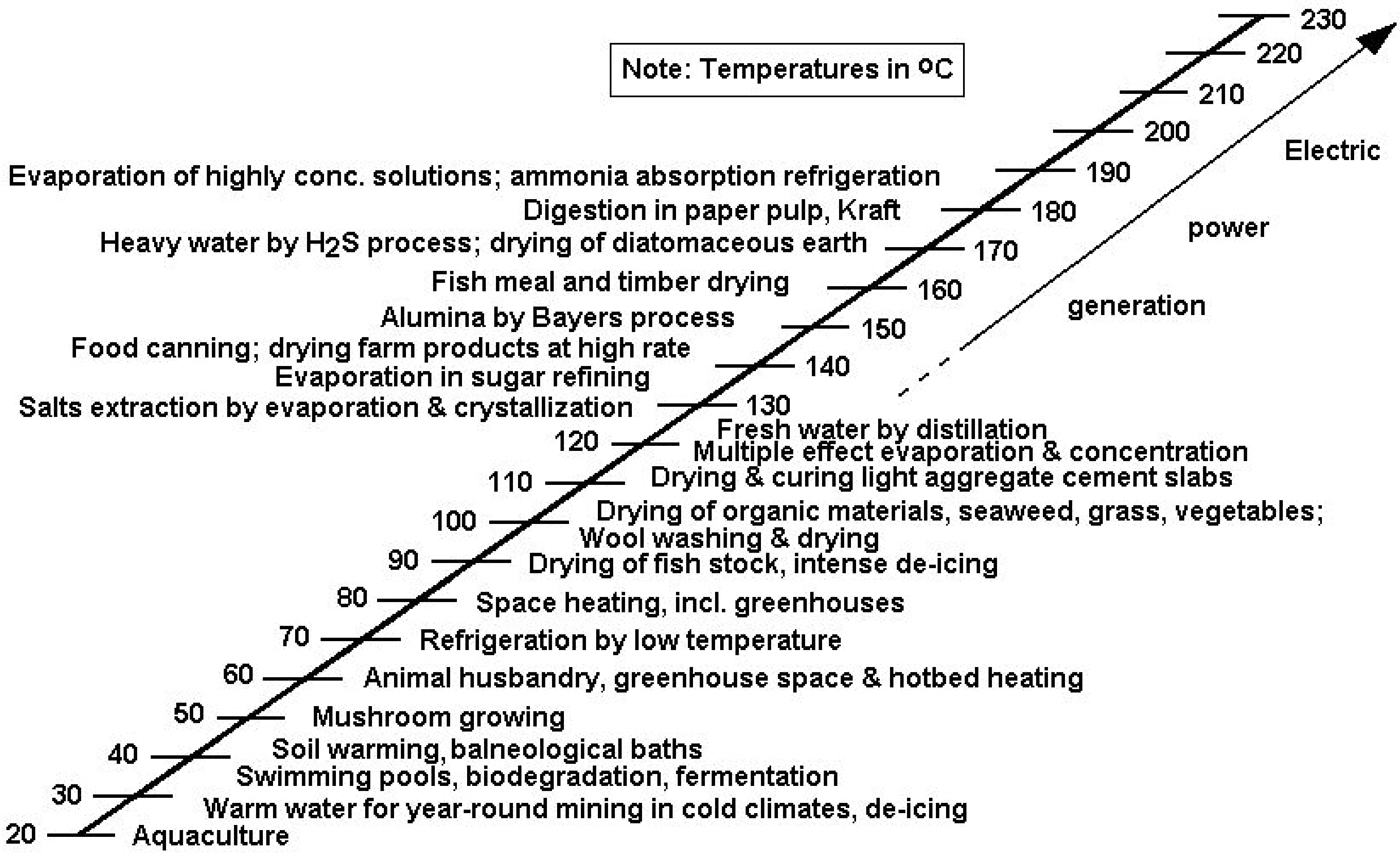
HOT ZONES ARE ACCESSIBLE TO DEPTHS UP TO 10 KM.



GEOTHERMAL ENERGY USES

- Direct heat applications
- Electricity generation

GEOTHERMAL ENERGY USES: LINDAL DIAGRAM



Source: DiPippo, 2008

GEOTHERMAL POWER GLOBAL STATUS

- 100+ years history of electricity generation
- Reliable source of continuous, base-load power
- Utilizes conventional power generation equipment
- High potential, but high up-front costs

