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Life-Cycle Analysis of Geothermal Technologies

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Analysis, Data System and Education

Project Overview

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- Project start date: June 2009
- Project end date: not applicable (annual GTP program)
- Percent complete: not applicable
- Budget:
  - FY09: $500K (100% DOE)
  - FY10: $500K (100% DOE)
- Barriers to address
  - Energy, GHG emissions, and water impacts of GTs
- Partners/collaborators: NREL, INL, and SNL

Relevance/Impact of Research

- This project was launched in FY2009 by GTP to help develop
  - GHG emission profiles of geothermal technologies (GTs)
  - Water resource impacts of GTs
  - To address GHG and water issues of other power generation technologies for comparison purpose
- The results and tools from the effort will help GTP and stakeholders determine and communicate GT energy and GHG benefits and water impacts
- The life-cycle analysis (LCA) approach is taken to address these effects
- The process of LCA helps identify key stages and issues affecting LCA results of GTs

Life-Cycle Analysis Approach for GTs

Raw Materials Extraction

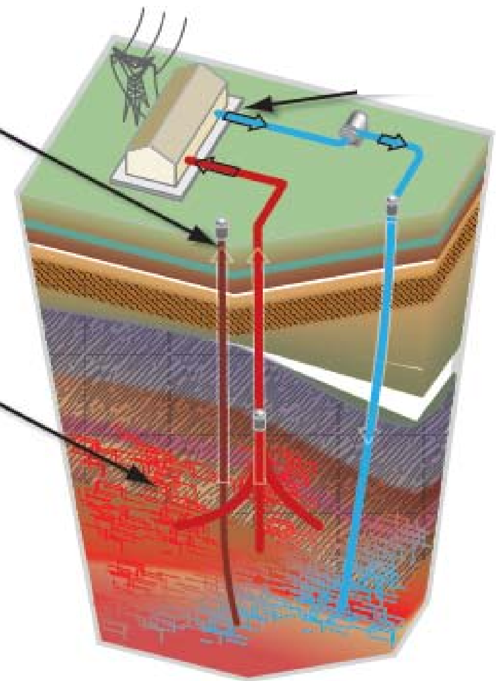
Component Manufacturing

Drill and Log Exploratory Well

Drill Injection Well

Stimulate/ Create Reservoir

Drill Production Well



Facility Construction

Complete and Verify Circulation Loop

Install Operations Equipment

Power Plant Construction

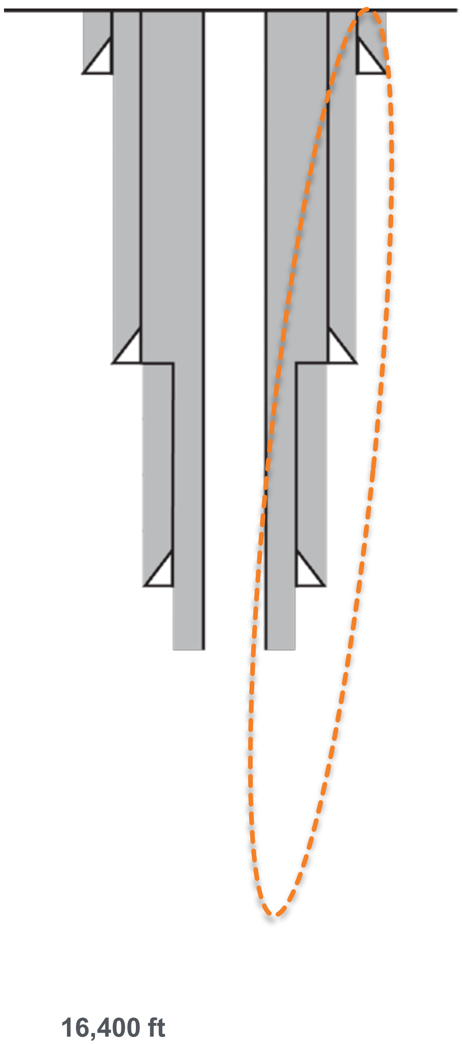
Decommission and Deconstruction (?)

Key Stages and Issues Are Been Addressing through This Project

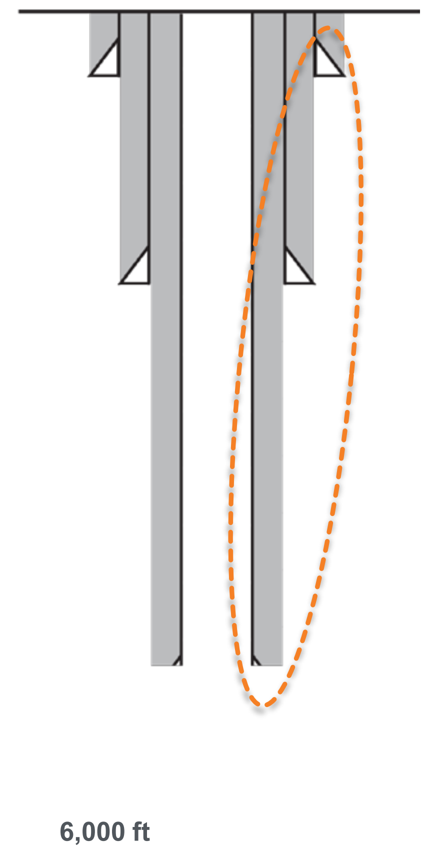
- Well characterization
  - Thermal characteristics: resource temperature, thermal drawdown rate
  - Well depth and size, number of exploration, injection, and production wells
  - Type and amount of materials for well construction
  - Interacted with GETEM simulations at INL; NREL scenario development; and expert consultation
- Power plant characterization
  - Size of power plants
  - Type and amount of materials for power plant construction
  - Geothermal field power use and net power production
  - Interacted with GETEM simulations at INL and NREL scenario development
- Geothermal operation
  - Working fluid characterization
  - Makeup water requirements
- Configuration of GT LCA
- Characterization of other power generation systems for comparison

