A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

MODELING PERFORMANCE AND ECONOMICS OF POWER GENERATION BY ENERGY RECOVERED FROM COPRODUCED GEOTHERMAL FLUIDS

Martin Vorum, P.E.

Dr. Gerald Nix, P.E.

National Renewable Energy Laboratory
Golden, Colorado

June 13, 2007

Agenda

- Goals
- Key Variables -- "Dials"
- Model Organization
- Case Studies
  - ✓ Temperature
  - ✓ Flow
  - ✓ Configuration
- Bases, Expansion
- Conclusions

Binary Systems

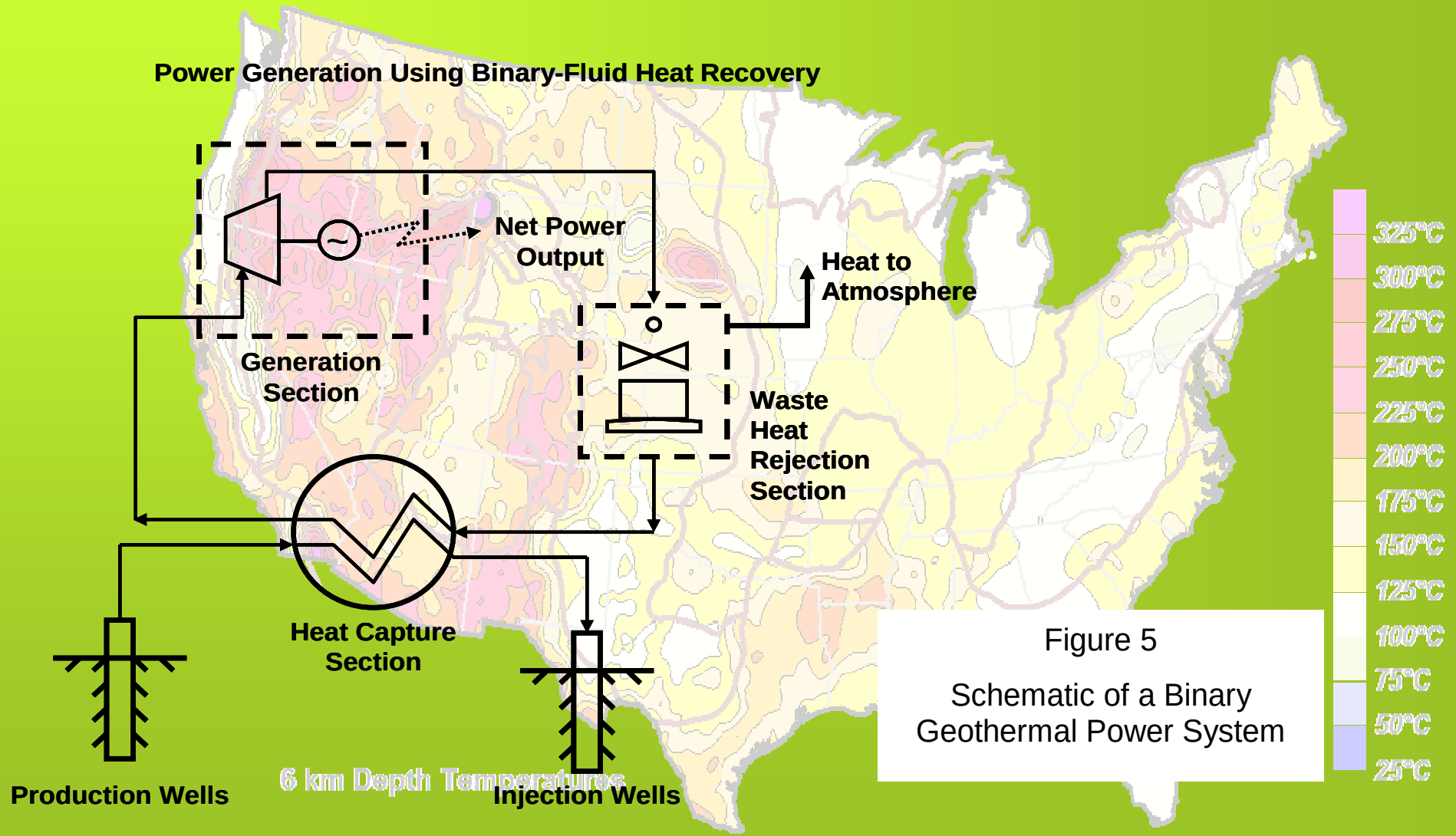


Figure 5

Schematic of a Binary Geothermal Power System

Goals

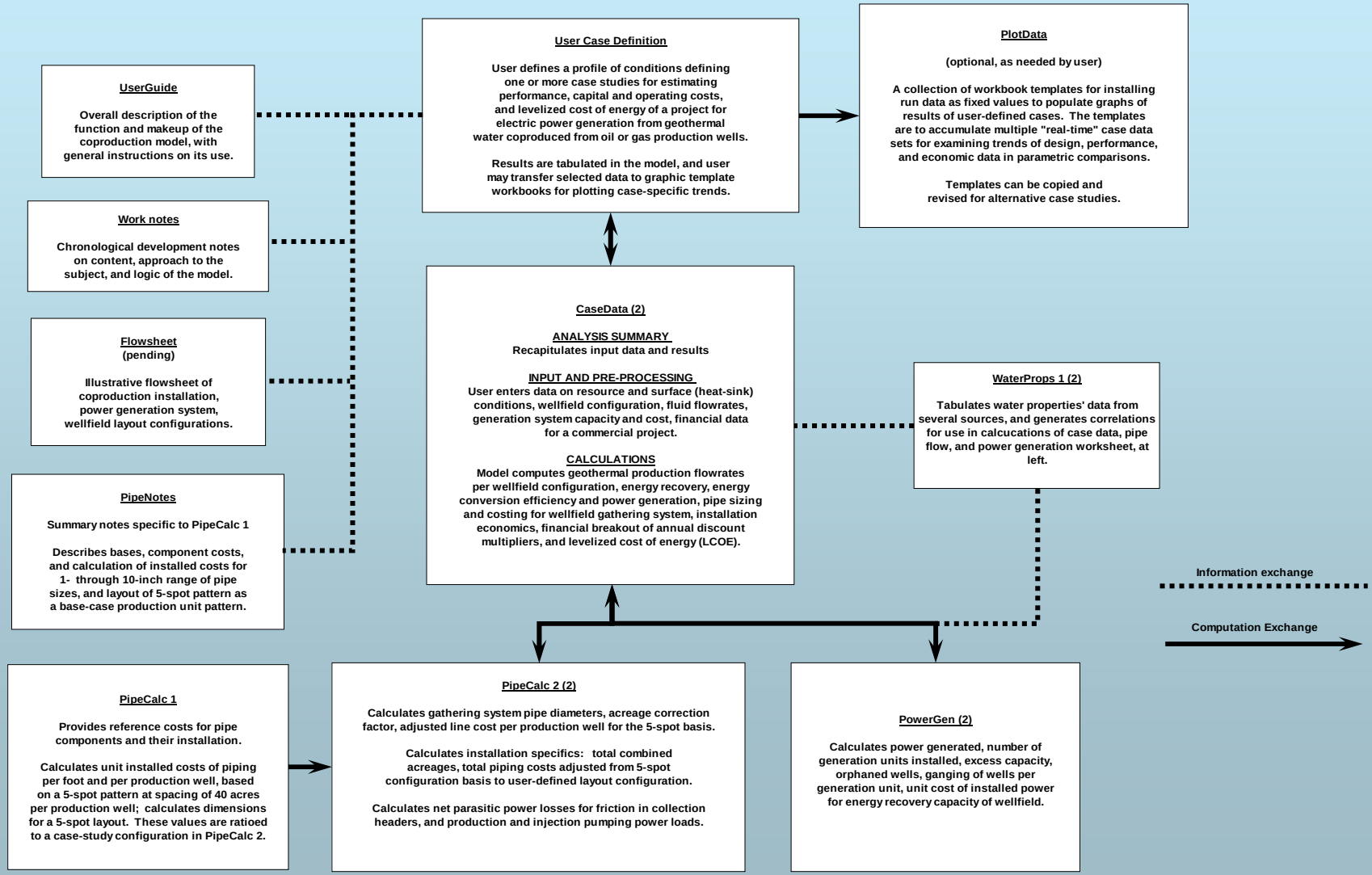
Functions

- Parametric
- Performance
- Economics
- Configuration
- COS

Parameters

- Temperature
- Flowrates
- System Capacities
- Capital Costs
- Financing Terms
  - ✓ Tax Credits