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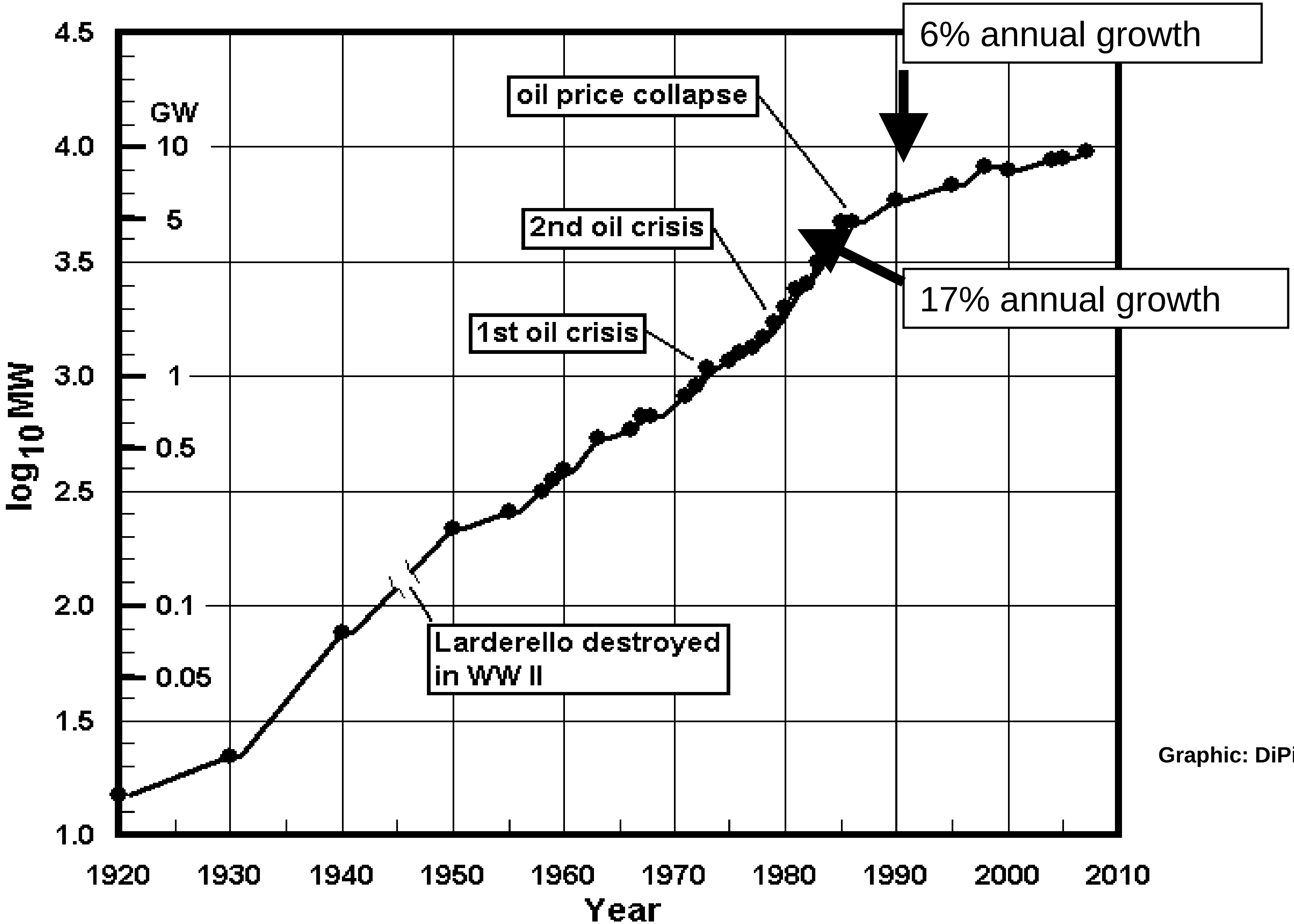
GROWTH OF GEOTHERMAL POWER



Graphic: DiPippo, 2008

WORLDWIDE GEOPOWER

Country	First year	No. of units	Power, MW
United States	1960	193	2556
Philippines	1977	58	1980
Mexico	1973	37	953
Italy	1904	33	811
Indonesia	1978	15	807
New Zealand	1958	39	572
Japan	1967	22	538
Iceland	1969	24	422
El Salvador	1975	7	204
Costa Rica	1995	5	163
Kenya	1981	9	130
Nicaragua	1983	7	109
Russia	1967	12	79
Papua-New Guinea	2003	6	56
Guatemala	1997	9	45
Turkey	1984	2	28
China	1970	13	28
Portugal (The Azores)	1980	5	16
France (Guadeloupe)	1987	2	15
Austria	2001	2	1.25
Thailand	1989	1	0.3
Germany	2003	1	0.2
Australia	1986	1	0.15
Totals		**504**	**9513**

ESTIMATED GEOPOWER POTENTIAL

Country	Power potential, MWe
United States - EGS	518,000
United States	39,000
Indonesia	16,400
Chile	16,000
Africa – East Rift Zone	14,000
Philippines	8,000
Australia (EGS)	5,500
Mexico	4,000
Czech Republic - EGS	3,400
Nicaragua	2,500
Russia (Kamchatka only)	1,130
Kenya	1,000
Iceland	1000
Turkey	905
Mexico (EGS)	800
New Zealand	500
Pacific Island Nations	450
Ukraine	414
Papua-New Guinea	300
Italy	250
El Salvador	100
Guatemala	100
Costa Rica	60
Japan	50
Upper Rhine Valley (France & Germany) (EGS)	42
Czech Republic	10
Totals	**633,911**

GEOTHERMAL POWER GENERATION

- **General Characteristics**

  Hot water/steam → Turbine → Generator → Baseload power

  Low emissions

  Reliable operation

- **Geothermal Power Requirements**

  Commercial hydrothermal fields need a unique combination of geologic, physical, and thermal characteristics

- **Energy Conversion Systems**

  Overall plant capacity may be large (100-200 MW), but individual power units (turbine/generator) are small (25-35 MW), compared to fossil or nuclear plants

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GEOTHERMAL POWER REQUIREMENTS