Well Characterization

EGS Scenarios



Hydrothermal Scenarios



Tester et al. 2006

Number of Wells

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- Scenarios were developed for use in INL's Geothermal Electricity Technology Evaluation Model (GETEM)
- Number of wells depend on several parameters including:
  - Power plant size
  - Temperature of the resource
  - Well depth
  - Flow rate
  - Producer to injector ratio

Scenarios	Average Number		
	Production Wells	Injection Wells	Total Wells
20 MW EGS	6	3	10
50 MW EGS	16	8	24
10 MW Binary	3	1	4
50 MW Flash	15	6	21

Water Quantity and Quality

- Quantity of water
  - Account for water required for drilling, cementing, and stimulating wells.
  - Account for water required for cementing surface pipeline.
  - Calculate makeup water requirements for operations phase according to available data.
- Quality of geofluid
  - Collect, aggregate, and analyze available data on geothermal brines.
  - Calculate distributions of chemical constituents.
  - Evaluate correlations between key reservoir properties and chemical constituent concentrations.
  - Qualitatively analyze potential challenges to operations and opportunities for mineral extraction.

EGS Stimulation (Water and Fuel)

- Reservoir stimulation occurs at the injection wells
- Water-based stimulation assumed
  - Literature values provided volume and flow rate information (average: 22,390 m^3, 97 L/s).

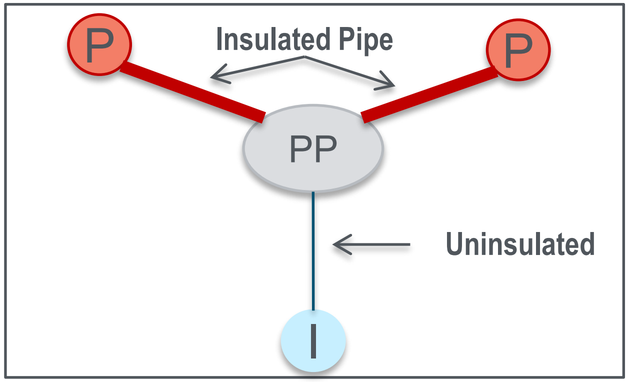
Location	Basement Depth (m)	Temperature (°C)	Volume of water (m^3)	Highest Flow Rate (L/s)
Cooper Basin, Australia	4,421	250	20,000	48
Soultz-sous-Forêts, France	5,091	200	34,000	93
Groß Schönebeck, Germany	4,200	150	13,170	150

- Diesel fuel consumption is based on industry experts
  - 5.7-7.6 L/minute (1.5-2 gpm) per pump
  - 1 pump can move 1.3-1.4 m^3/minute (8-9 bpm) of stimulation fluid
- Fuel consumption per job is assumed to be 118.5 m^3 (31,300 gal)

Scenarios	Water for Stimulation (m^3)	Diesel for Stimulation (m^3)
EGS, 20 MW	71,019	376
EGS, 50 MW	177,152	937

Surface Pipeline

- Pipelines connect production wells to central plant to injection wells
  - Pipeline length: 1000 m
- 8-10 inch diameter pipe requires support every 19 ft.
  - Structure includes forming tubes, cement foundation, rebar, and steel support
- Insulation used for pipe and support contacts
- Installation of pipeline requires water and fuel



Scenarios	Total Steel (Mg) (pipe, support, rebar)	Total Class A Cement (Mg) (foundation)	Total Forming Tube (Mg) (foundation)	Total Water (gallons) (foundation)	Diesel fuel consumption (gal)	Total Insulation (Mg)
EGS, 20MW	332	335	22	39,148	63,282	22
EGS, 50MW	**827**	**835**	**54**	**97,651**	**157,852**	**55**
Binary, 10MW	155	157	10	18,314	29,604	10
Flash, 50 MW	**769**	**769**	**50**	**89,959**	**145,417**	**50**

↑ Power,
↑ # of Wells,
↑ # of Pipelines

Power Plant Construction Characterization

- Material composition of GT plants was obtained from Icarus Process Evaluator.
  - For the selected plant types, the provided quantities of rebar, structural steel, concrete, various sizes of pipes and wire and equipment were converted to weights of concrete, steel, copper, aluminum, wood, etc.
- Material composition of conventional power plants is based on extensive literature review.

