

# Baseline System Costs for 50.0 MW Enhanced Geothermal System *-- A Function of: Working Fluid, Technology, and Location, Location, Location --*



15 June 2011  
SMU



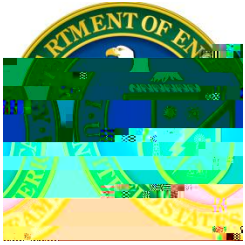
Presented By: Paul Dunn (PI), COO  
Gas Equipment Engineering Corp.



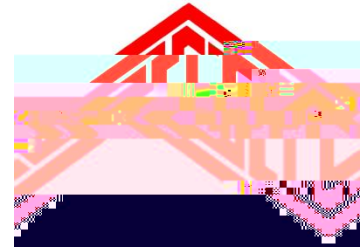
Impact  
Technologies  
LLC







## What Does This Mean?



**Last time we were at this conference, DOE announced this grant award (thank you)**

**Today, we will tell you the preliminary results, for 50 MW EGS Cost in a really challenging environment (Western MA)**

**50 MW Net Water-EGS (70 MW Gross)**

**50 MW Water-EGS Diesel / CNG Hybrid (20 MW Water Pumps)**

**50 MW CO<sub>2</sub> EGS  $\ddot{E}$   $\dot{H}_c X_{und}$  7 cgh--- No Magic**

**50 MW CO<sub>2</sub> EGS  $\ddot{E}$  Cost with reasonable application of CO<sub>2</sub> Generation and Drilling Technology**

**We will also tell you what other (reasonable) locations we will study**

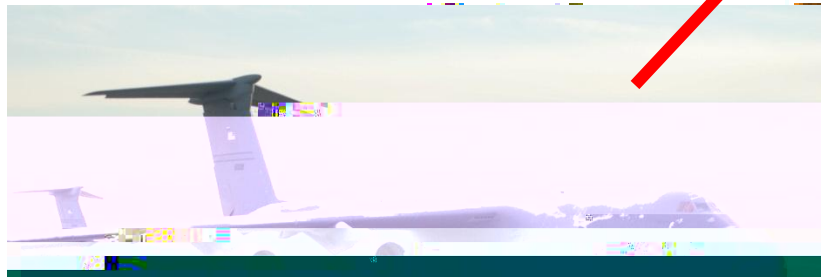
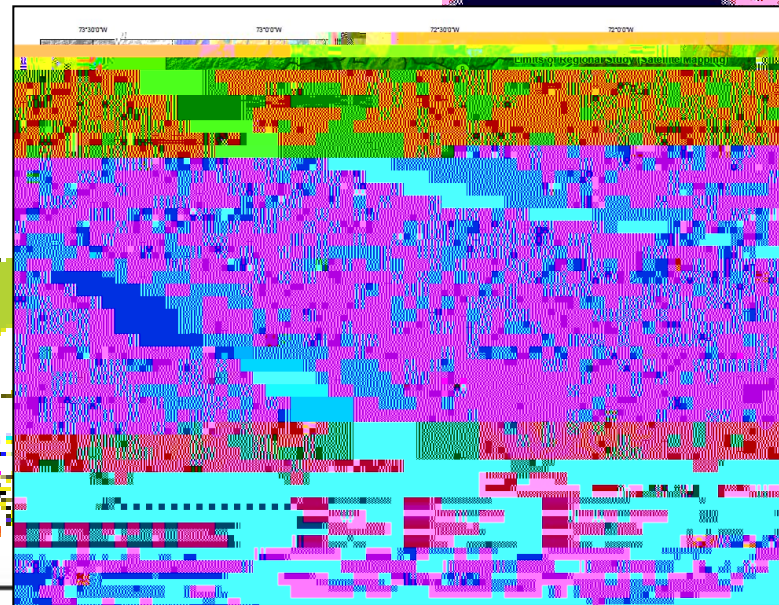
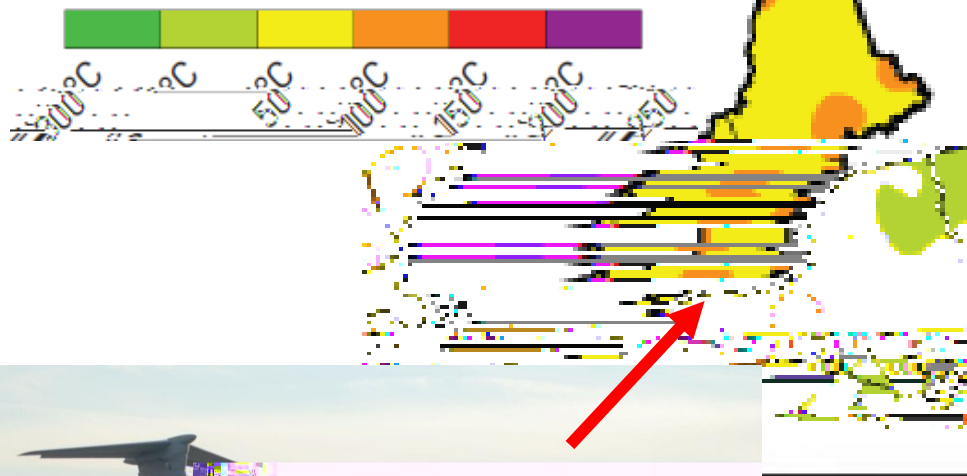
**We expect a final report to be produced later this year**



