Carbon Dioxide Sequestration / Generation and Top Side Equipment in Support of Enhanced Oil Recovery, Enhanced Geothermal Systems, or Both!

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Bottom Line Up Front

- **Next generation Enhanced Geothermal Systems (EGS) and Tertiary Enhanced Oil Recovery (EOR) may have at least one thing in common, supercritical CO_2**

- **Gas Equipment Engineering Corporation, founded in 1921 as a producer of CO_2, has teamed with Plasma Energy, Fairbanks Morse Engine, and many others in several efforts which pursue the common need of low cost topping systems that enable the research and broader development of EGS-CO_2 and Tertiary EOR, as well as new lower or zero emission power generation technology**

NAVY1
85 MW
California
1987
IOC

GEECO

Introductions

FAIRBANKS MORSE ENGINE

an EnPro Industries company

PLASMA

- **GEECO is a supplier of custom, high performance Air Separation Units and specialty gas equipment to the US Navy and other <u>very demanding</u> customers**

- **Fairbanks Morse Engine is the original U.S. manufacturer and today's premier provider of customized medium-speed engine systems and generator sets, diesel or dual fuel, from ~1 to over 20 MW. Primary markets include stationary power generation for commercial, industrial and nuclear customers and marine propulsion for the United States Navy and the US Coast Guard.**

- **PLASMA Energy Technologies, Inc. has created a carbon capture technology for fossil fuel powered generation plants. Solid or liquid sulfurous fuels such as coal, pet coke or heavy oil fractions can be utilized and all of the carbon or carbon dioxide (CO_2) emissions, and 99.9% of the sulfur dioxide are captured.**

EGS / EOR Working Fluid: High Pressure Water or Carbon Dioxide?

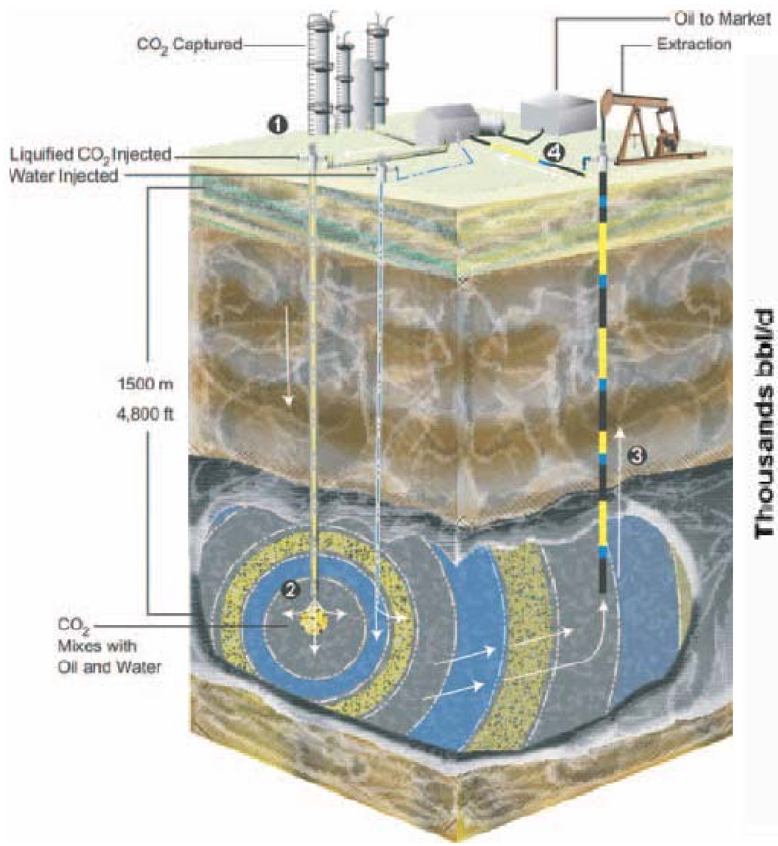
- Recent technical papers have exposed the concept of CO_2, as a supercritical fluid, as an alternative to high pressure water for EGS
  - "Enhanced Geo-Thermal Systems, Comparing CO_2 and Water as Heat Transmission Fluids", Pruess, 2002
  - "Enhanced Geo-Thermal Systems, Using CO_2 as a Working Fluid – A Novel Approach for Generation of Renewable Energy with Simultaneous Sequestration of Carbon", Pruess, August 2006
  - "On Production Behavior of Enhanced Geo-Thermal Systems with CO_2 as a Working Fluid", Pruess, February 2008
  - "CO_2 Thermo-Siphon for Competitive Geo-Thermal Power Generation", Atrens et al, October 2008