Program Organization



Temperature Effects

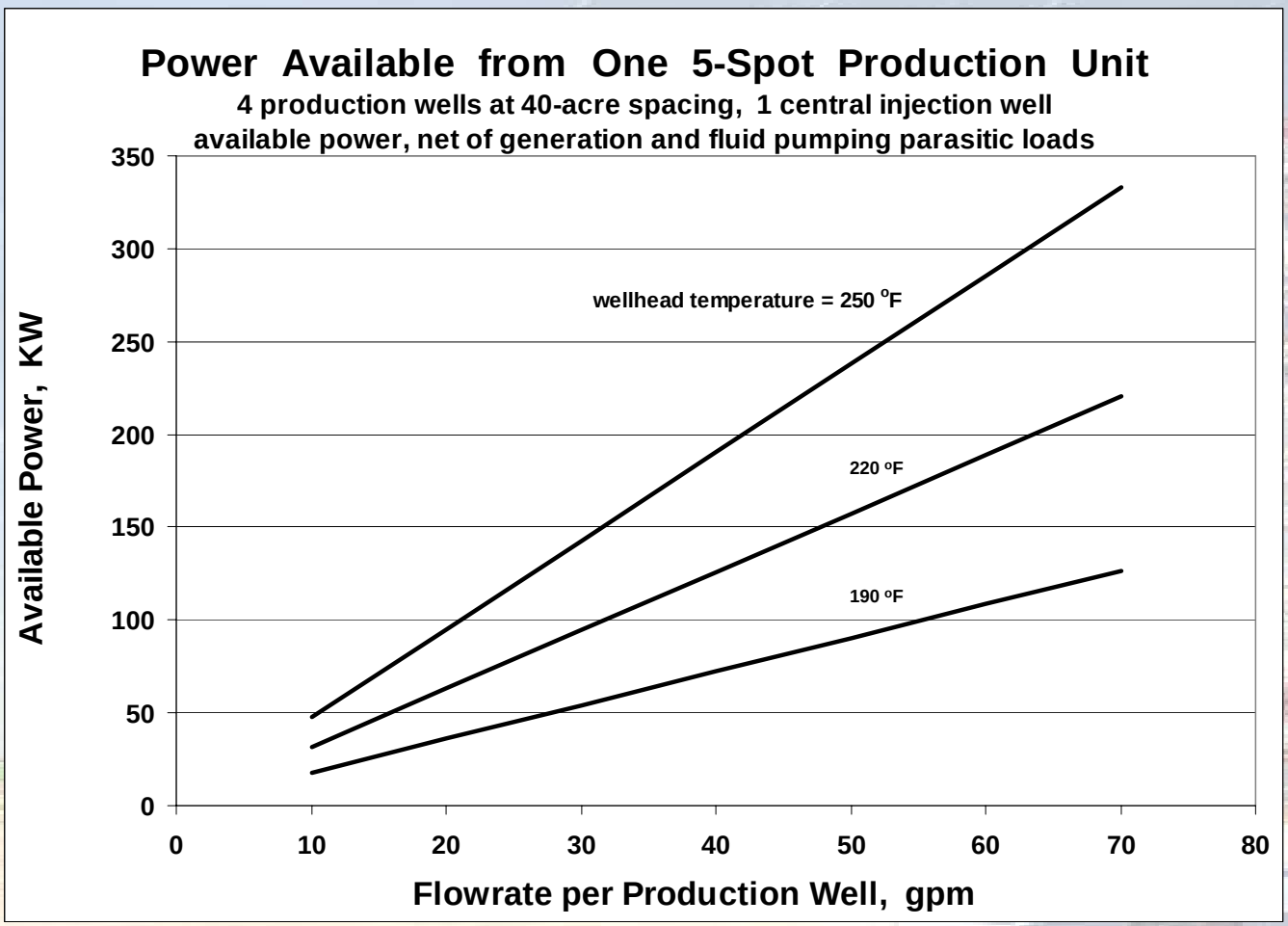


Figure 5 -- Net Available Power

COS

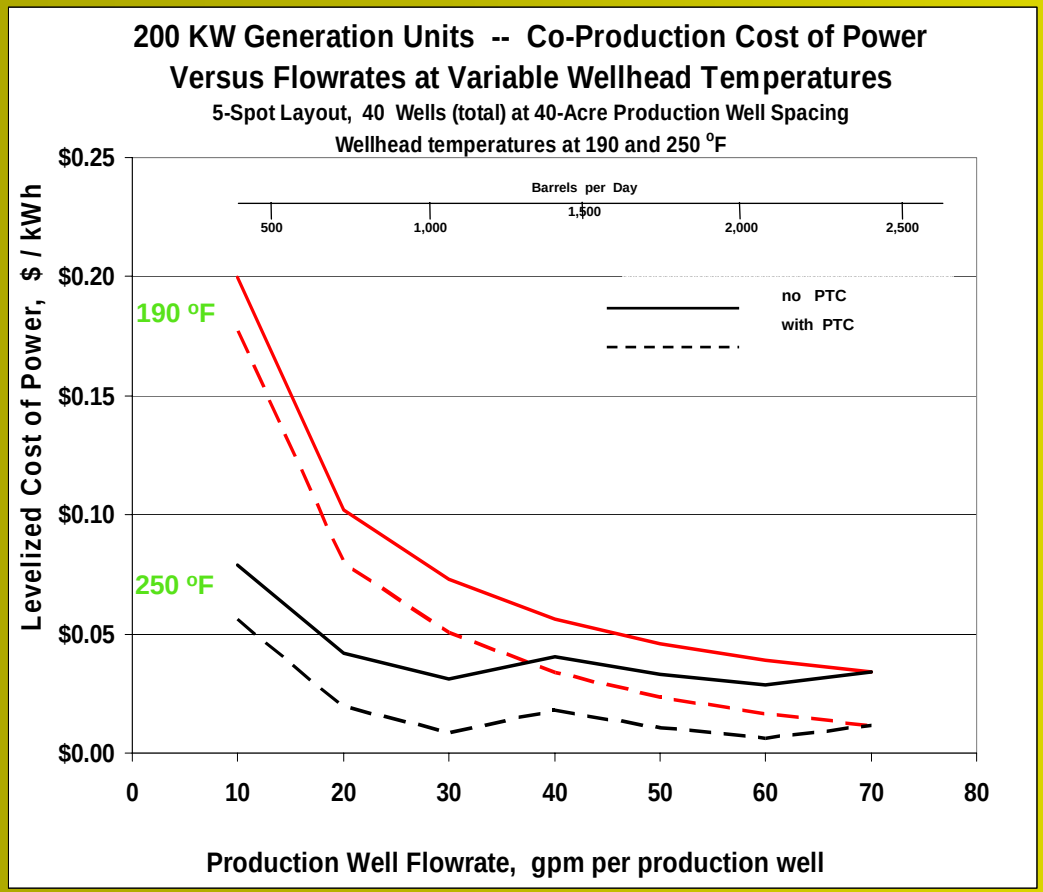


Figure 1 -- Effect of Production Well Flowrate