# Westover Air Force Base Chicopee, MA



10 km

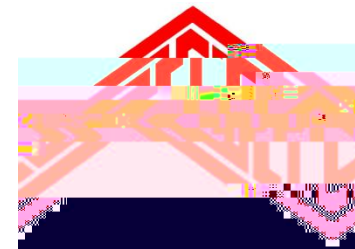


## Westover:

- ~400 F @ 30,000 ft
- ~300 F @ 21,000 ft



## 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

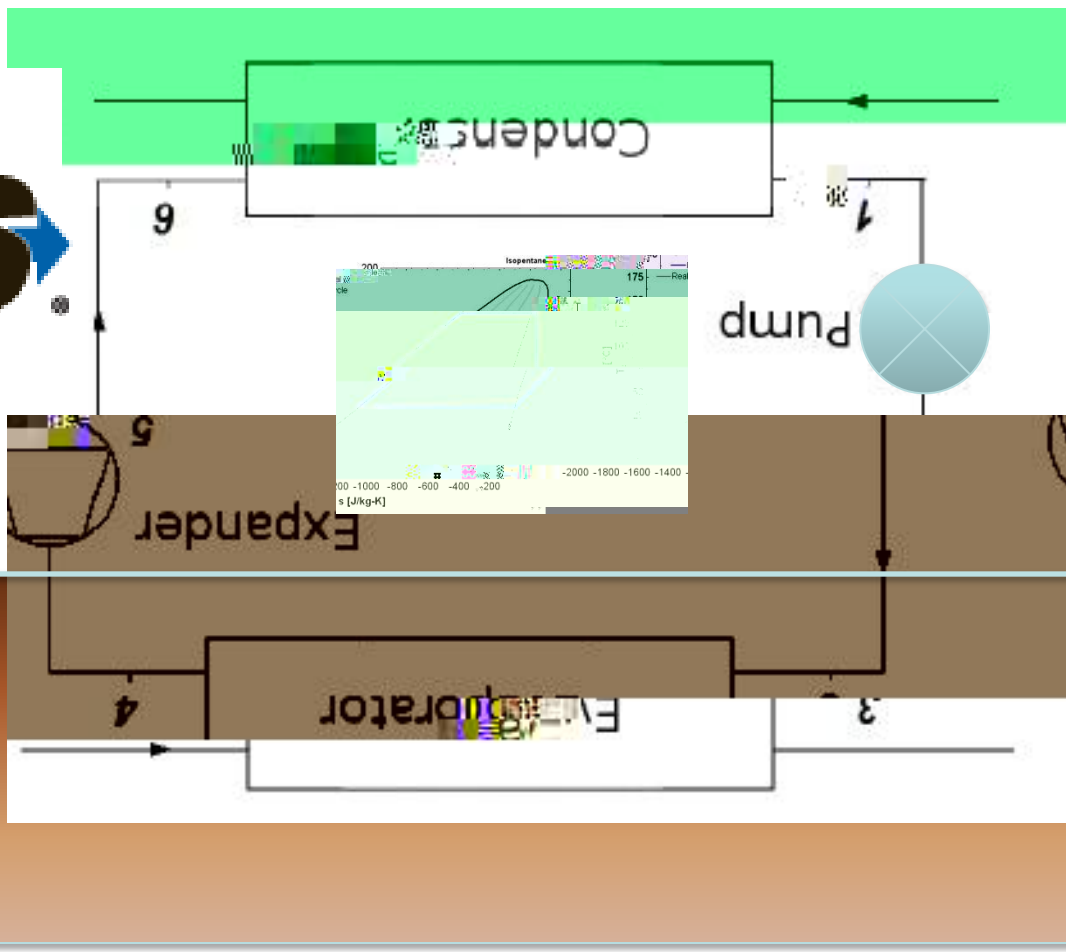
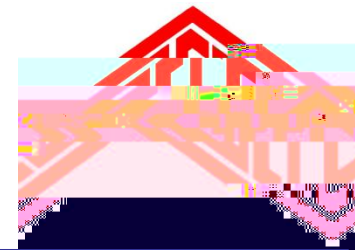
Very high pumping power