Heat source

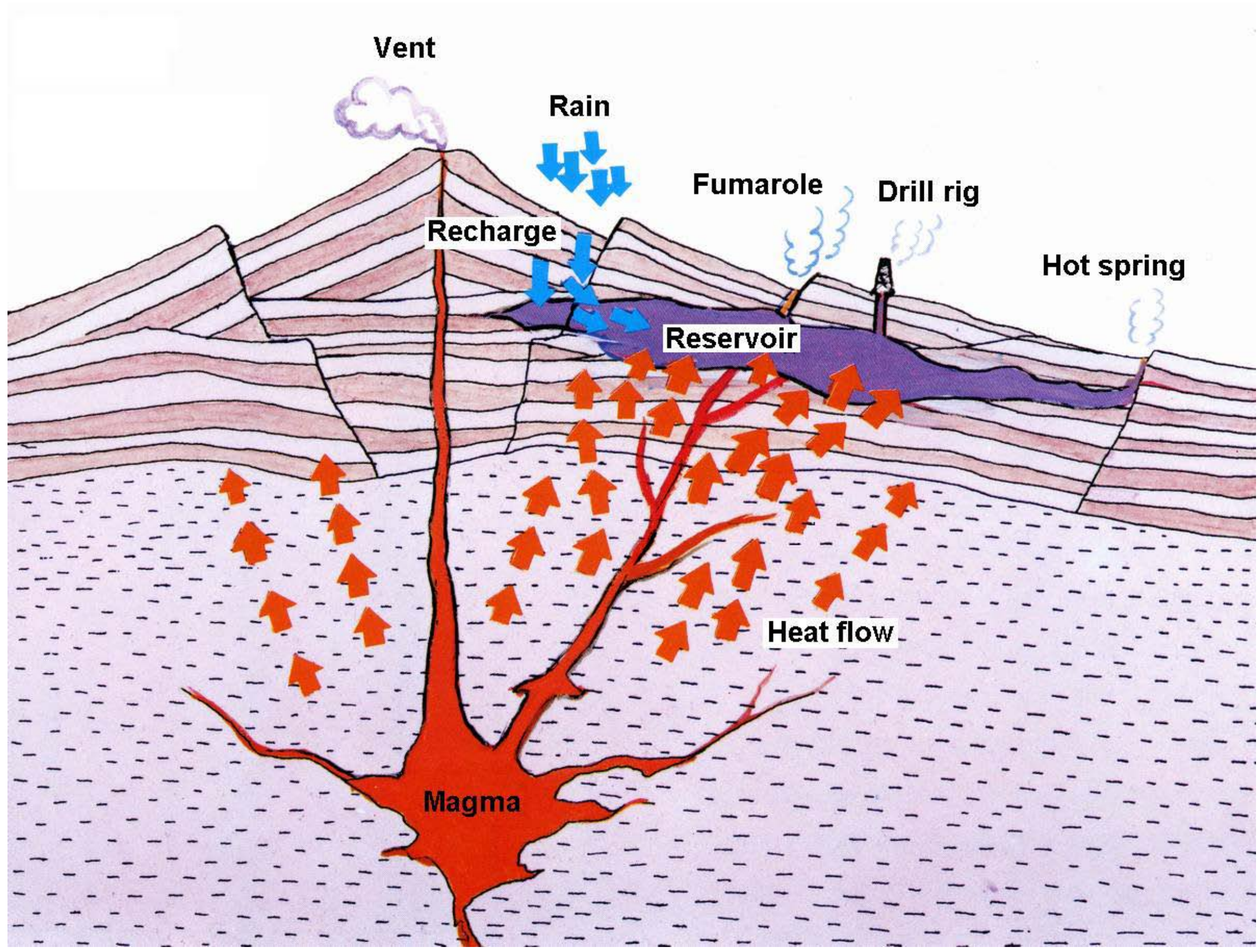
Reservoir

Geofluid

Recharge

Caprock

Temperatures >150°C

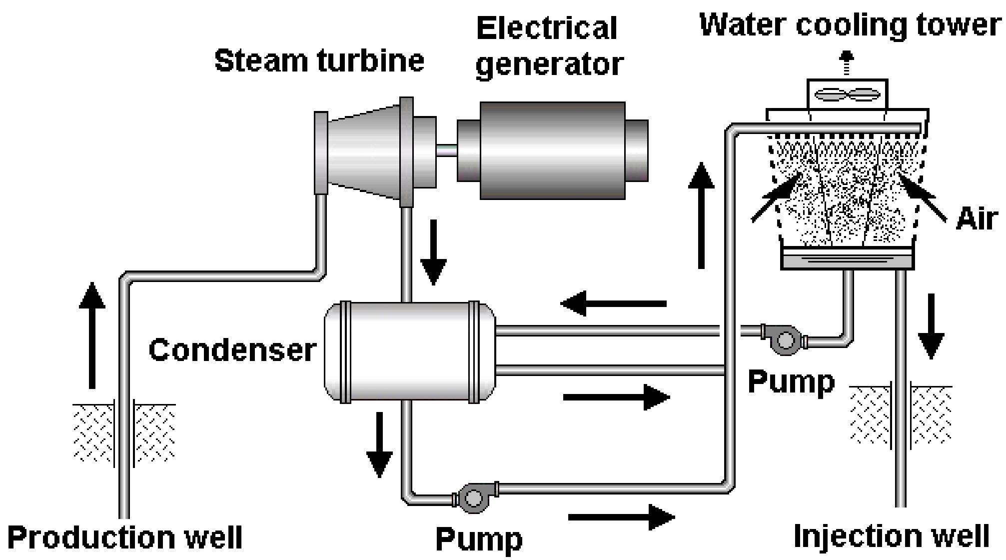


GEOTHERMAL POWER TECHNOLOGIES

- Direct Steam Plants
- Flash Steam Plants
- Binary Steam Plants
- EGS Plants

Selection of plant technology depends upon the characteristics of the resource