and Wellhead Temperature on Levelized Cost of Energy

Trends

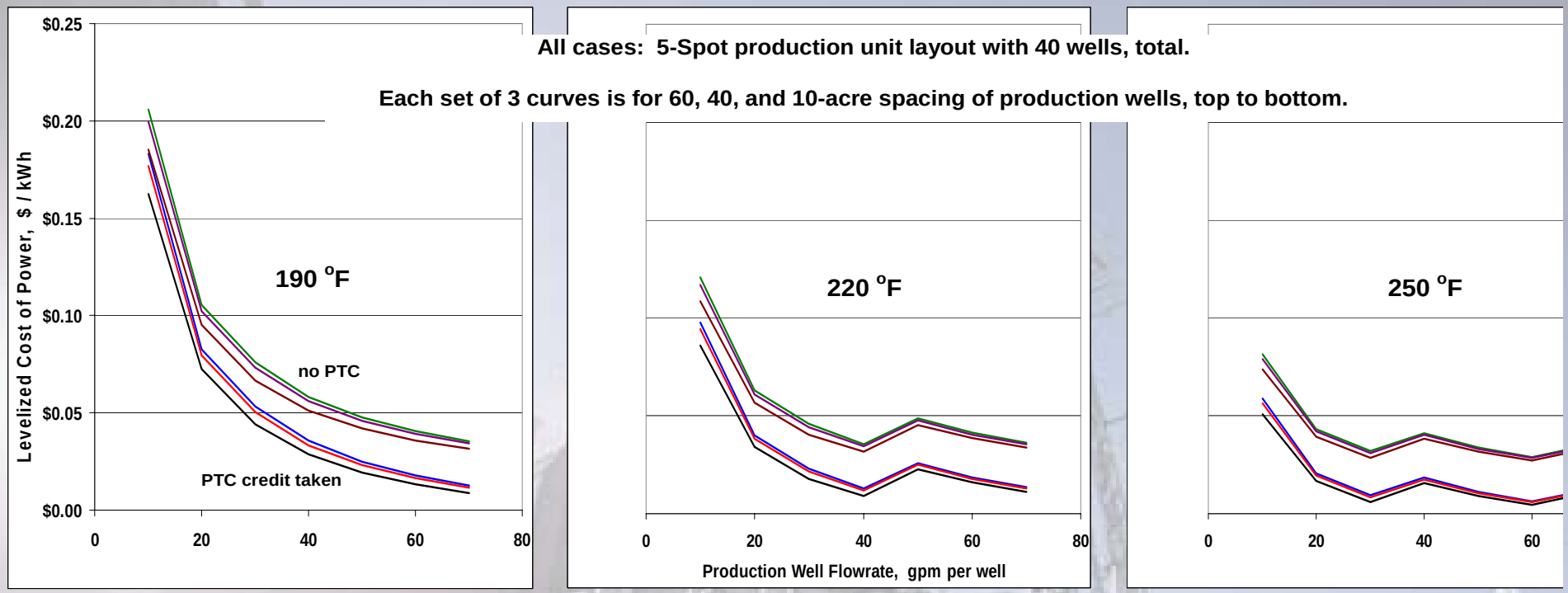


Figure 3 – Cost of Energy versus Production Well Flowrate at Wellhead Temperatures of 190°F, 220°F, and 250°F