Could be ~40% of gross power

High specific heat



# EGS by CO<sub>2</sub> 8 [f YWñ9I dUbg]cbÅ Turning ORC Upside Down!

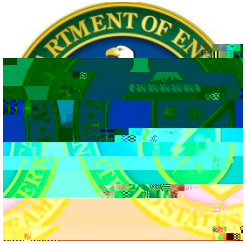


**Pump not required**

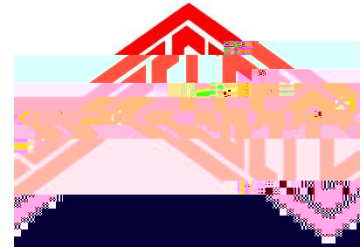
**Down hole compression provides pre-heat**

**Up hole expansion results in loss of temperature, but not enthalpy**

**Lots of pressure available to make power directly topside**



# Technical Observations -- Surprises

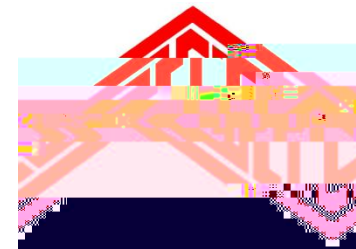
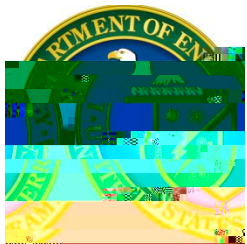