Plant Material Intensity: Steel Use in Tonnes/MW

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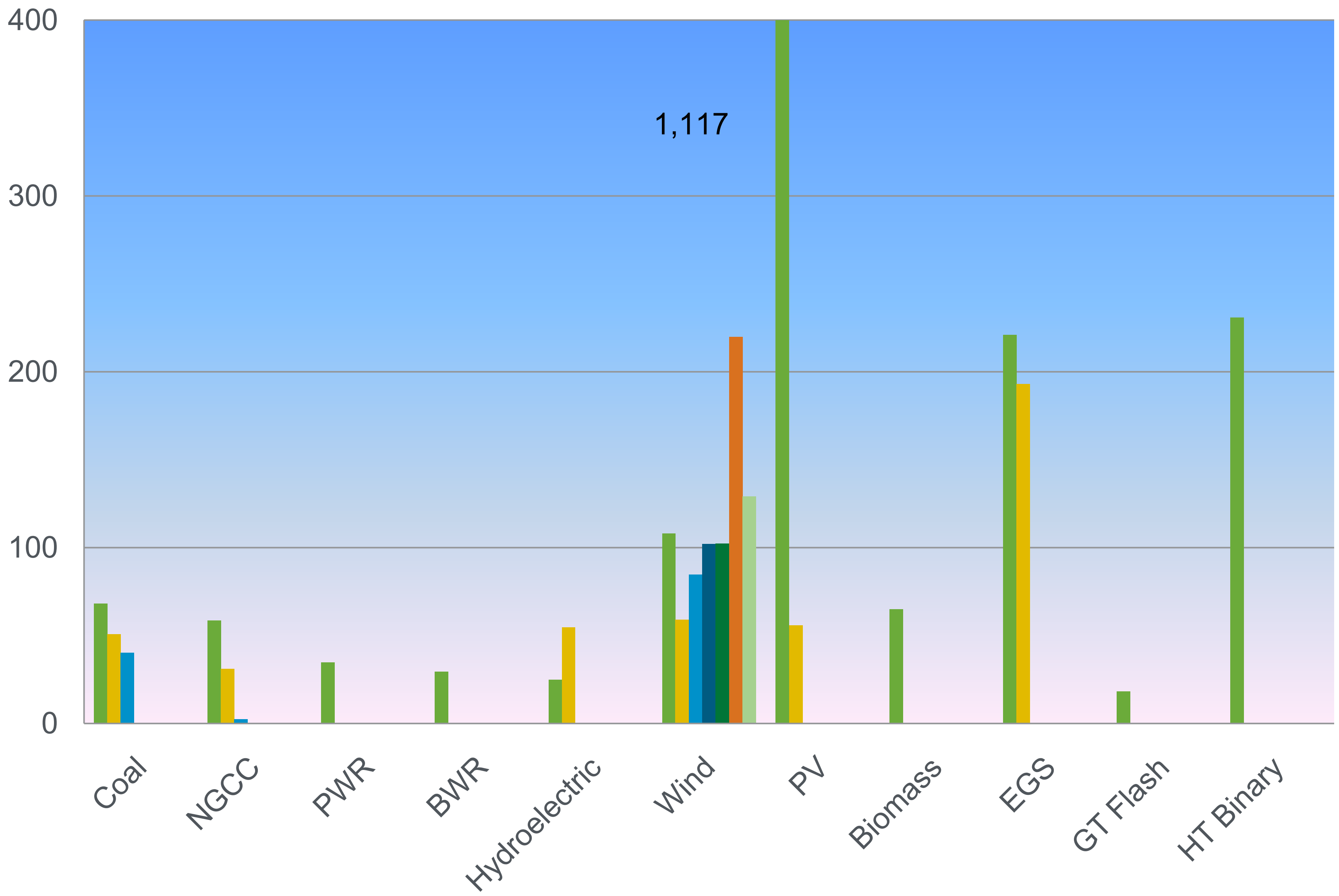