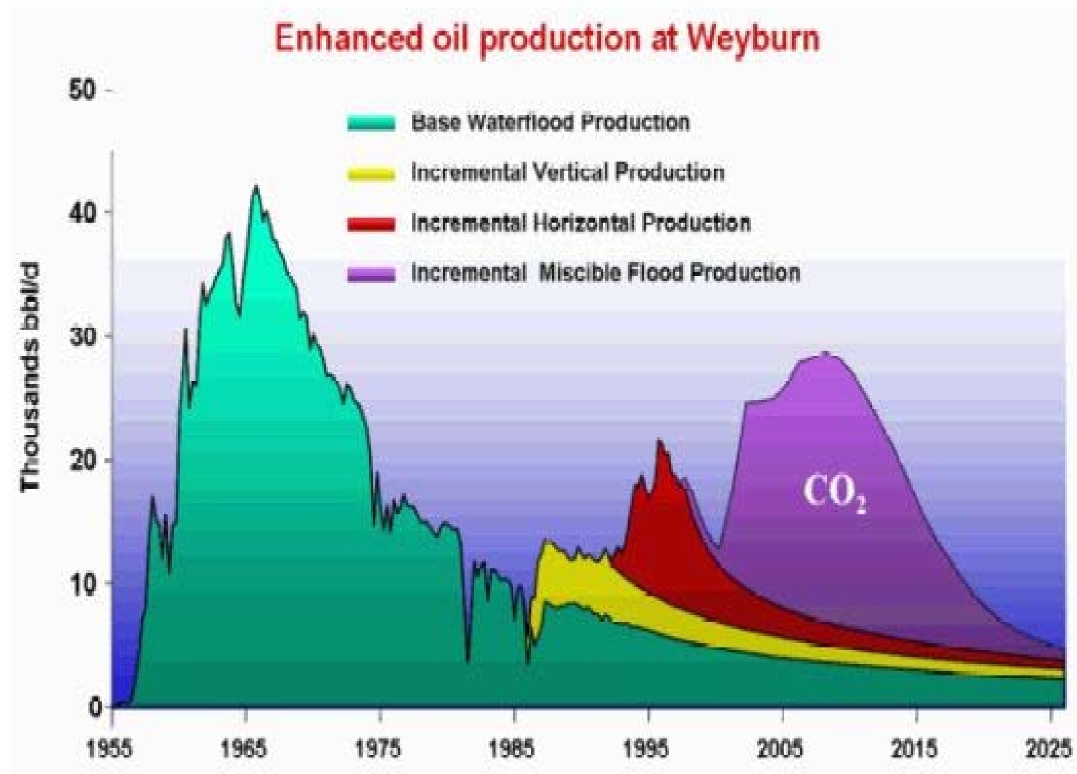
- Tertiary EOR, using supercritical CO_2, will increase yield / field production in many cases.

- Combination of the technology is possible, but there have been barriers…
  - Which we think we can remove