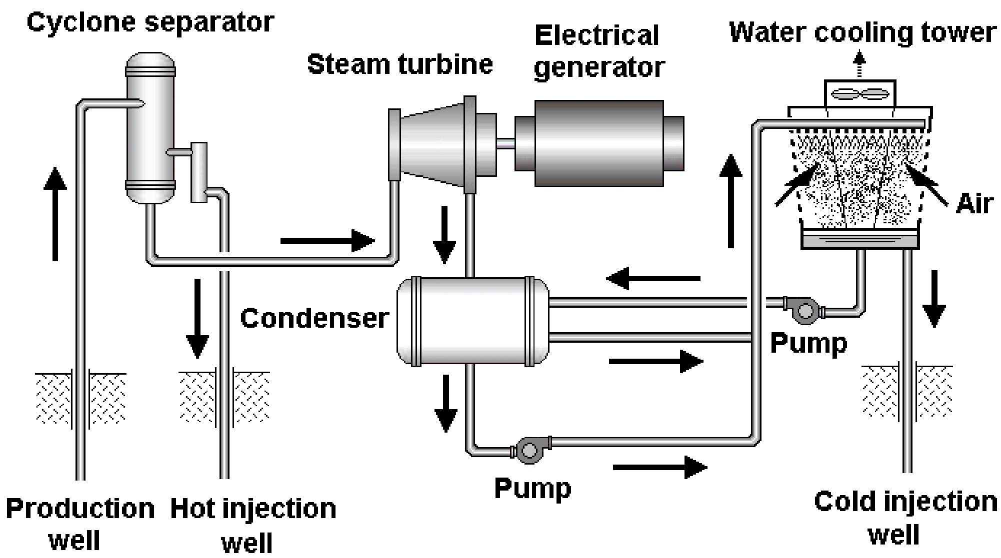
TECHNOLOGY: DIRECT STEAM PLANTS



SONOMA UNIT, 72 MW
THE GEYSERS, CALIFORNIA, UNITED STATES

[operational since 1983]

TECHNOLOGY: FLASH STEAM PLANTS



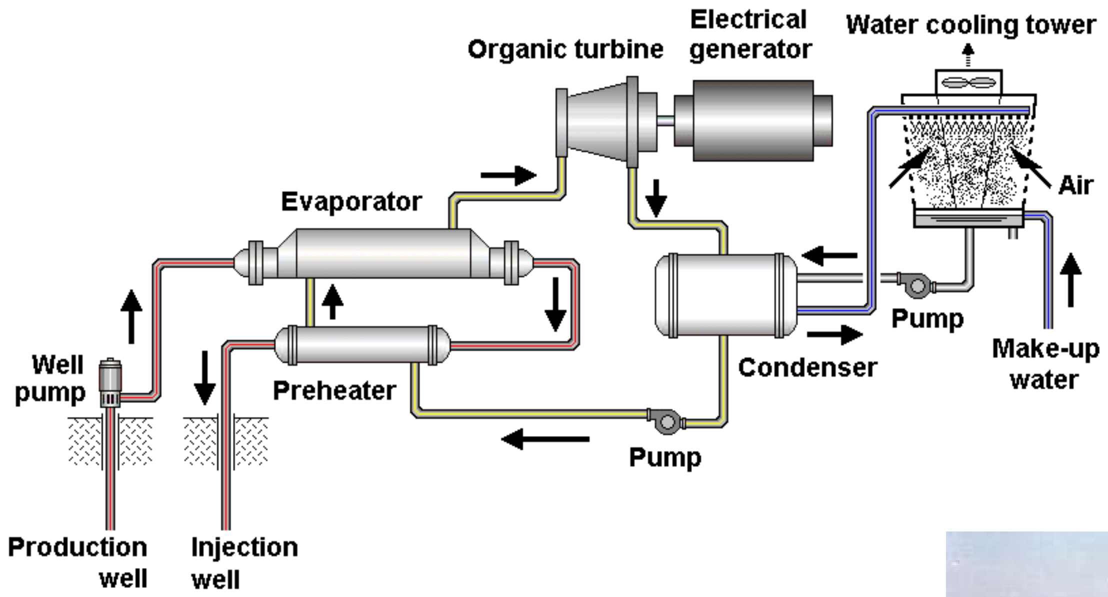
AHUACHAPÁN, EL SALVADOR

3 POWER UNITS:
2x30 MW, 1x35 MW

[operational since 1983]

Photo credit: LaGeo

TECHNOLOGY: BINARY PLANTS (WATER COOLED)