Four Stage LCA Effort

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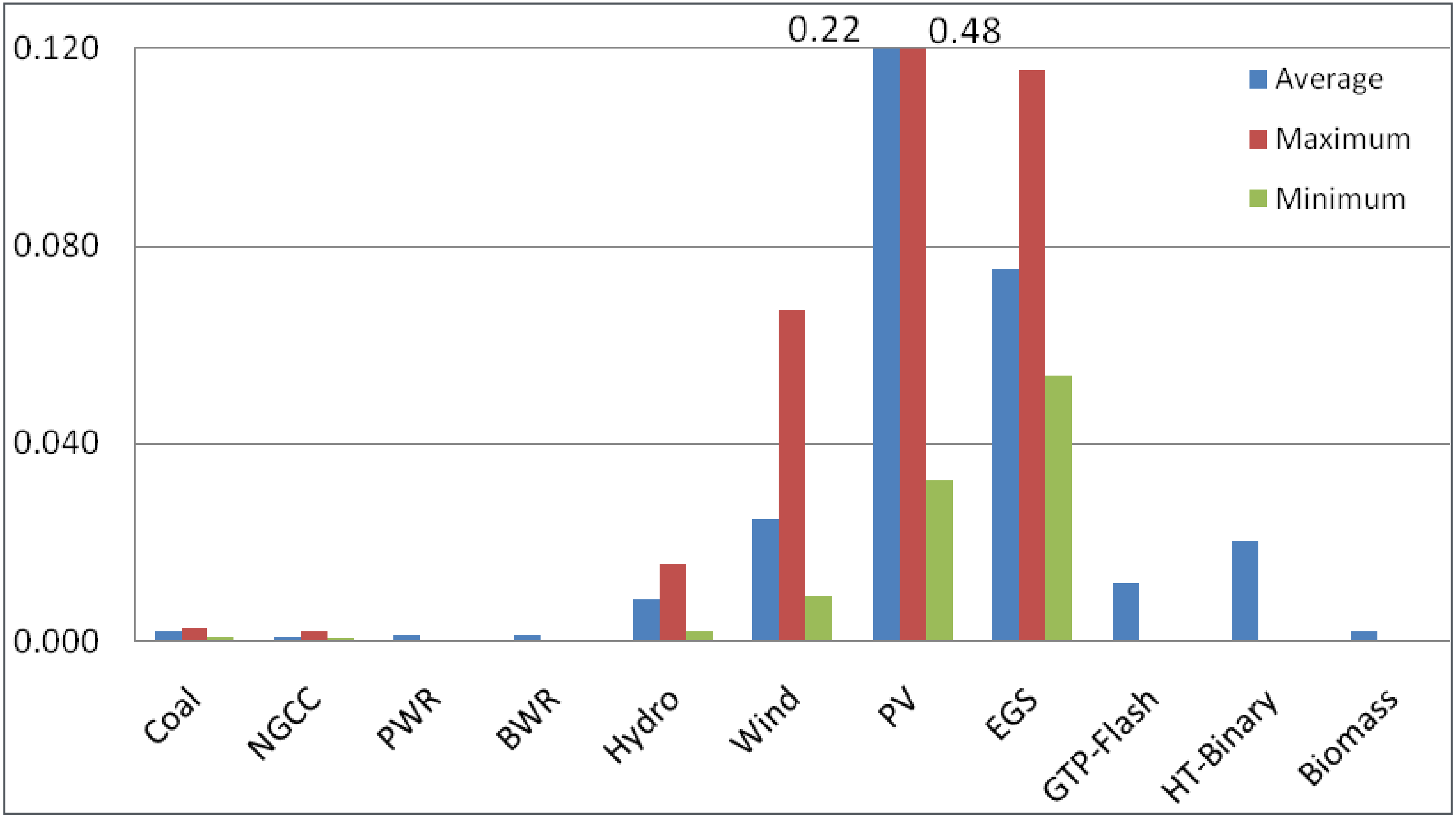
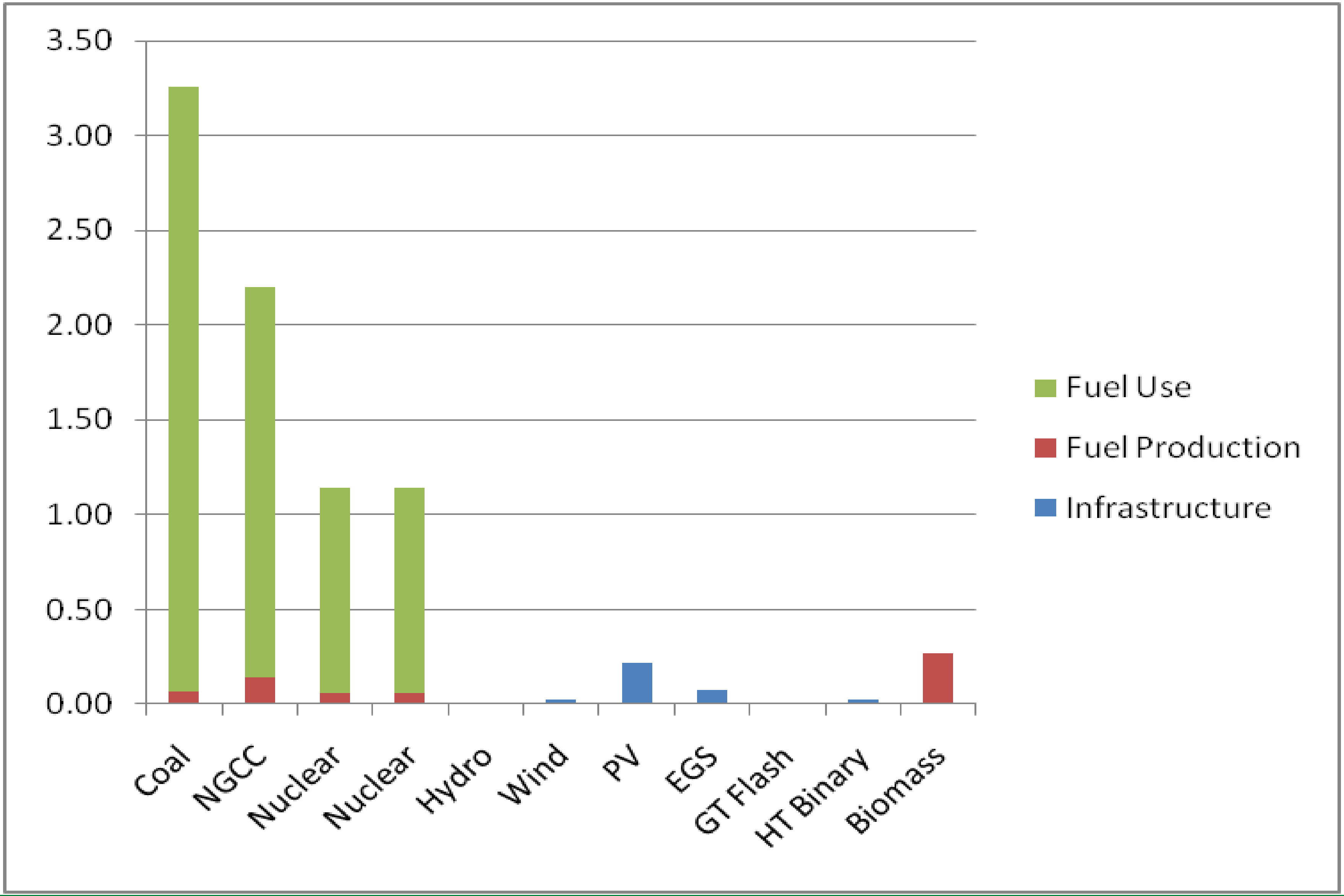
- ❑ Facility construction (infrastructure-related activities)
  - Gather data for all power plant types (geothermal, coal, etc.) including:
    - ✓ Plant and equipment material composition
    - ✓ Construction energy (diesel for excavators, craness) added where data available
  - Construction for conventional power plants was added to GREET this time
- ❑ Fuel production (e.g. drilling and delivering geothermal fluid, oil, gas, etc.)
  - For most fuels, production is well characterized in GREET
  - For geothermal well infrastructure, drilling energy and water requirements were estimated for binary and flash technologies
- ❑ Power plant operation
  - GT plant operating emissions for the flash plant were obtained from available literature
  - Makeup water estimate is in process
  - Operation of conventional power plants is well simulated in GREET
- ❑ Integration of infrastructure construction, fuel production, and plant operation into GREET for LCA modeling