All cases use generation unit capacities of 200 kW

Wellfield Configuration

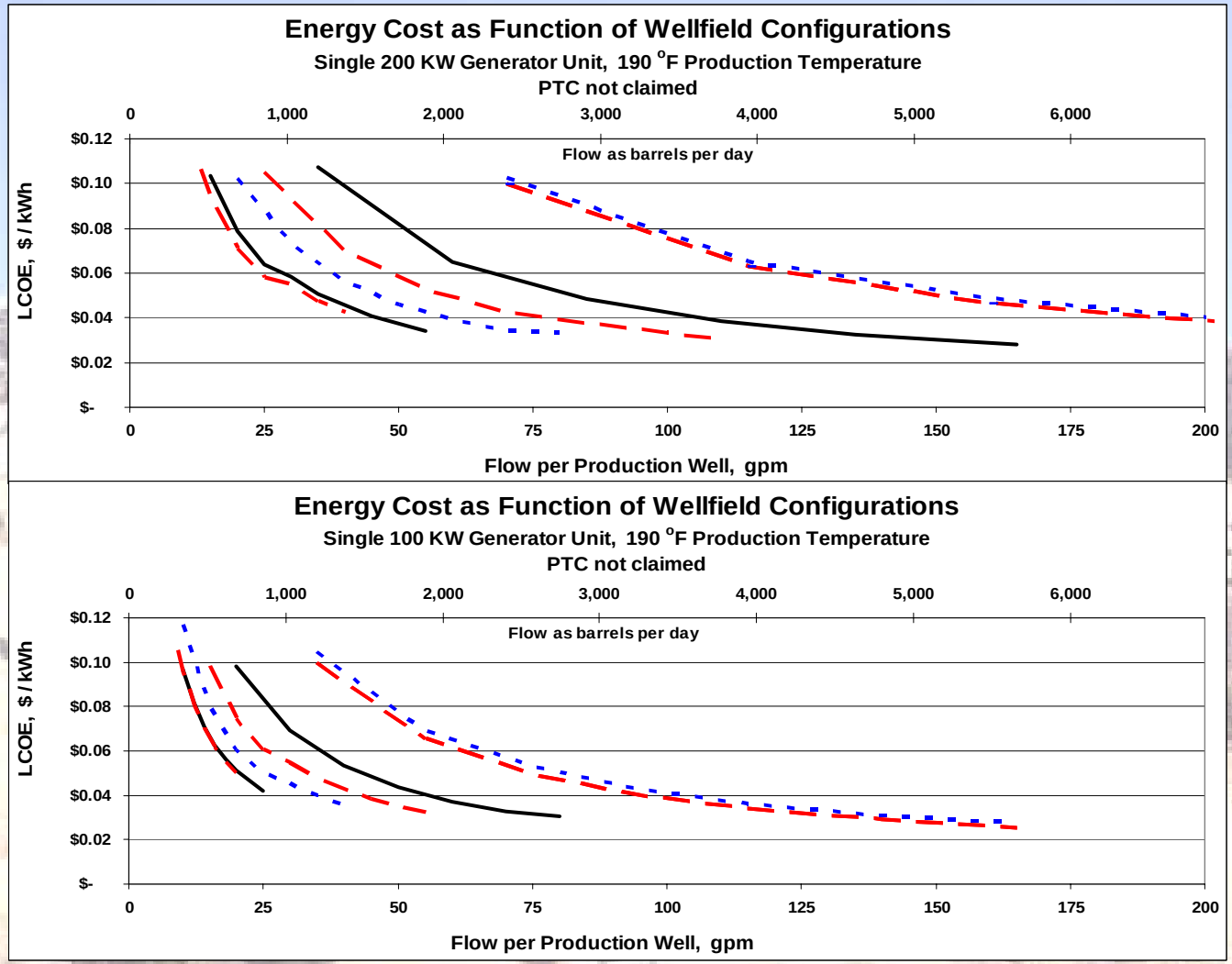


Figure 4

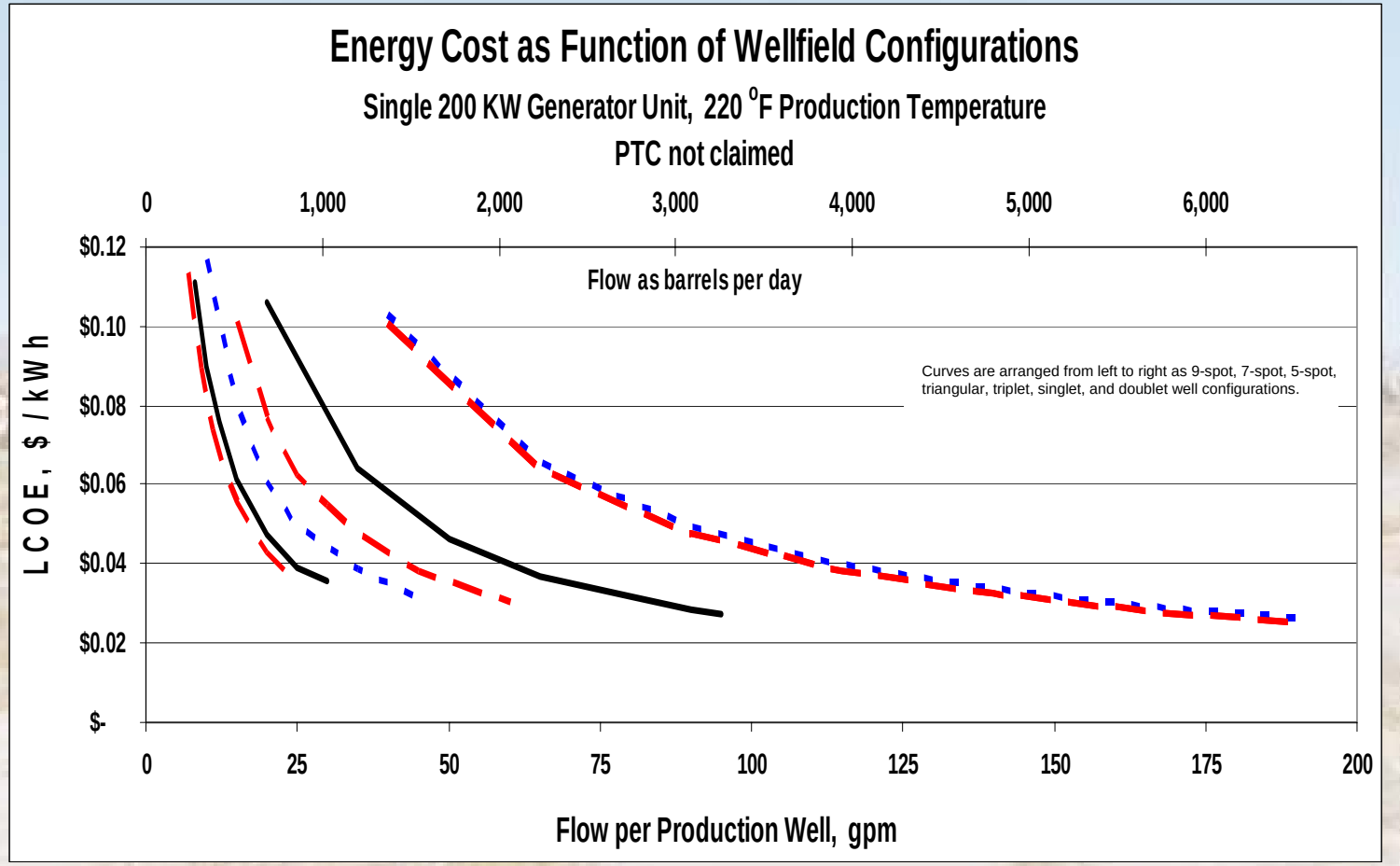
Cost of Energy as a Function of Flowrate for All Wellfield Configurations

Curves are arranged from left to right as 9-spot, 7-spot, 5-spot, triangular, triplet, singlet, and doublet well configurations. In the bottom panel, the 9-spot and 7-spot curves are virtually coincident. PTC is excluded.