One Example of the Benefit of CO2 EOR…

Weyburn, SK Canada – Enhanced Oil Recovery CO_2 Flood Model

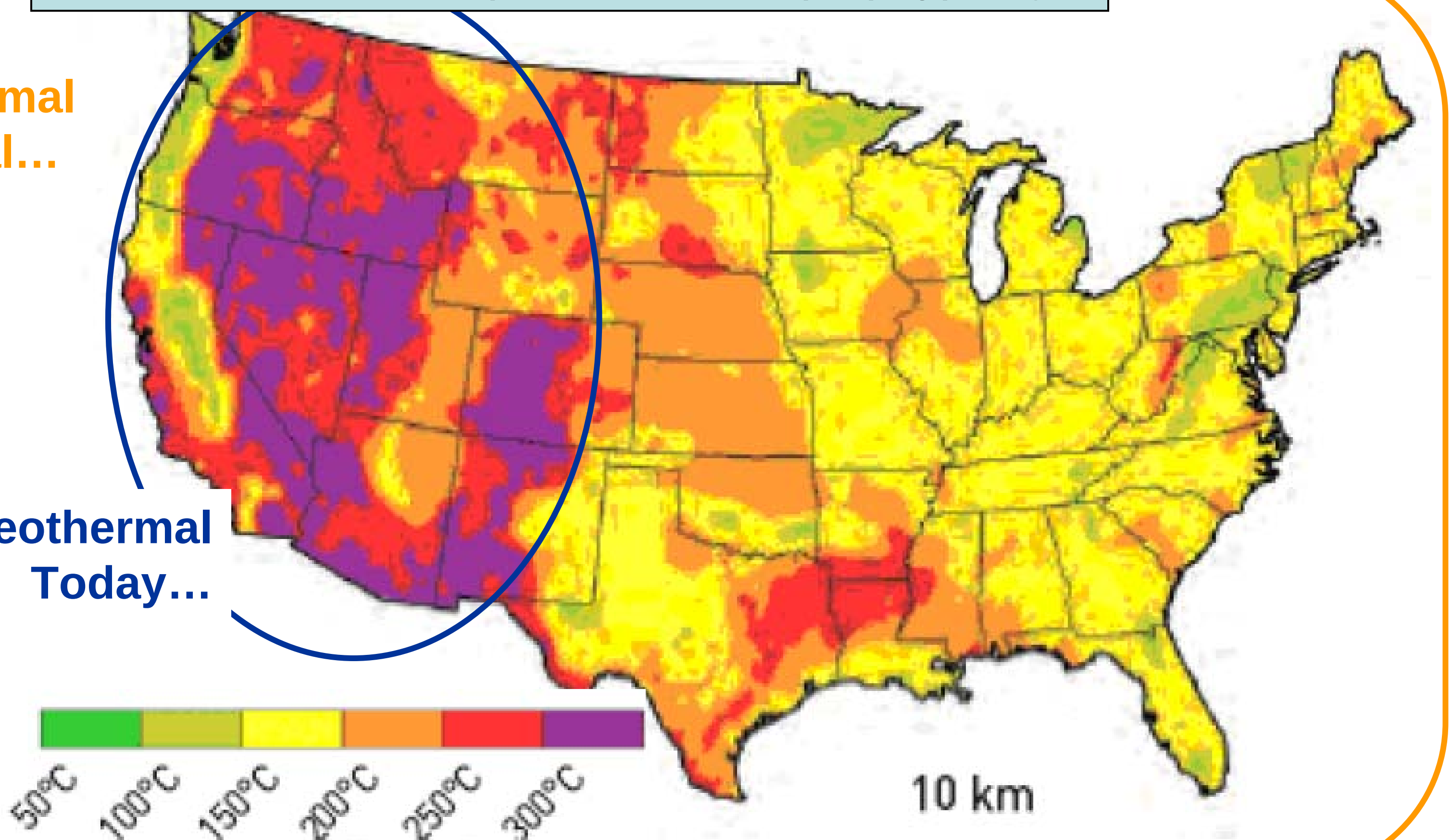




And… CO2 EGS Enables Greater Exploitation Of Geothermal Energy

Geothermal today is exclusively in areas of high heat flow. Exploitation of geothermal is possible nearly anywhere in the lower 48, but lower reservoir temperatures will increase the pumping power burden. CO2 EGS thermal siphon eliminates the "pumping penalty".