Summary for 50 MW Net Power

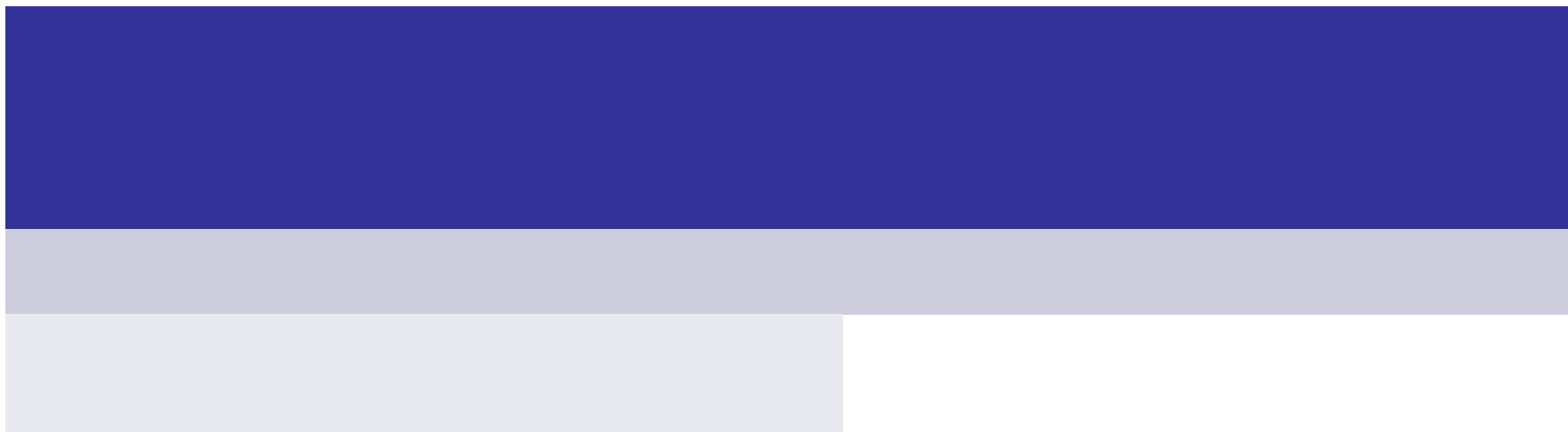
Depth    Massflow

- 1
- 2
- 3

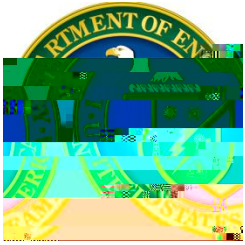
1. Traditional CO2 ORC appears to be a loser (compared to water, in MA)  
No pumps, but much deeper holes, plus cost of CO2!!
2. CO2 Turbo expander (direct turbine generator) looks very good  
Higher cycle efficiency and lowest machinery / auxiliary costs
3. Not really better, or hugely complex / risky (turbines 5 miles below surface)



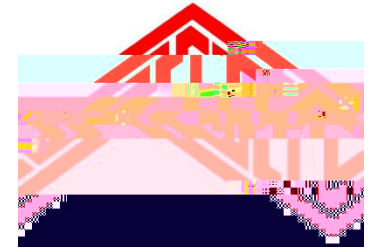
## A Subset of the Variants Considered (All Western MA)







# SOPO 1.0 Summary Result Sheet: Baseline H2O EGS



**Even with unrealistically cheap money (4%), the conventional EGS does not look good in Western, MA**

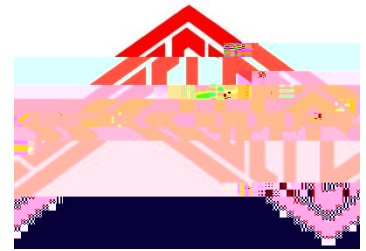
**No huge surprise**

**The hybrid diesel pump version (next page) is better than all electric pumps**

**Lower capital cost  
Better ROI**

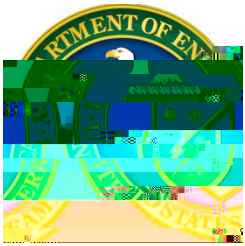
Parameters:		Comment
Gross Power	50	Geothermal Gross Power, Not Plant
	20	
	\$167	
	\$81	
	\$13	

Ne1 37949e7(W0.0 1 2.25 3123630280 175 349.3\$1T61T7T/F721T2T5T/F721T0T6 Tc(\$13)T275 Tf1 0.0 1280 175 349.3)8