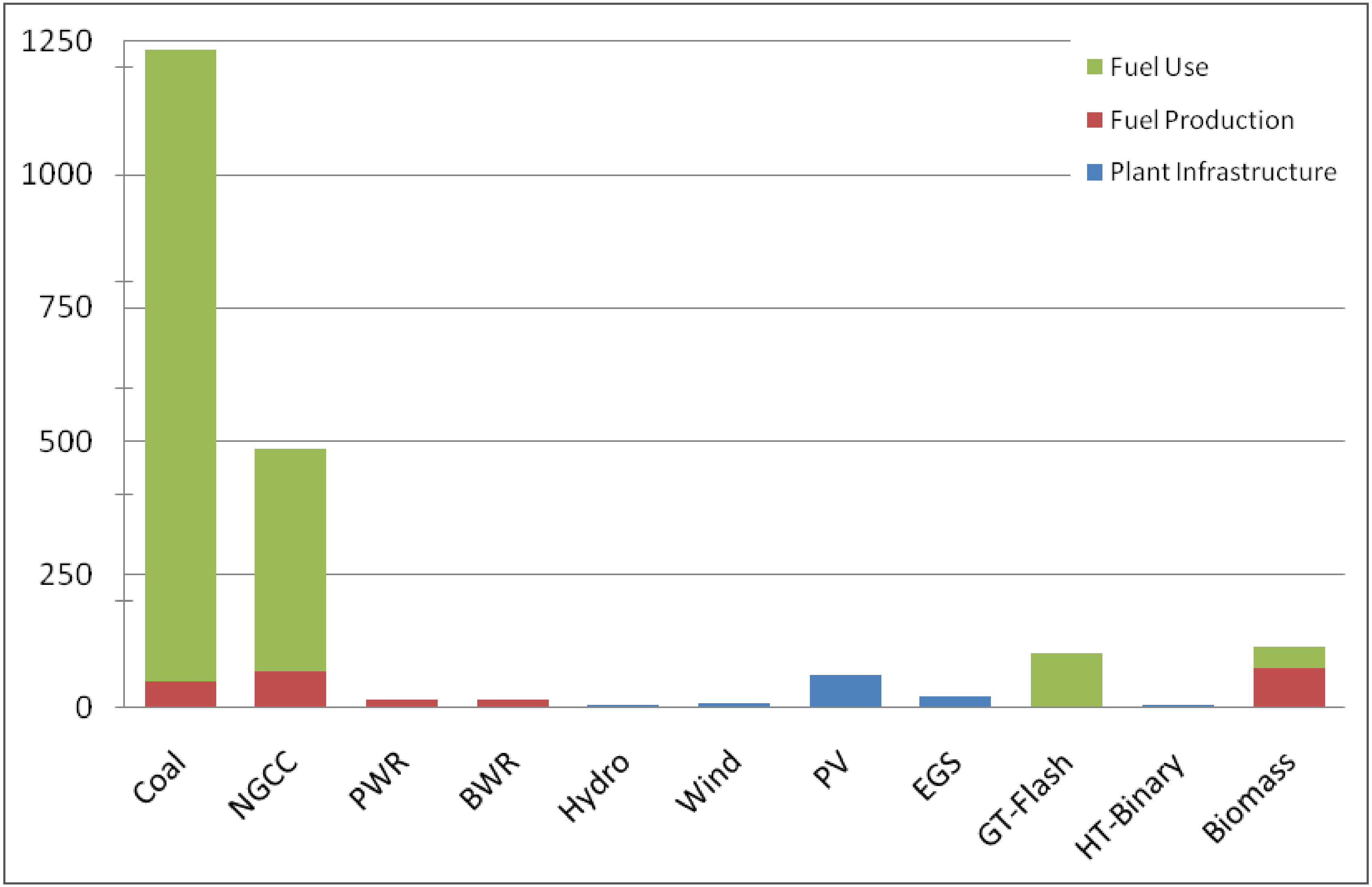
Ratio of Energy Input to Energy Output: Facility Construction Only