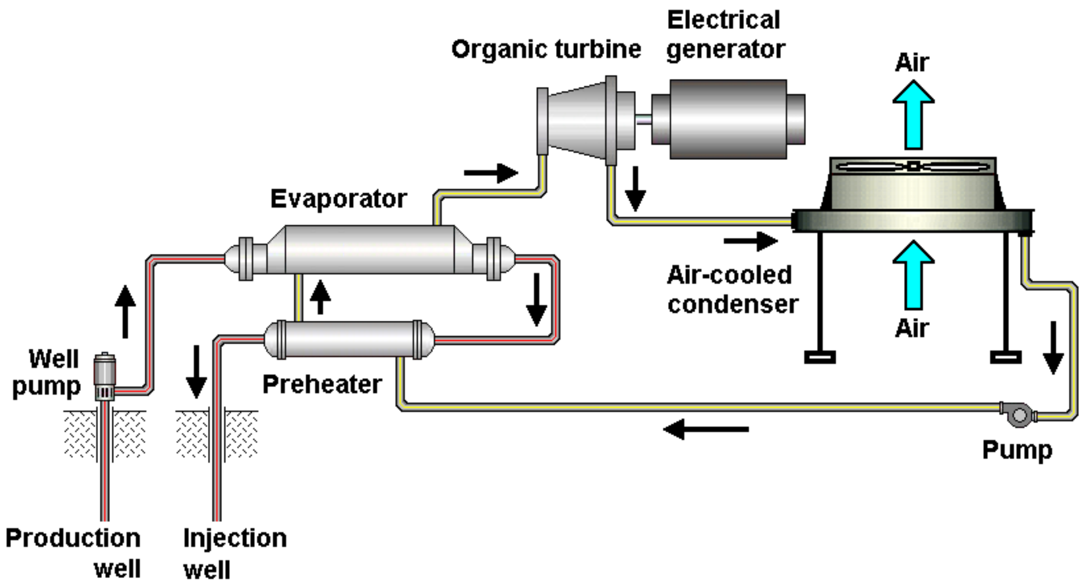
HEBER 2 POWER PLANT
HEBER, CALIFORNIA

12 UNITS: 33 MW TOTAL

[operational since 1983]

Photo credit: Ormat

TECHNOLOGY: BINARY PLANTS (AIR COOLED)



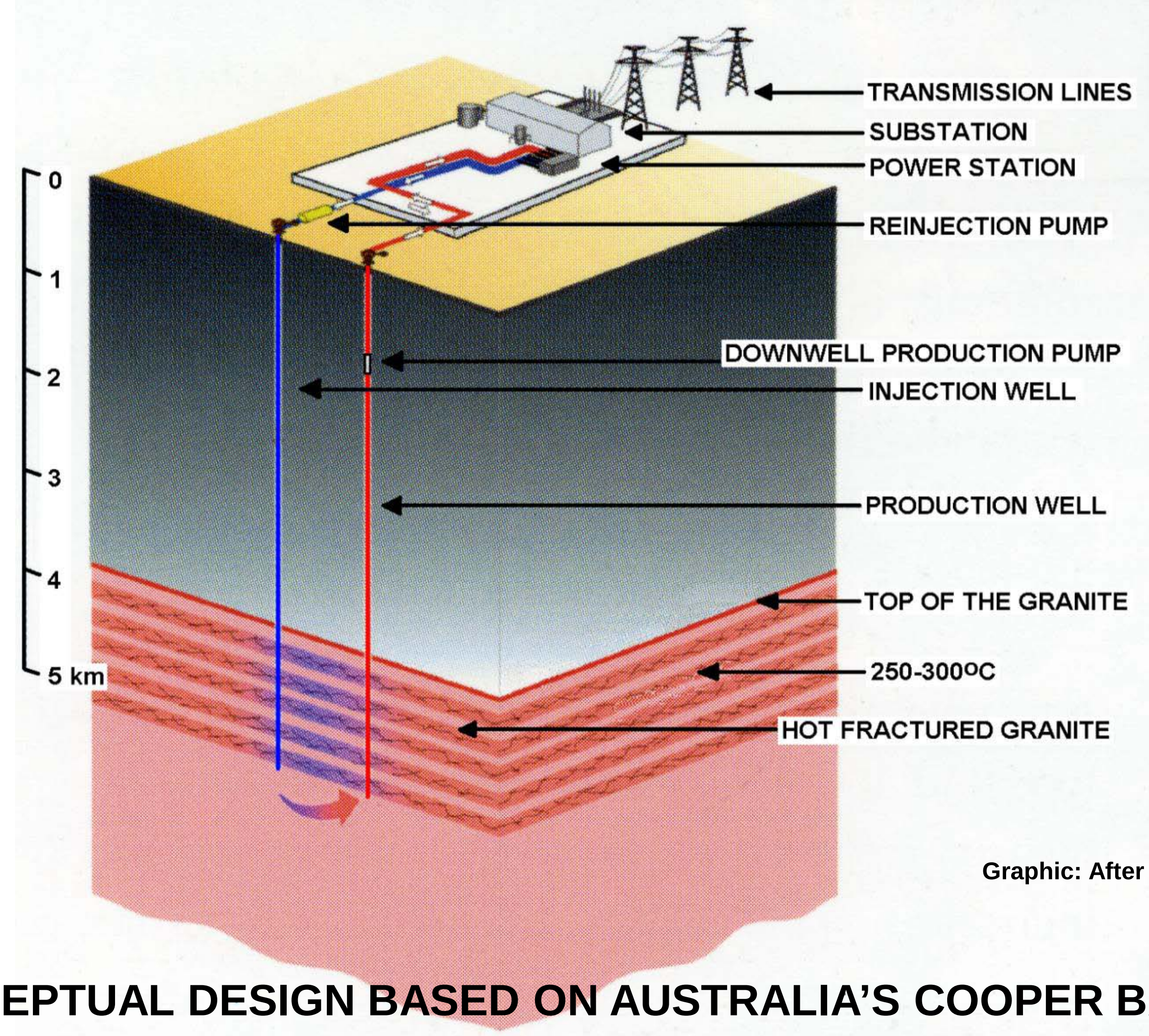
STEAMBOAT PLANTS 2 & 3
NEVADA, UNITED STATES