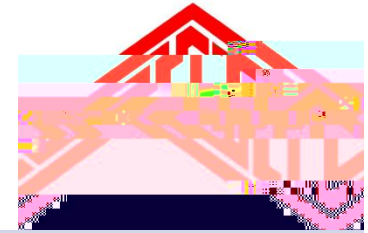








# SOPO 2.0: Impact of CO2

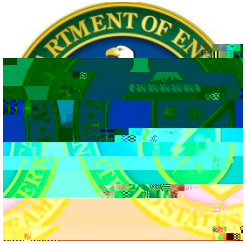


**CO2 EGS,  
without any  
technology  
tricks, will  
require  
stacks of  
money**

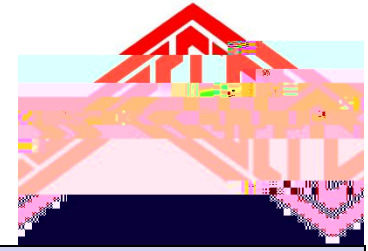
**Mostly  
driven by  
TRL9  
decision on  
corrosion  
control  
Nothing  
proven (and  
inexpensive)  
is out there  
bck Å**

Parameters:		Comment
Geothermal Power (Net)	50	Geothermal Net Power
	50	Yearly Total (Not Including Filling)
	0	
	\$167	
	\$81	
	\$13	
	4.0%	
<u>Cost Item</u>	\$	
		2.0%
Purchased Costs (Fuel / CO2)		
Total Annual Cost		
		50.0%





# SOPO 2.0 WBS3: Price of CO2 (and topside fluid management)



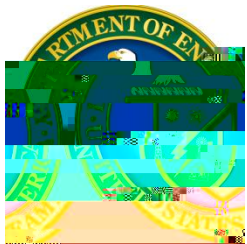
**Though not the driver as shown, the CO2 is pricey, but the biggest deal here is risk**

**If porosity estimate is off by factor of 3 you are out another >\$0.5B**

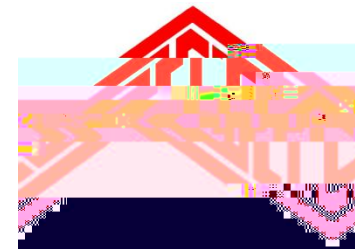
	MT Required
Filling CO2 Price / Ton (In Massive Quantity)	
Electric Blower to Start Thermal Siphon? 1000 hp multi-stage compressor, electric drive (Solar Turbines) Diesel Genset for Backup Power	ROM 