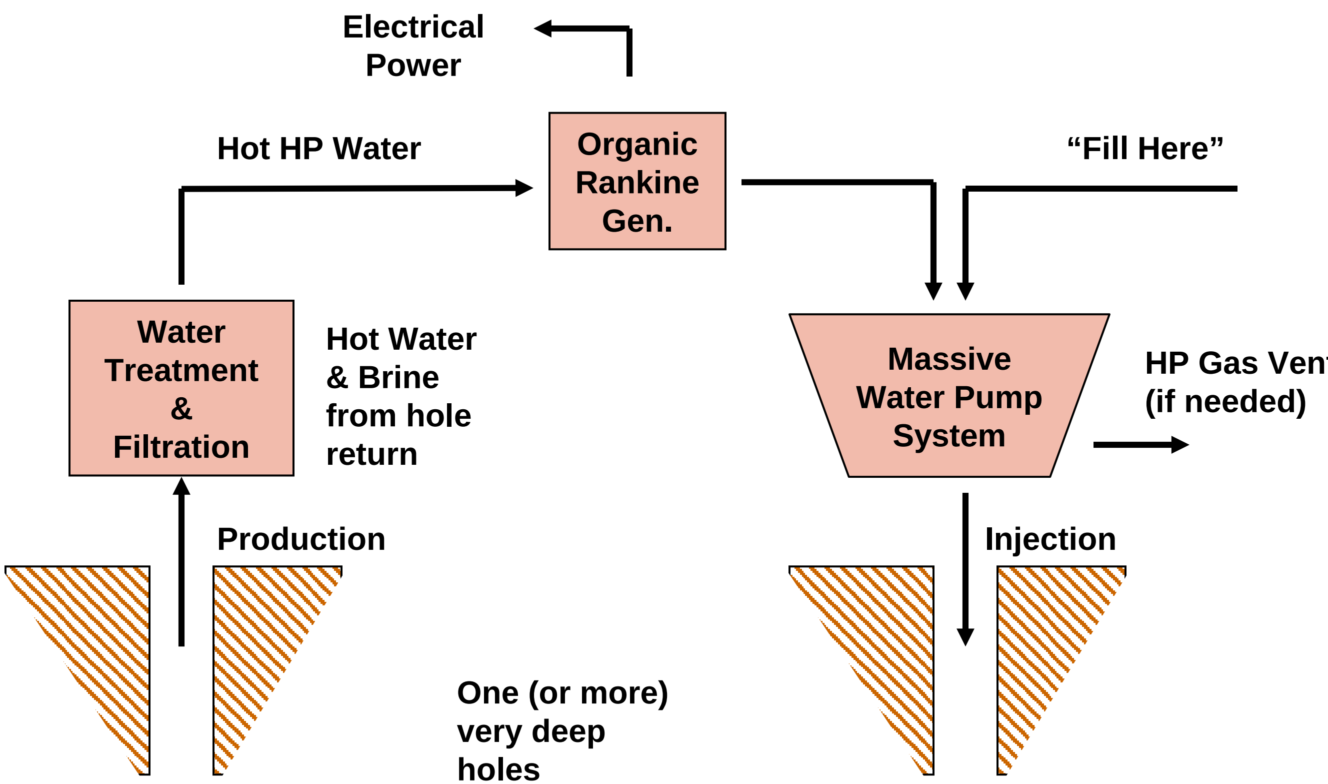
Geothermal Potential…



Geothermal Today…

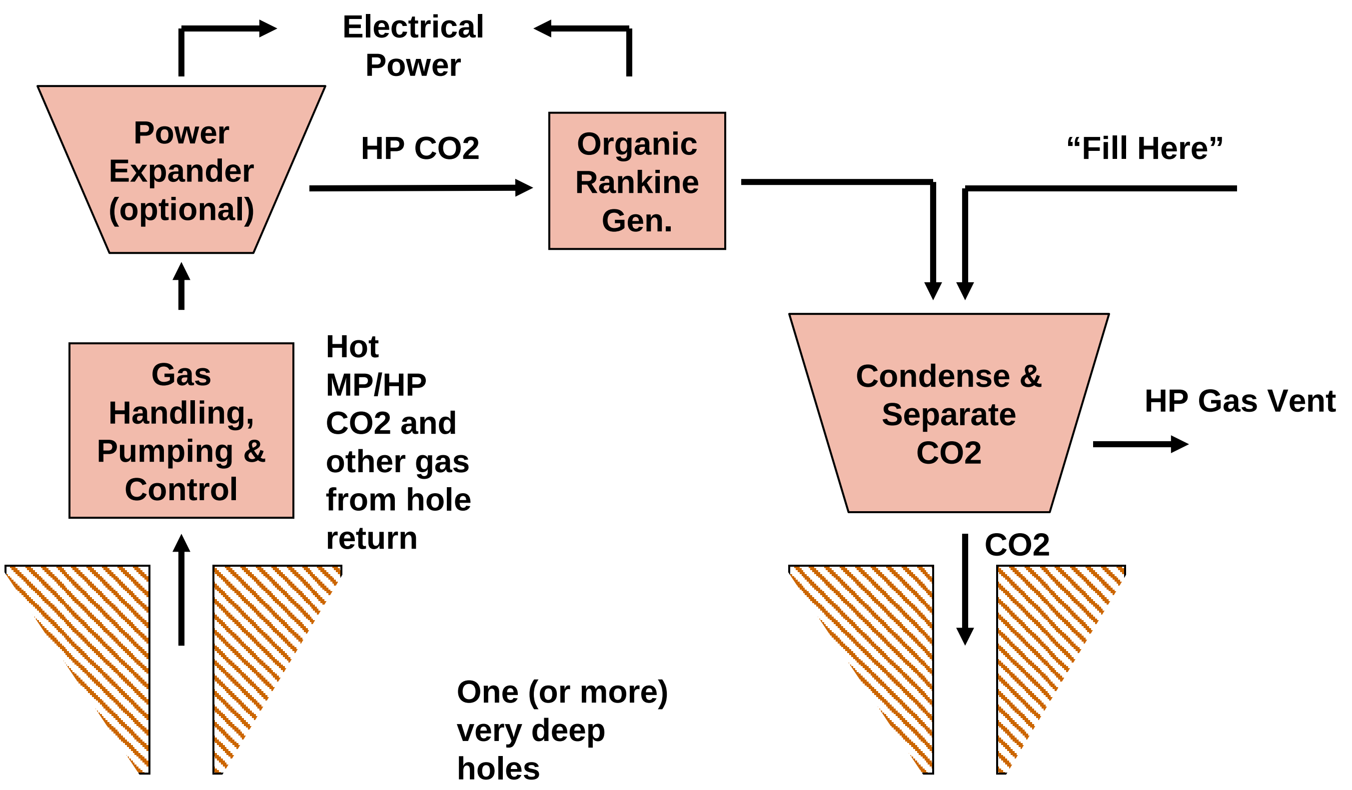
Development of Top Side Equipment Concept