4 UNITS: 28 MW TOTAL

[operational since 1983]

Photo credit: R. DiPippo

TECHNOLOGY: ENHANCED GEOTHERMAL SYSTEMS



Graphic: After Geodynamics

CONCEPTUAL DESIGN BASED ON AUSTRALIA'S COOPER BASIN

TECHNOLOGY: EGS REQUIREMENTS

- Select a suitable site
- Drill at least 2-3 very deep wells
- Create or enhance permeability
- Stimulate a connection between or among the wells
- Maintain a continuous flow of fluid
- Achieve high mass flow rates and high fluid temperature from the production wells
- Replicate the above to create a network of wells
- Design, construct, and operate a power plant
- Deliver the electricity to users

EGS – IT CAN BE DONE!

SOULTZ-SOUS-FORÊTS, FRANCE

1.5 MW-net PLANT

SOULTZ WELLS: (L-R)
GPK4, GPK3 & GPK2 (w/pump)

BRINE-ISOBUTANE HXERS;
AIR-COOLED CONDENSER (in rear)

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ENVIRONMENTAL IMPACTS

- **Environmental Advantages**
- **Potential Environmental Problems**

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ENVIRONMENTAL ADVANTAGES

- Very low gaseous emissions
- No contamination of fresh water supplies
- Negligible or no solid waste emissions
- Low noise during plant operation
- Low land usage
- Low water usage; zero water use if air-cooled

CO_2 EMISSIONS COMPARISONS

Plant type	CO_2 emissions kg/MWh	Emissions relative to a coal plant
Coal-fired steam plant	994	1.00
Oil-fired steam plant	758	0.76
Natural-gas-fired combustion turbine	550	0.55
Natural-gas-fired combined cycle	365	0.37
The Geysers (CA) dry-steam plant	40.3	0.041
Flash-steam plant (typical)	27.2	0.027
Geothermal binary plant	0	0

LAND USE COMPARISONS

Power plant technology	Land usage	
	m^2/MW	m^2/GW-h
110 MW geo-flash plant (including wells)	1,260	160
20 MW geo-binary plant (excluding wells)	1,415	170
670 MW nuclear plant (plant site only)	10,000	1,200
2,258 MW coal-fired plant (including strip-mining area)	40,000	5,700

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POSSIBLE ENVIRONMENTAL PROBLEMS

- Well blowouts
- Thermal pollution
- Destruction of thermal manifestations
- Disturbance of natural habitat, cultural artifacts, wildlife, vegetation, and vistas
- Ground subsidence
- Induced seismicity, landslides, and earthquakes

ENVIRONMENTAL ISSUES: POTENTIAL LANDSLIDES

LANDSLIDE AT ZUNIL, GUATEMALA

Photo credit: Google Earth

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PROJECT DEVELOPMENT FLOW

- Resource identification
- Resource assessment
- Exploratory well drilling and testing
- Development well drilling
- Plant and fluid gathering systems design
- Construction phase
- Performance testing, verification, and acceptance
- Long-term operation

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PROJECT TIME FRAMES AND COSTS

Project Phase (30 MW plant)	**Time Frame years**	**Est. Cost M US$ (2008)**
Resource identification	2-3	$6
Resource assessment		
Exploratory well drilling and testing		
Development well drilling	3-4	$20
Plant and fluid gathering systems design	2-4	$75
Construction phase		
Performance testing, verification and acceptance		
Long-term operation (annual costs)	25+	$2
Installed cost (US$/kilowatt)	**$3,365**	

FACTORS AFFECTING COSTS

- Quality of resource
- Technical problems and delays
- Availability and cost of professionals and trained labor
- Cost of capital, exchange rates
- Plant reliability
- Plant capacity factor
- Electricity price for base-load, non-dispatchable power

COMPARATIVE COSTS OF GENERATION

Technology	Plant Size, MW	Capital Cost, US$/kW	Development Time, years
Nuclear	1,000-1,200	4,500-7,500	10+
Coal	300	2,000-4,000	6+
Combustion Turbine	250	700-1,000	2-3
Combined-Cycle Gas Turbine	500-1,400	800-1,200	3-4
Geothermal Steam	50	2,000-3,000	10
Geothermal Binary	20	2,500-3,500	5-7
EGS Binary	5	15,000 est.	10

GEOTHERMAL INVESTMENT ISSUES

- Business Models
- Permitting
- Incentives
- Financing

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ISSUE: BUSINESS MODELS

Utility-Owned and Developed

- ICE/Miravalles field, Costa Rica

Independent Power Producer (IPP)