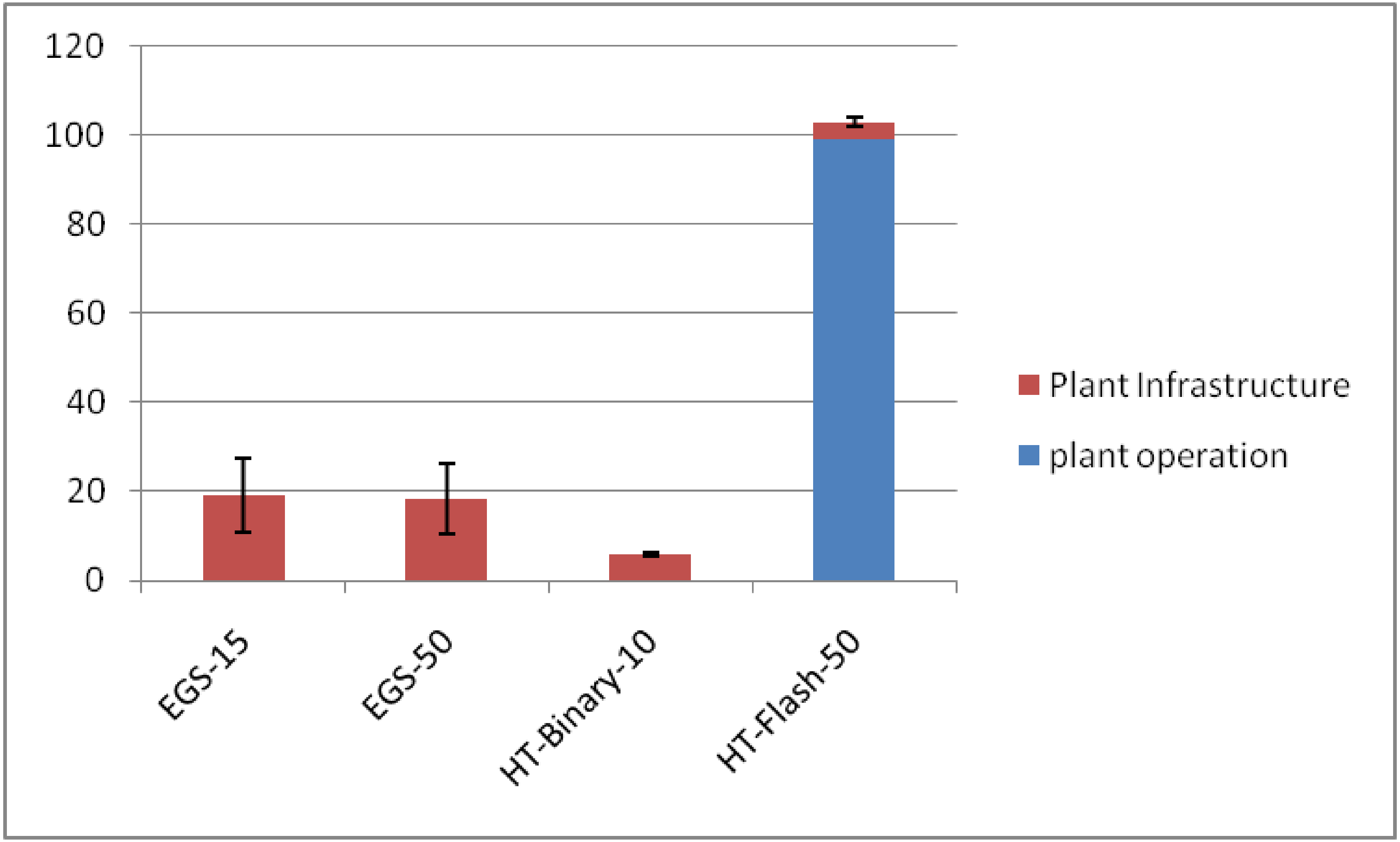
Ratio of Energy Input to Energy Output: All Life Cycle Stages



GHG Emissions of Power Generation by Life Cycle Stage in g/kWh



Comparison of Geothermal GHG Emissions Due to Infrastructure (g/kWh)



Error Bars apply only to infrastructure

GHG Emission and Energy Use Key Findings

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- Plant Infrastructure Production
  - Estimation of the material and construction needs for GT and other power technologies is complete
- Fuel Production
  - Estimation of GT well production is complete and has been added to GREET
- Of the renewables, GTP-flash, biomass, and PV have the highest life-cycle GHG emissions, though arising from different life cycle stages
- Life cycle GHG emissions from fossil plants are much larger than those from renewable plants
  - For coal, an order of magnitude than the largest renewable emitter
  - For efficient fossil like NGCC, 5 times larger
- With the possible exception of GT flash, GT power is in the lower segment of renewable power GHG emitters

Next Steps

- Re-examine critical issues affecting LCA results.
- Incorporate pump material information into inventory.
- Complete aggregation and integration of water quantity information.
- Continue analysis of water quality data.
  - Compare results on GHG constituents with literature estimate of GHG emissions used in the LCA for the flash plant scenario.

Supplemental Slides

Relevant Publications and Presentations

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Clark, C., Harto, C., Sullivan, J. and M. Wang. *Water Use in the Development and Operations of Geothermal Power Plants*. Argonne National Laboratory. In process.
- Sullivan, J., Clark, C., Han, J., and M. Wang. *Life Cycle Analysis of Geothermal Systems in Comparison to Other Power Systems,* Argonne National Laboratory. In process.
- Sullivan, J., Clark, C., Han, J., and M. Wang. "Life Cycle Assessment of Electricity Generation: Conventional, Geothermal and Other Renewables," *GRC 2010 Annual Meeting*. Sacramento, CA. October 24-27, 2010.
- Clark, C., Wang, M., Vyas, A., and J. Gasper, "Life Cycle Approach to Understanding Impacts of EGS," *GRC 2009 Annual Meeting*. Reno, NV. October 4-7, 2009.
- Clark, C. "Water Use and Large-Scale Geothermal Energy Production," *Water/Energy Sustainability Symposium at the GWPC Annual Forum 2009*. Salt Lake City, UT. September 13-16, 2009.