Wellfield Configuration

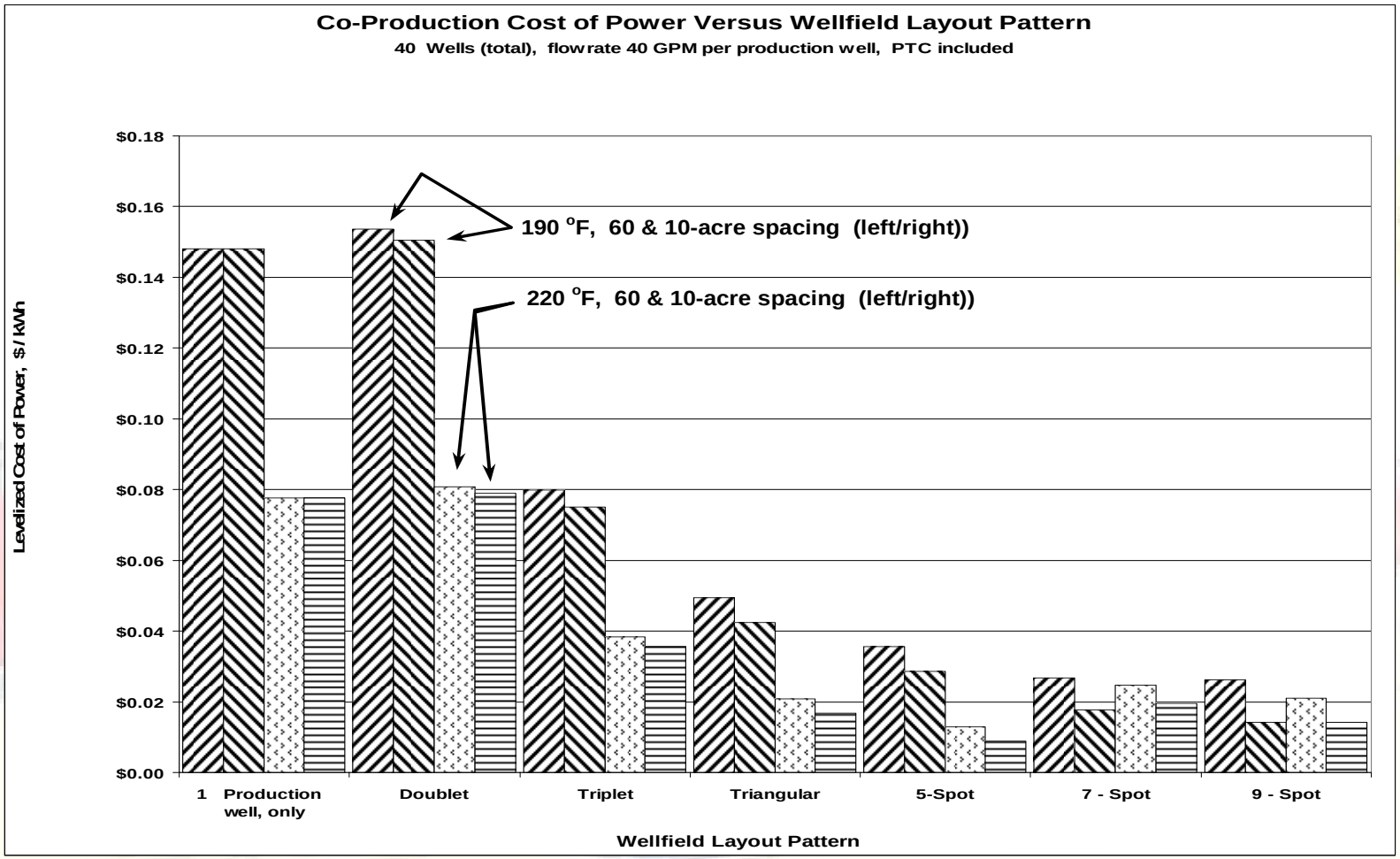
Figure 2

Effects of Wellfield Configuration



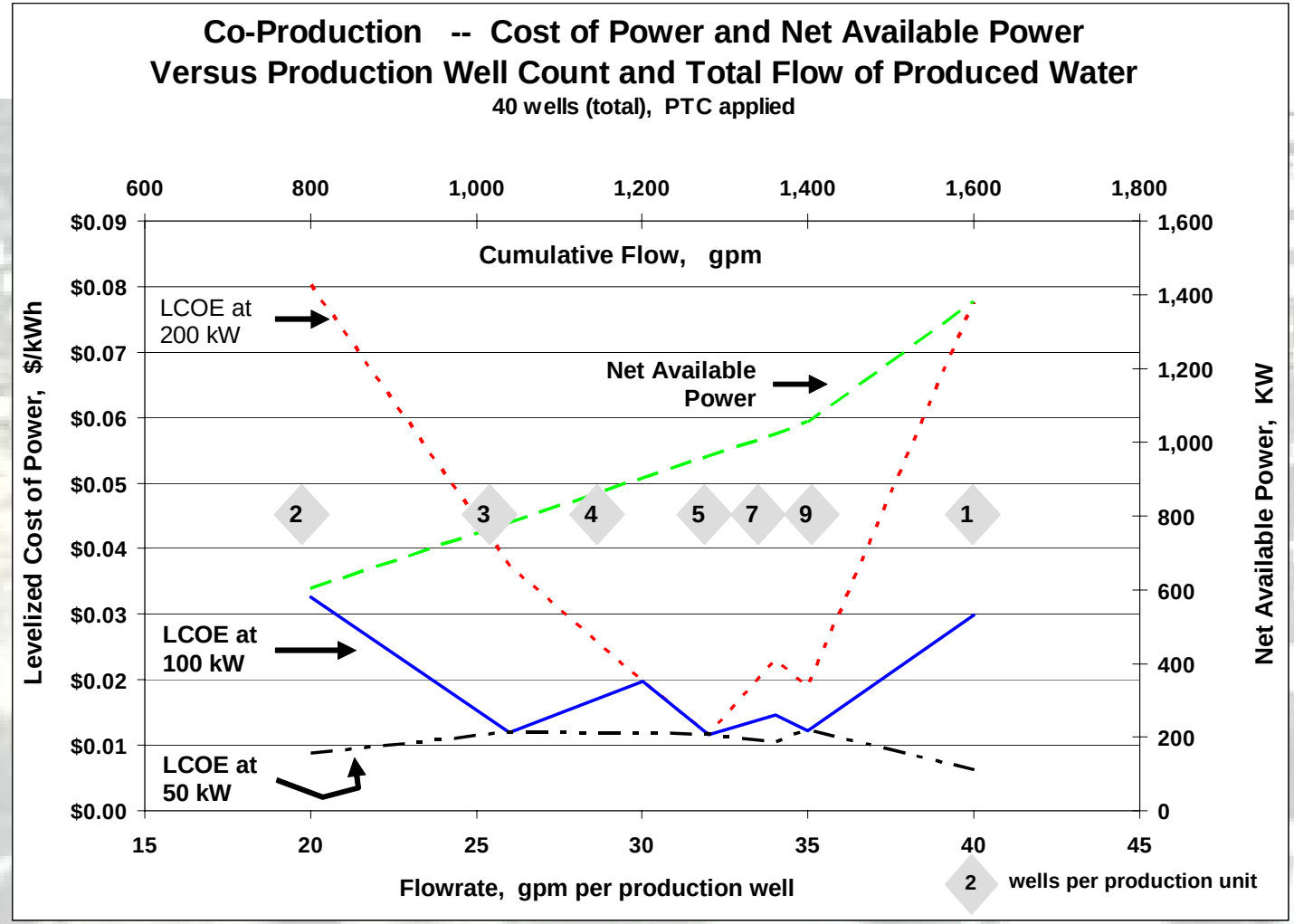
Wellfield Configuration

Figure 7
Effects of Wellfield Configuration on Cost of Electricity



Wellfield Configuration

Figure 9
Comparison of Configuration and Generation Capacity Effects



Input Variables

Resource and Wellfield Data

INPUT 1	1	Production temperature
INPUT 2	2	Well layout pattern -- for a single or repeated "PRODUCTION UNIT"
INPUT 3		Production well spacing
INPUT 4		Production well pump -- wellhead horsepower
INPUT 5		Row count, wellfield array
INPUT 6		Column count, wellfield array
INPUT 7		Include or omit gathering system piping costs ??
INPUT 8	3b	Total Well Count -- production + injection

Input Variables

Flow Data

INPUT 9A	4	Flow per well production well -- as gallons per minute
INPUT 9B		as barrels per day

Surface Data

INPUT 10	5	Ambient temperature

GenSystem Data

INPUT 11	10	GeoFluid approach to ambient temperature
INPUT 12	12	Power generation unit cost
INPUT 13		Nominal unit capacity per generation package
INPUT 14		Installation multiplier -- bare equipment cost markup for site prep, structure, transformer, I&C, etc.
INPUT 15		Generation Unit Count -- limit or float ?