- **Simplistic Water EGS**

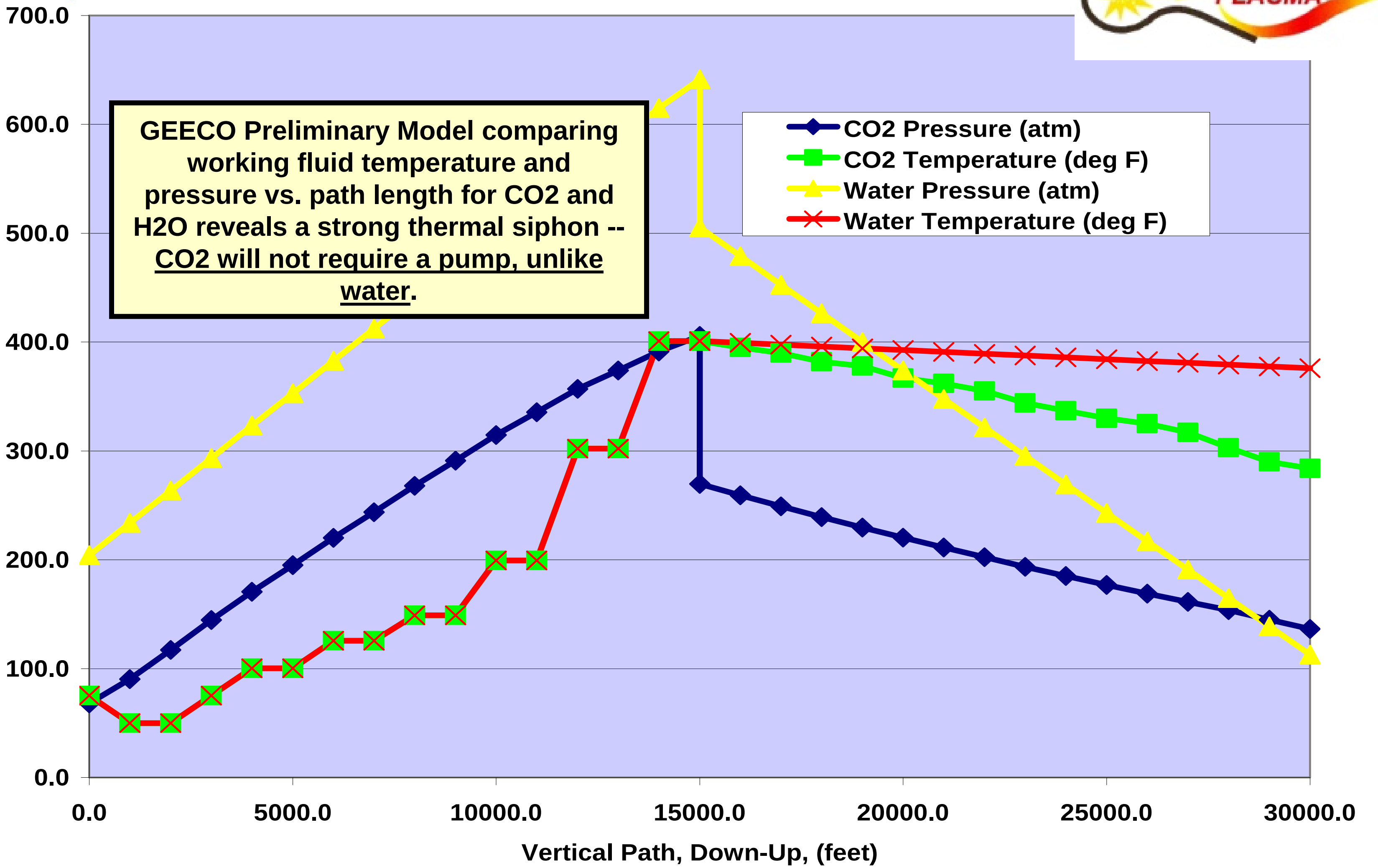


Development of Top Side Equipment Concept

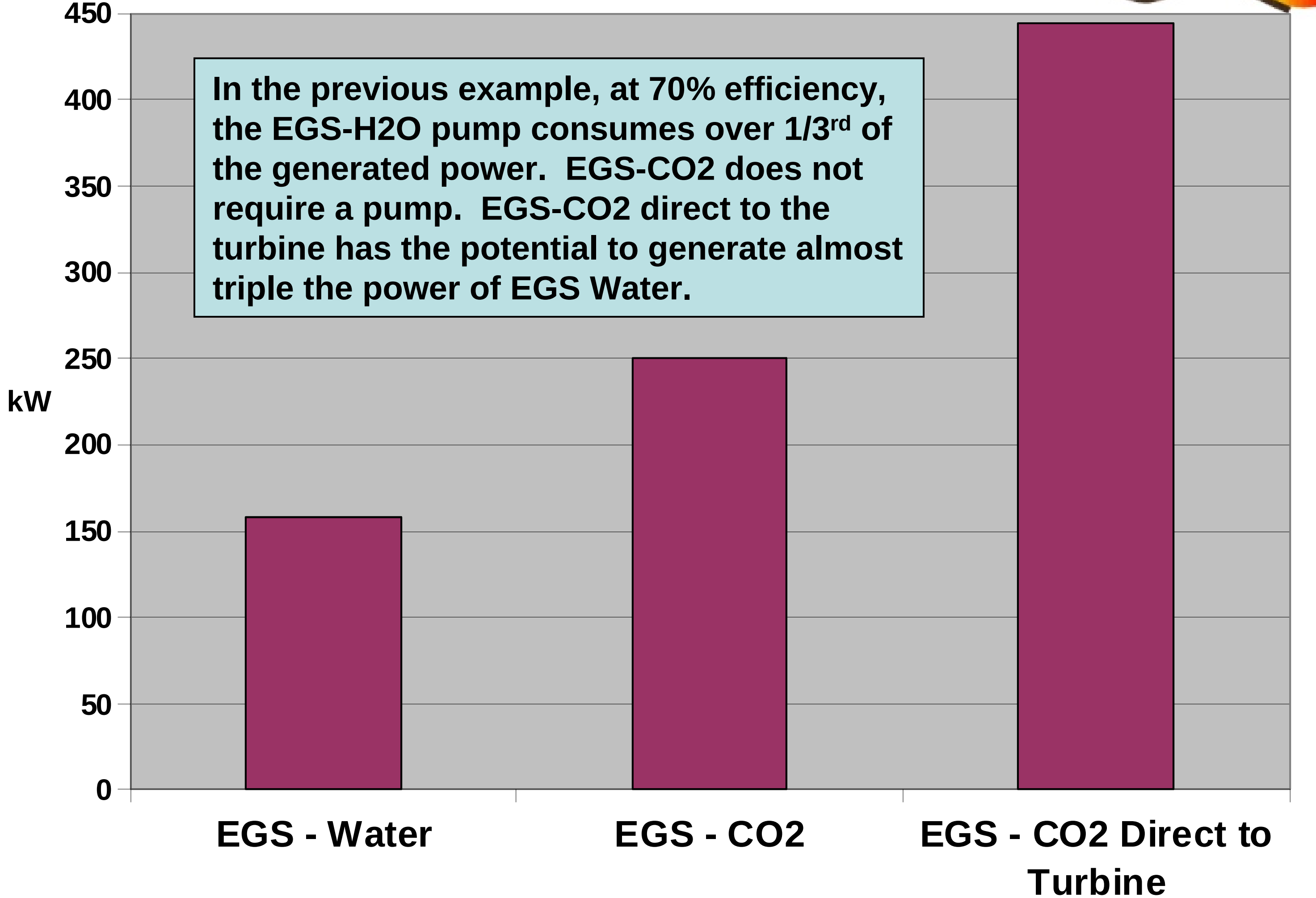
- **Basic CO2 EGS Thermal Siphon with Optional Power Turbine**



EGS Working Fluid Temperature and Pressure: Total Vertical Path for CO_2 and H_2O, for 400 F @ 15,000 FT



Efficiency Advantage of EGS CO2 vs. EGS Water



EGS Working Fluid: High Pressure Water or Carbon Dioxide?