## **SOPO 3.0: CO2 + Technology Capital Cost Tab**

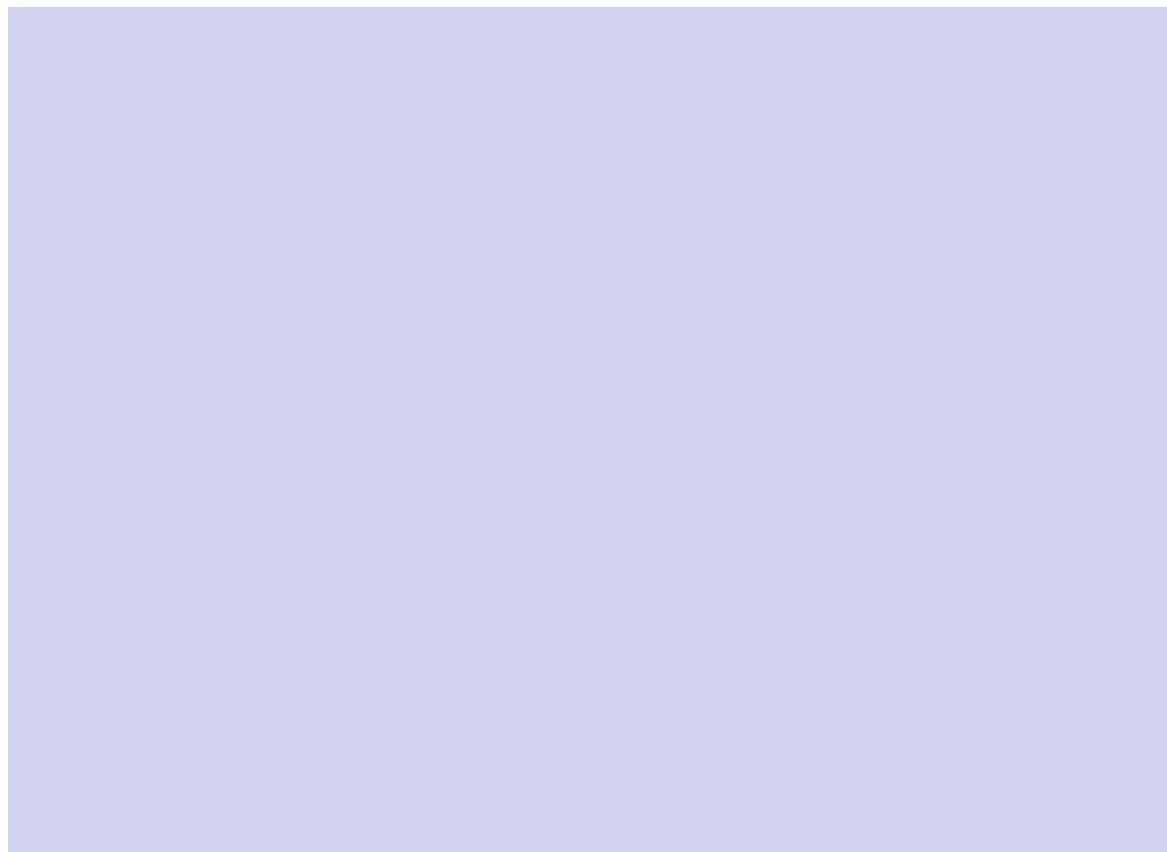


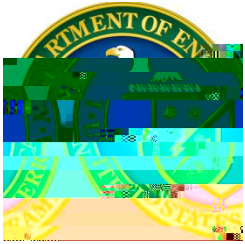
**WBS2 Costs are lower mostly as a result of clad liners vs. stainless E and lower price of CO2 enabled shallower depth design (21kft)**