Input Variables

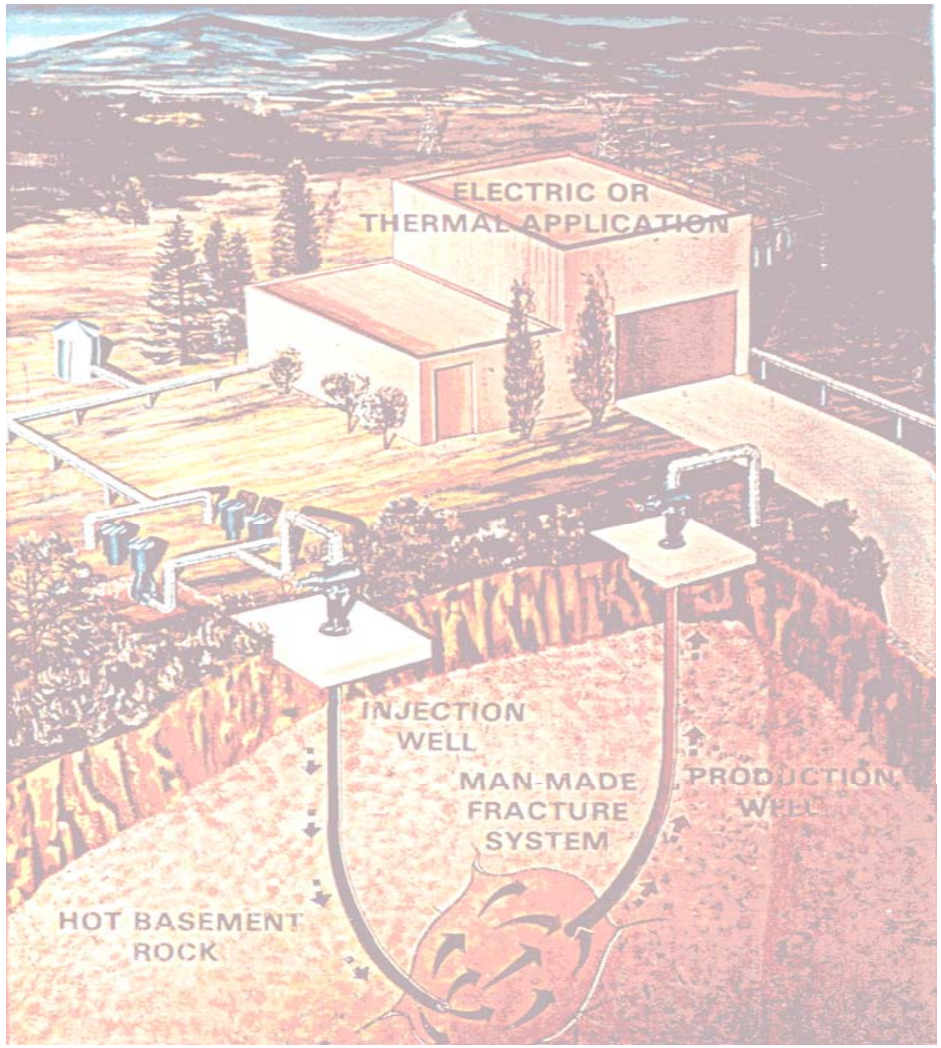
Financial Data

15 **Cost and Performance Factors**

INPUT 16	**Unit cost fixed -- conversion system**
INPUT 17	**Unit cost fixed -- piping**
INPUT 18	**Fixed O&M ($/kW-yr)**
INPUT 19	**Fixed Distribution cost ($ / kW-yr)**
INPUT 20	**Variable O&M ($ / kWh)**
INPUT 21	**Variable Transmission ($ / kWh)**
INPUT 22	**Grid Connection Capital Cost (GCC, 2007 $/MW-mile)**
INPUT 23	**Distance to Nearest Grid Connection (miles)**
INPUT 24	**Annual Plant Capacity Factor**
INPUT 25	**Production tax credit (PTC)**
INPUT 26	**PTC term**
	Inflation -- general escalation rate
INPUT 27	**Fixed charge rate**
INPUT 28	**Weighted avg. cost of capital (WACC)**
	Debt discount rate (imbedded in WACC)
	Equity discount rate (imbedded in WACC)
	Debt fraction (imbedded in WACC)
INPUT 29	**Tax rate**
	Capital Recover Factor (CRF)
INPUT 30	**Book life of system (per tax rules)**

Bases

- Engineering
  - Perry
  - McCabe and Smith
  - Smith and VanNess
- Costs
  - Means
  - Contact
- "Open Architecture"
  - parametric "spread"
  - cut 'n paste new features
    - well losses
    - conversion system
    - user-defined configurations



Conclusions

- Model covers a profile of project variables:
  - ✓physical (process engineering),
  - ✓configurational,
  - ✓E&C,
  - ✓operational
- Application -- a broad regime of economically competitive field conditions for coproduction power:
  - ✓ for the sake of field operations, per se, or
  - ✓for net-back metering.