High Pressure Water

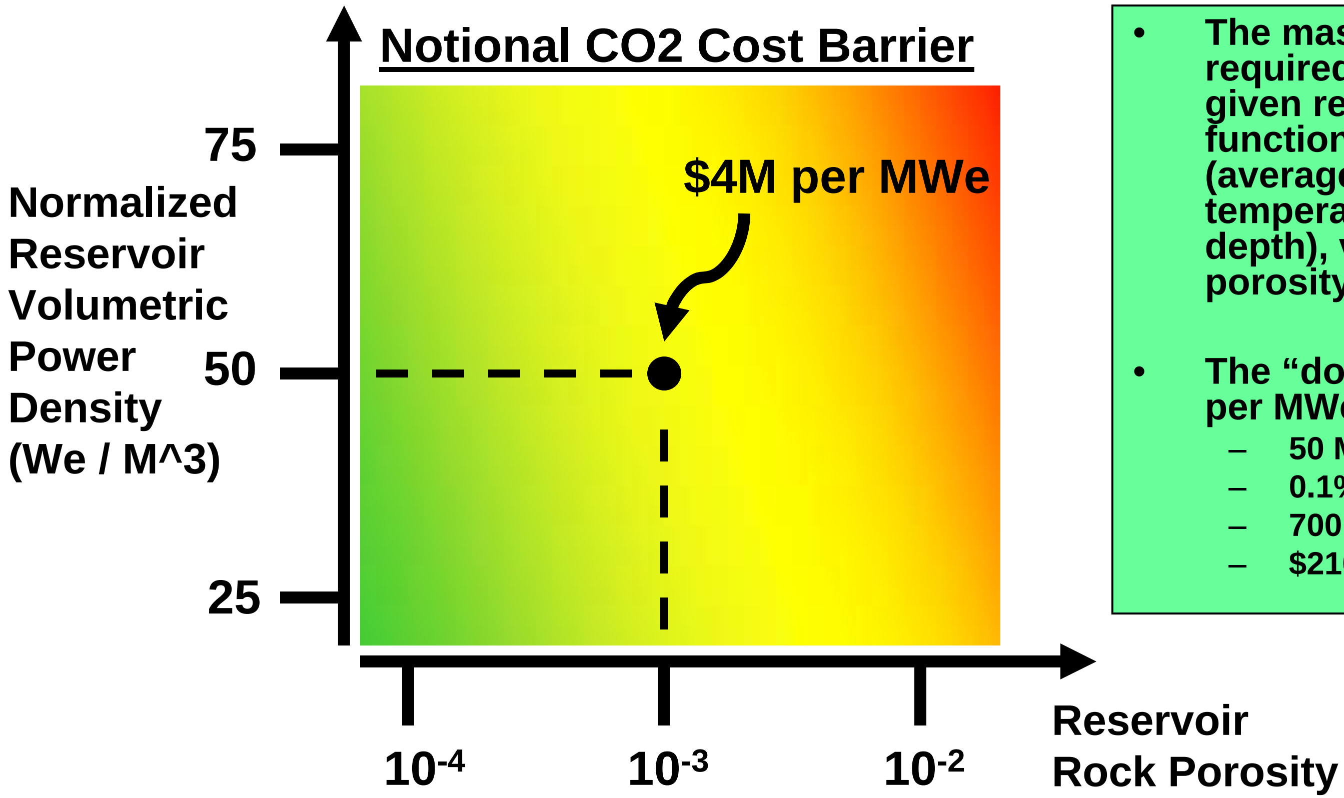
- Well understood
- Reacts with bedrock
  - Direct use of steam problematic
- Mobility low and pressure drop high at depth
  - Viscosity / Density not favorable
- Very high pumping power
  - Could be ~40% of gross power
- High specific heat
- Temperature loss up-hole can be low (heat transfer driven)
- Cheap (working fluid price)
  - At least locally

Super Critical Carbon Dioxide

- Not as well understood
- Reacts with bedrock, but for the most part favorably
  - After development, direct use of working fluid in machinery may be possible
- Mobility higher and pressure drop lower than water at depth
  - Viscosity / Density favorable
- "Negative" pumping power
  - Strong thermal siphon
- Lower specific heat than water
  - But more than compensated by flow rate
- Temperature loss up-hole more complex
  - Think isentropic expansion
- "Lost" CO2 in the process is sequestered in deep rock (carbonates)
  - And that by itself is good
- Very high purchase price
  - And carbon credits are currently trading at low values

The yellows and greens are interesting, but the barrier to date, with a big "B", is the purchase price of CO2

How Much CO_2?
EOR Will in General Use More (per acre) than EGS, but even EGS Uses a Lot…



- The mass of CO_2 required to charge a given reservoir is a function of the density (average at temperature and depth), volume, and porosity
- The "dot" is at ~$4M per MWe, e.g.
  - 50 MW, 1 km^3
  - 0.1% porosity
  - 700 ktons CO_2
  - $210M @ $300/ton