**WBS3 Costs are offset by \$74M of one time (filling revenue) & 125% of yearly revenue (top-off)**

**Net result:**

**60ish% of the costs  
125ish% of the revenue**



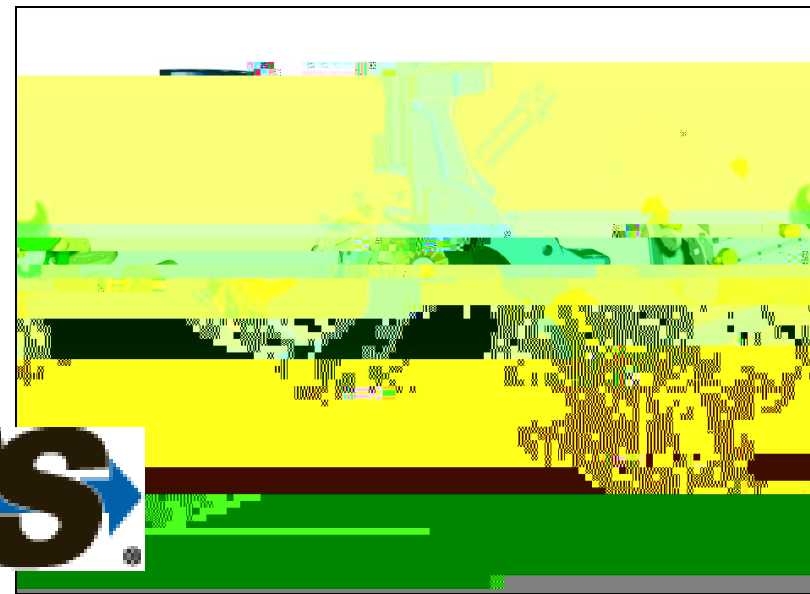
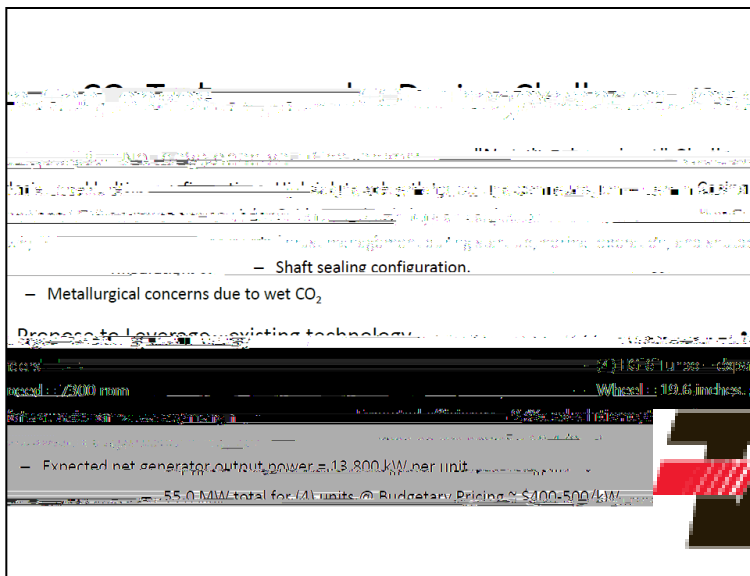


# Turbines, Turbines, Turbines

Plasma reservoir filling system uses Dresser Rand Model 1

Semi-closed combustion turbine with captured CO<sub>2</sub>

Main power turbines by TAS







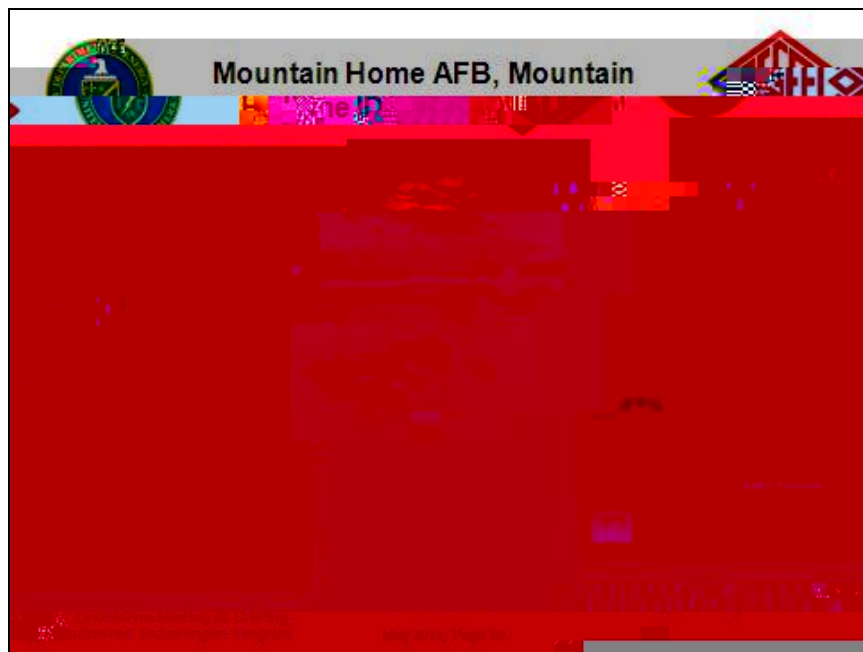
# SOPO 4.0 Locations (with Technology)

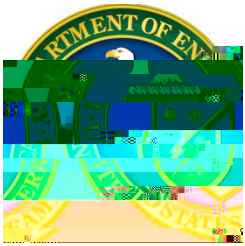
**Ft. Bliss will be a Water EGS**

It might be a good site for CO2 sequestration, but not EGS!!