Water Use in Geothermal Plant Operations

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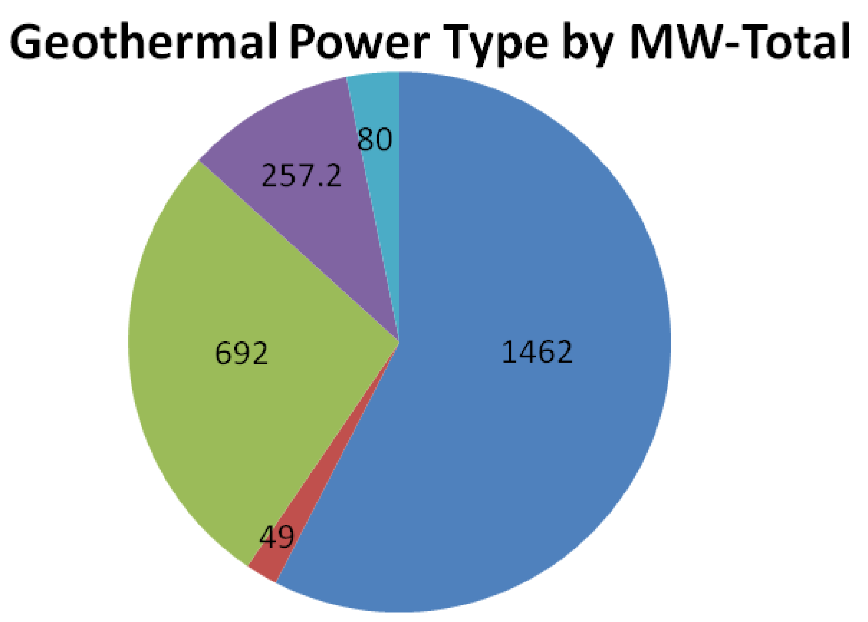
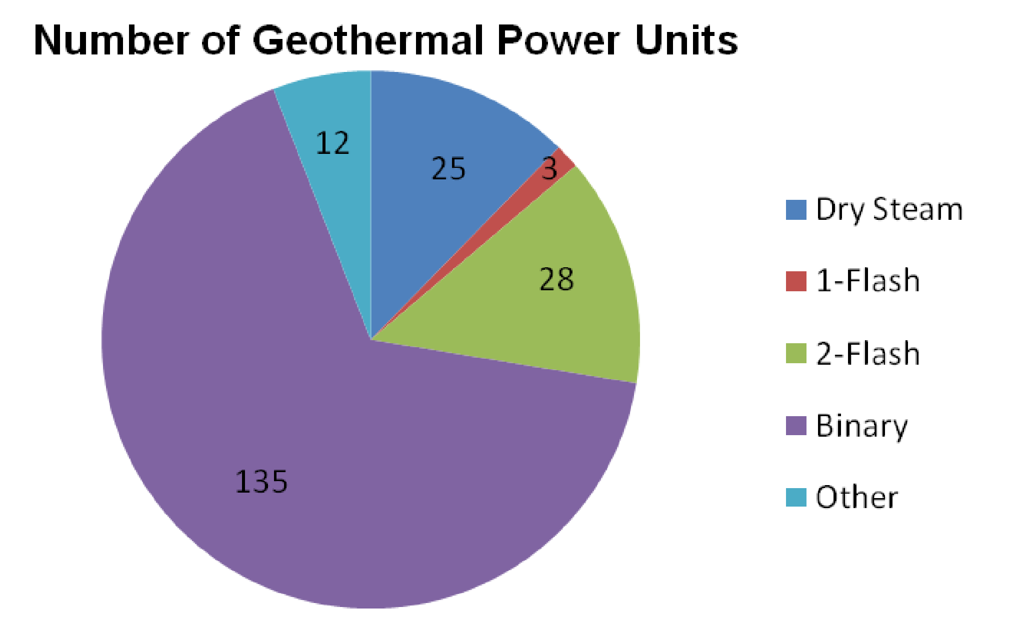
- Estimates provided in *Energy Demands on Water Resources* were from one geothermal power production site (the Geysers)
  - 2,000 gal/MWhe withdrawal; 1,400 gal/MWhe consumption
- The Geysers is unique
  - It is the only known dry steam field in the US
  - It is the largest geothermal power producer in the world
- The majority of industry power unit installations are binary