A big barrier for early implementation of EGS-CO2 is CO2 cost / technical risk

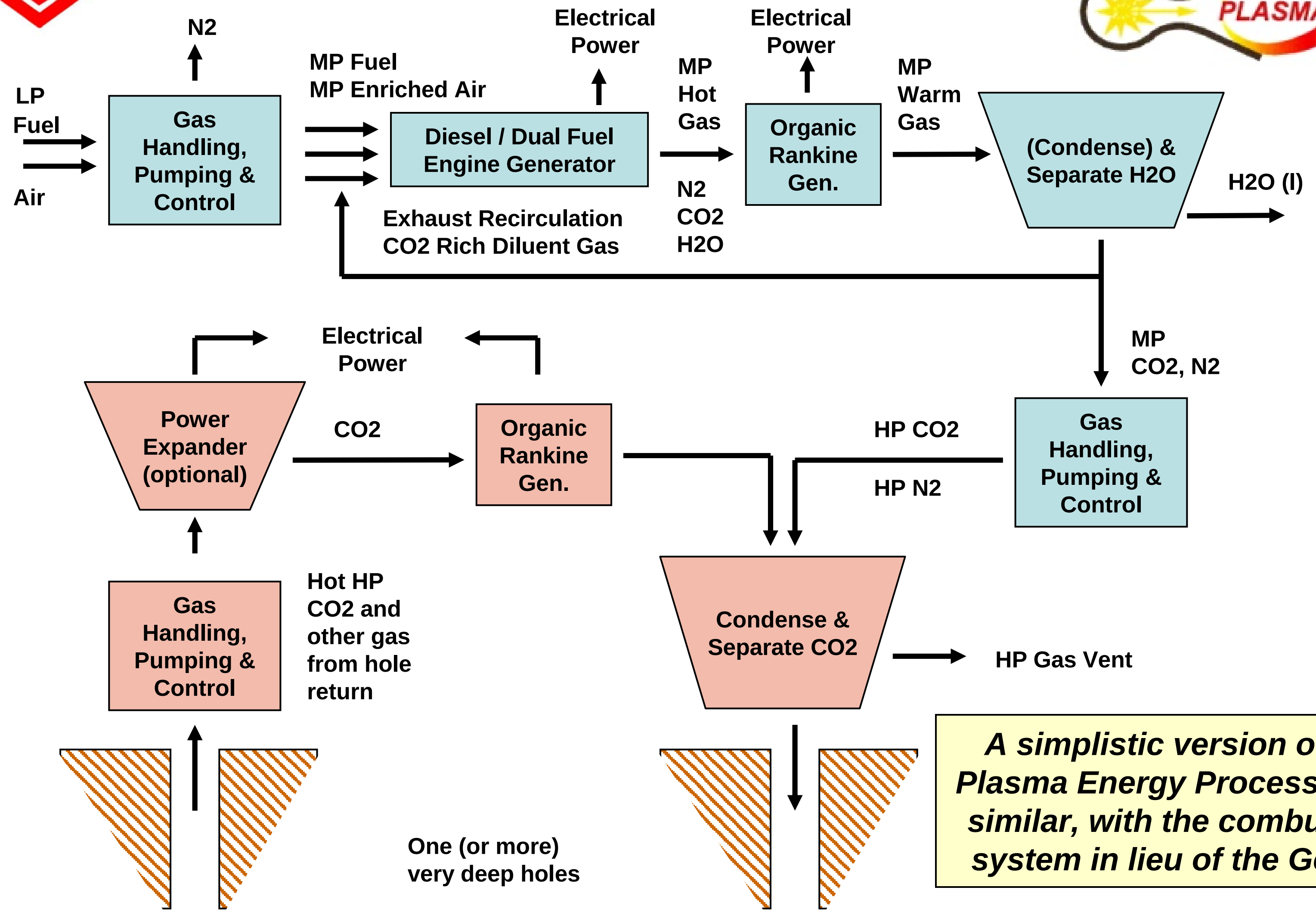
Removing the CO2 Cost Barrier

- **Highly efficient, and highly non-emissive power systems can be operated with enriched air (or pure oxygen)**
  - **The NOx emission problem can essentially go away; enabling higher combustion temperatures / greater efficiency**
  - **From refined fuels, using a FME Dual Fuel genset, modified for closed cycle with EGR, the exhaust stream can be essentially pure CO2 and water**
  - **From unrefined fuels, using a Plasma Energy process, the same pure gaseous exhaust exists, and metal / salt particulates are captured**

- **Since both concepts generate net power, and power can be sold or used in lieu of purchased power, the effective cost barrier for CO2 is removed**

Removing the CO2 cost barrier enables (reduces cost of) EGS-CO2 research & demonstration work now and ultimately enables broader deployment of EGS-CO2 and Tertiary EOR

Diesel Hybrid CO_2 EGS Working Fluid Generation and Processing (EGR and EA)



A simplistic version of the Plasma Energy Process looks similar, with the combustion system in lieu of the Genset

Air Enrichment is the Key

- **The FME diesel can use a lower purity oxygen from a Vacuum Pressure Swing Adsorber (VPSA)**

Effect of Enriched Air, Diesel Hybrid System

Effect of Enrichment	Engine Inlet			Net Engine Exhaust (After Recirculation)	
	O2	N2	Ar	N2 Removal	N2 / Argon Comp. Red.
Air	21.0%	79.0%	1.0%		
VPSA Product	66.0%	30.9%	3.1%	60.9%	59.9%
VPSA Product	80.0%	16.2%	3.8%	79.5%	78.5%
VPSA Product	94.0%	1.5%	4.5%	98.1%	97.1%

- **The Plasma Energy System will use the classic GEECO low pressure cryogenic ASU (>99.5% O2)**

The use of oxygen enables the Plasma Energy process, and for FME enriched air reduces the compressor power associated with gas separation (Nitrogen) by over an order of magnitude

Net Cost of CO2
FME Dual Fuel Example with Natural Gas (70 psi)