- Public auction of resource rights
- Private development of resource and plant
- Long-term sales agreement with utility

Hybrid Utility/IPP

- The Geysers field, California
- Miravalles field, Costa Rica

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ISSUE: COMPLEX PERMITTING PROCESS

Laws Governing US Geothermal Projects

- ✓ Clean Air Act
- ✓ National Environmental Policy Act
- ✓ National Pollutant Discharge Elimination System Permitting Program
- ✓ Safe Drinking Water Act
- ✓ Resource Conservation and Recovery Act
- ✓ Toxic Substance Control Act
- ✓ Noise Control Act
- ✓ Endangered Species Act
- ✓ Archeological Resources Protection Act
- ✓ Hazardous Waste and Materials Regulations
- ✓ Occupational Health and Safety Act
- ✓ Indian Religious Freedom Act

ISSUE: FINANCING

- Power Purchase Agreements (PPA)
- Incentives vs. disincentives

  - loan guarantees
  - tax credits/reductions
  - early depreciation

- Public-private partnerships

BARRIERS TO MARKET PENETRATION

- Infrastructure inadequacies
- Site accessibility
- Social barriers
- Education vs. misconceptions

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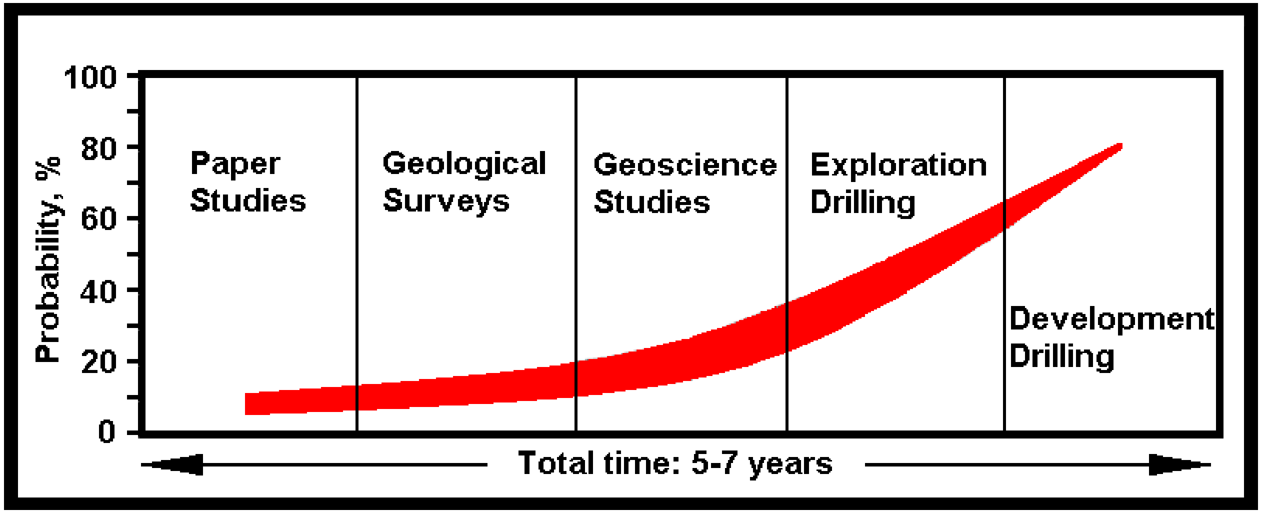
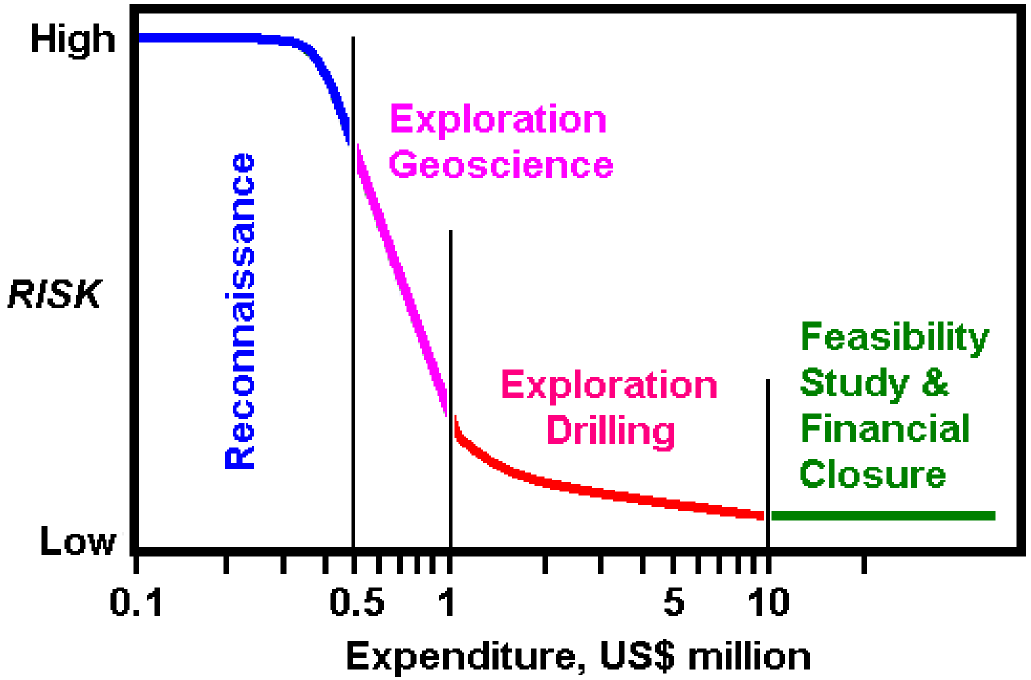
BARRIER: TECHNOLOGICAL LIMITATIONS