National Renewable Energy Laboratory

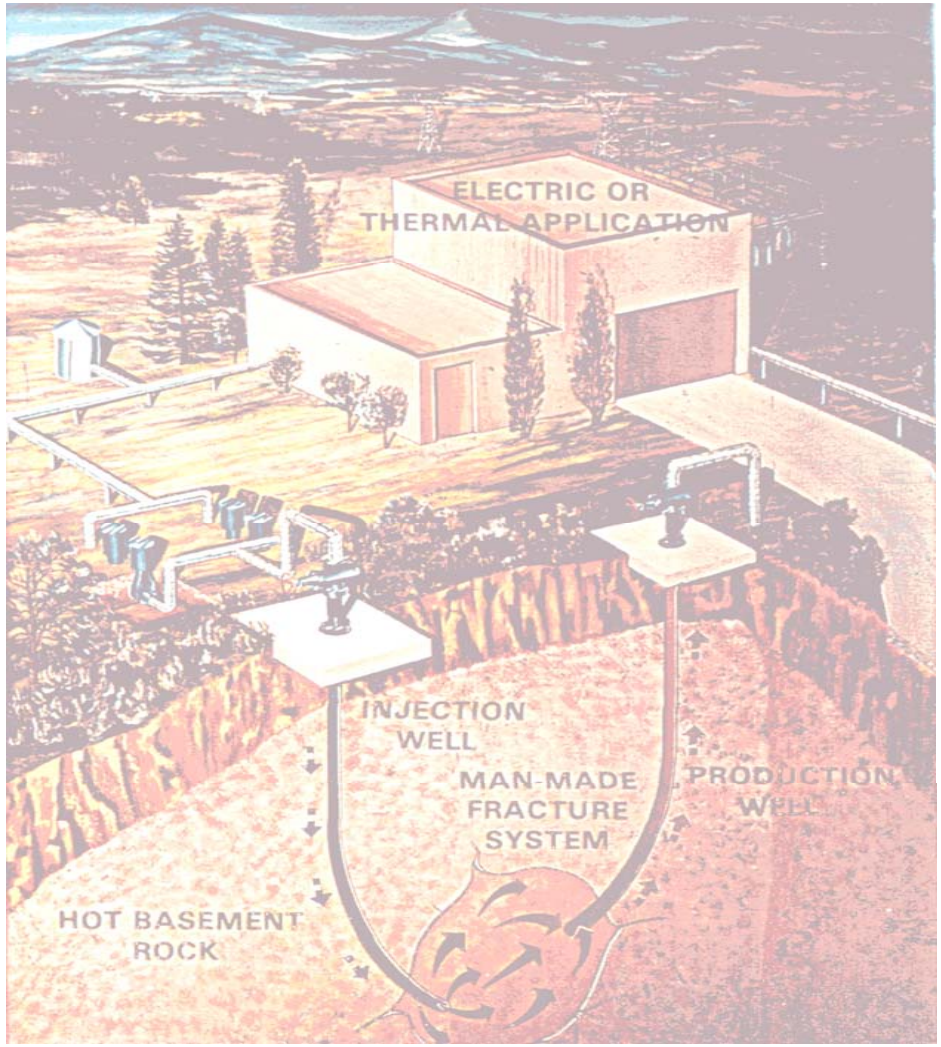
Innovation for Our Energy Future

who makes it happen?

Thank You

BACKUPS

- ALTERNATE AMBIENT TEMPERATURE
- POWER VERSUS RESOURCE TEMPERATURE



Temperature Effects

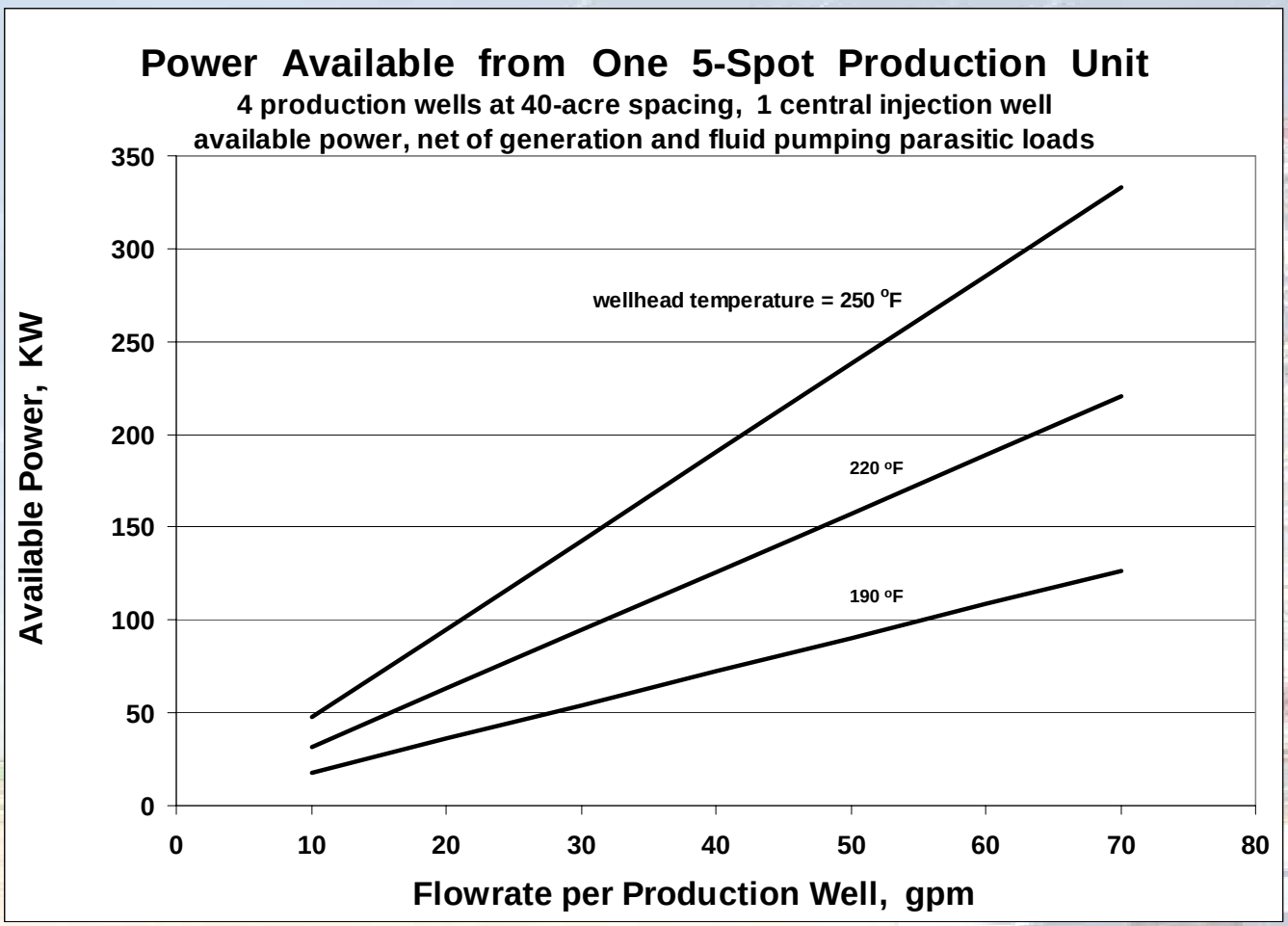


Figure 5 -- Net Available Power