Net Cost of CO2, Diesel Hybrid System

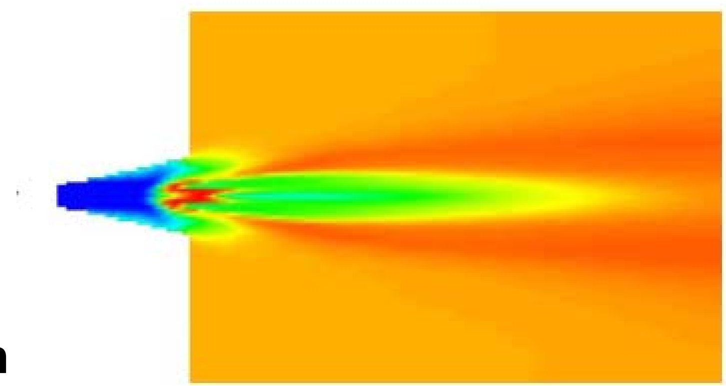
3 MW Generator, 1391 lbm/hr Natural Gas @ Fuel Cost $372 / hr						Net Cost of CO2 per Ton			
Net Revenue Generating Power and Net Cost of CO2 per Ton	Generator Output (kWe)	CO2 & N2 Comp. (hp)	PVSA (hp)	Net CHP (kWe)	Net Power (kWe)	@ Buying / Selling Electric Rate ($ per kW-hr)			
						$0.05	$0.10	$0.15	$0.20
Case 1, 180% Excess Air, 0% N2 / Inert Adsorbtion	3000	5888		540	-620	$210.62	$226.85	$243.07	$259.30
Case 2, 180% Excess Air, 60% N2 / Inert Adsorbtion	3000	1098	940	540	2080	$140.02	$85.64	$31.27	($23.11)
Case 3, 180% Excess Air, 78% N2 / Inert Adsorbtion	3000	773	940	540	2307	$134.07	$73.73	$13.40	($46.94)
Case 4, 180% Excess Air, 97% N2 / Inert Adsorbtion	3000	448	940	540	2535	$128.11	$61.82	($4.47)	($70.76)

- **Our FME design goal is basically Case 4**
  - 94% Oxygen (balance mostly Argon) to the engine
  - Reduction in inert compression power to capture CO2 of 97%
  - Net cost of CO2 $0.00 at $0.14 / kW-hr electricity (with expensive gas)

Plasma Energy Thermal CO2 System Flexibility…

- **High temperature oxygen combustion system with the flexibility to combust lower-cost, lower rank solid or liquid fuels**
- **Provides high quality thermal inputs with zero greenhouse gas emissions**
- **Pure CO2 stream with complete carbon and sulfur capture**
- **Modular in-field cogen system designed to operate in harsh field condition**
- **The net result will usually be a lower break even point with respect to local electric rate than with refined fuels**

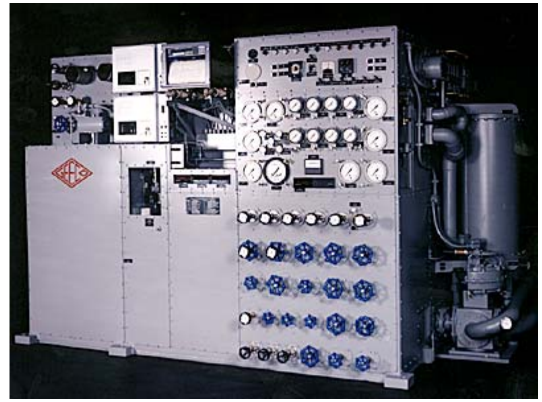
Oil Comp	wt frac-rcvd
C	0.8375
H	0.1194
O	0.0050
N	0.0179
S	0.0179
ash	0.0023
H2O	0.0000
Density, kg/m^3	930
HHV, kcal/kg	10,535



Outlook / Plans

- GEECO and our partners plan to demonstrate these capabilities, including ultimately the EGS / EOR portion
- We believe the GEECO / FME Dual Fuel approach will work in modular manner, it can go anywhere there is refined fuel, and produce CO_2
- The Plasma Energy System, though it has a lower cycle efficiency on the power conversion side (rankine and/or kalina cycle) than a diesel, will often be the right answer since it can burn “anything” that exists in an oil field / refinery and is also adaptable to existing fixed power station conversion (higher power levels)
- Further gains are possible via greater integration with oil field processes, integration of EGS and EOR, and alternative cycles / machinery
- GEECO, Plasma, and FME are dedicated to new solutions to the Nation’s current and future energy crisis that have substantial environmental, energy security, and cost benefit and look forward to working with all of you

Summary



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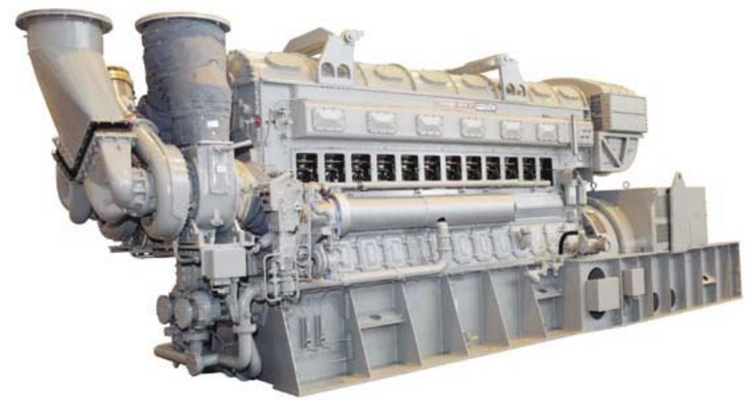

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Thank You