- Resource identification and assessment
- Resource longevity
- Transmission line access and cost

PROJECT DEVELOPMENT RISKS

PROBABILITY OF PROVING UP A VIABLE PROJECT





RISK AS A FUNCTION OF EXPENDITURE

Graphics: Barnett et al, 2003

BEST PRACTICES: GEOTHERMAL POWER

- Community involvement from the beginning
- Respect for the environment
- Respect for local culture
- Early buy-in from utility (PPA)
- Secure financing
- Community enhancements, rural electrification

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SUCCESSFUL GEOTHERMAL PROJECTS

- Olkaria project - Central Kenya
- Berlín project - Eastern El Salvador

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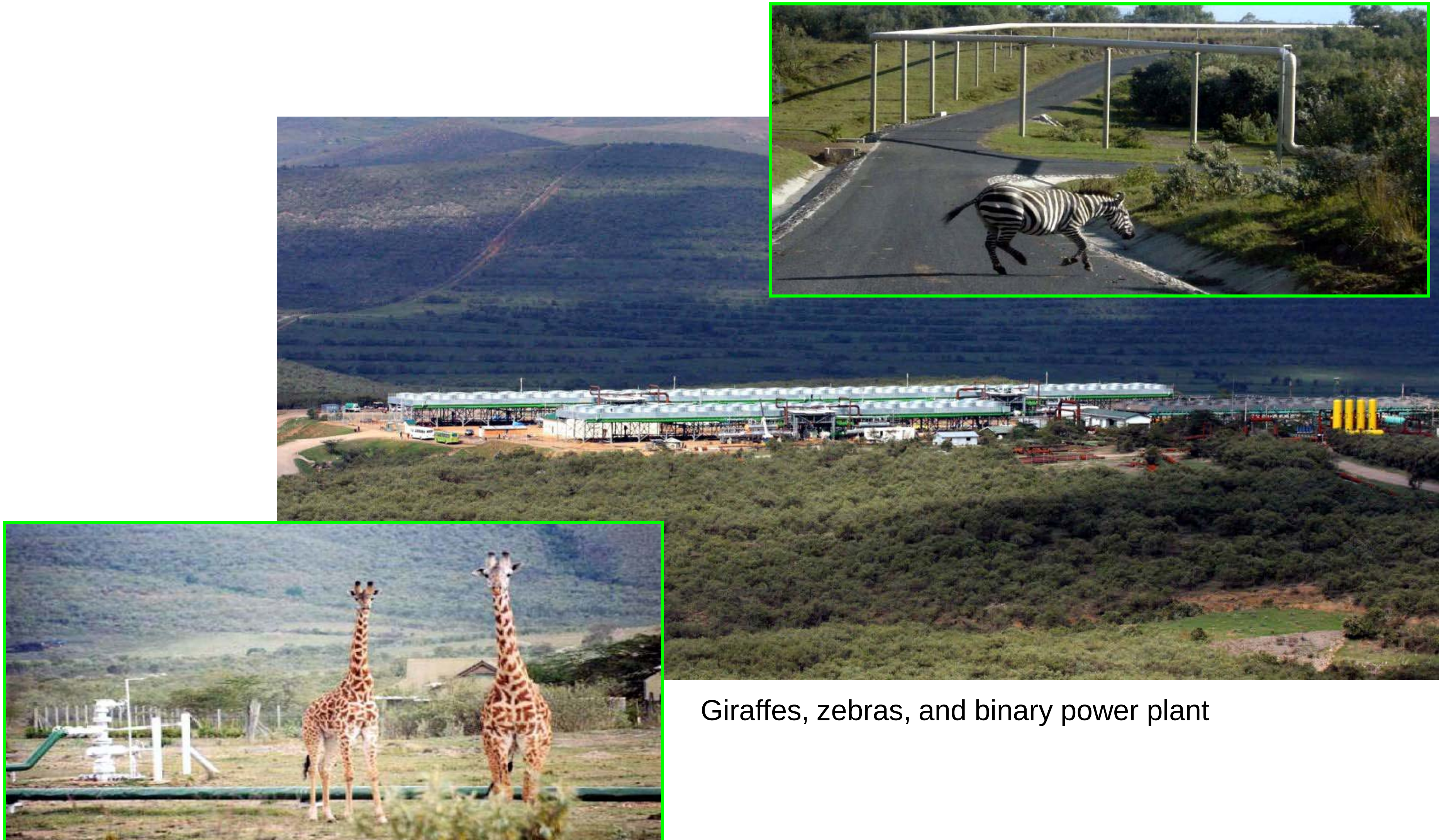
OLKARIA, KENYA



Giraffes, zebras, and binary power plant

BERLÍN, EL SALVADOR

LaGeo Computer Center

Geothermal greenhouse

El Tronador park and geothermal pool