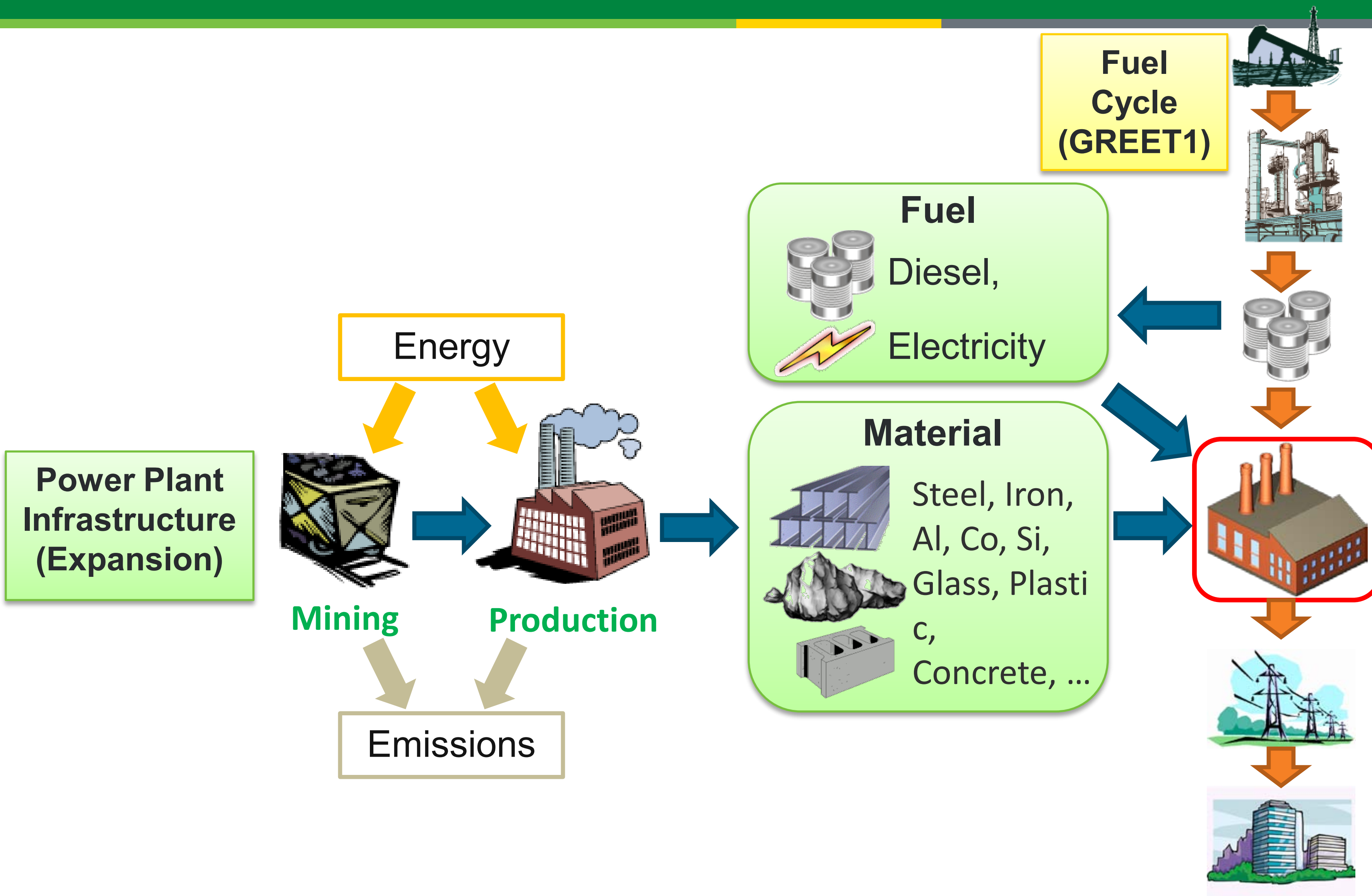


Data as of May 2007 (DiPippo 2008).

Water Quality Data and Analysis

- Obtained five geochemical data sets
  - Great Basin Center for Geothermal Energy – Great Basin Groundwater Geochemical Database
  - USGS/Nevada Bureau of Mines and Geology – GOETHERM
  - Kansas Geological Survey – NATCARB brine database
  - Nevada Bureau of Mines and Geology – Nevada Low-Temperature Geothermal Resource Assessment
  - USGS – Chemical and Isotope Data (Mariner Database)
- Merged into a single, aggregated data set of 53,000+ data points.
  - Parameters such as location, depth, temperature, pH, and TDS.
  - Concentrations for 52 elements/ions.

GREET Expansion for Power Plant Infrastructure



Electricity Generation Systems in GREET

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1. Coal: Steam Boiler and IGCC
Coal mining & cleaning
Coal transportation
Power generation

2. Natural Gas: Steam boiler, Gas Turbine, and NGCC
NG recovery & processing
NG transportation
Power generation

3. Nuclear: light water reactor
Uranium mining
Yellowcake conversion
Enrichment
Fuel rod fabrication
Power generation

4. Petroleum: Steam Boiler
Oil recovery &transportation
Refining
Residual fuel oil transportation
Power generation

5. Biomass: Steam Boiler
Biomass farming & harvesting
Biomass transportation
Power generation

6. Hydro-Power

7. Wind Turbine

8. Solar Photovoltaics

9. Geothermal

Life Cycle Analysis for Power Plant Infrastructure

- Material use per TWh of lifetime generation
  = Material Use / (Generation Capacity x Utility Factor x Lifetime)
- Cradle-to-Gate energy uses and emissions for materials
  - Energy uses and emissions data are obtained from
    - ✓ Fuels (diesel and electricity) from GREET1
    - ✓ Most materials from GREET2
    - ✓ Concrete and cement from NREL LCI database
    - ✓ Silicon from de-Wild-Scholten & Alsema
- Energy uses and emissions for power plant infrastructure
  = ∑ (Material Use) x (Cradle-to-Gate Energy Uses and Emissions)