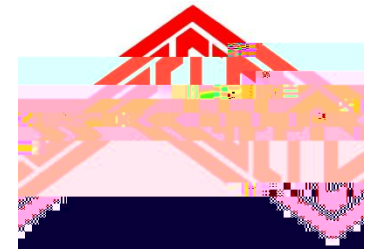
**Others will be CO2**

**Net result is a range of locations, EGS designs, and costs**





# Summary



Detailed WBS based EGS cost models have been developed as a result of a DOE Grant

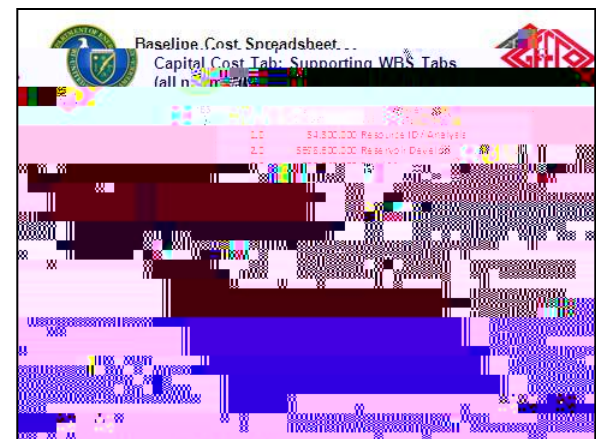
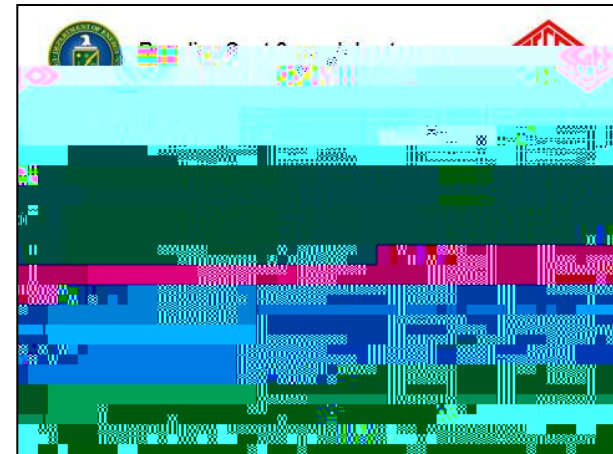
The baseline (50 MW Water EGS) in Massachusetts is untenably high cost (well over \$1B capital – 70+% of which is associated with reservoir development) and is not profitable, even with high electric rates, unless money is close to free!

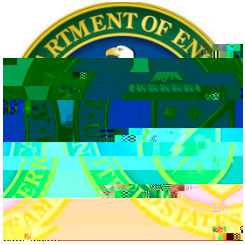
CO2 EGS (with direct turbine) operates at a much higher net cycle efficiency, resulting in a smaller reservoir (lower cost), but requires greater massflow (larger drill diameters, or closer spacing, fancy completions, and a corrosion program)

CO2 EGS is only practical in areas with locally available low cost CO2, or with CO2 generated on site (hybrid system) – until the CO2 rules change

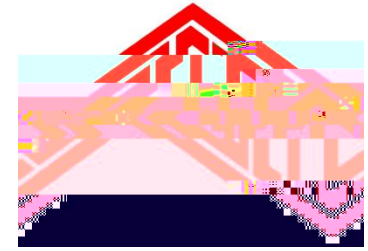
We are studying a wide range of other locations (CA, TX, ID) and electricity costs

We will complete and publish this year





# Acknowledgement



This briefing material has been assembled from a number of sources generated by the team

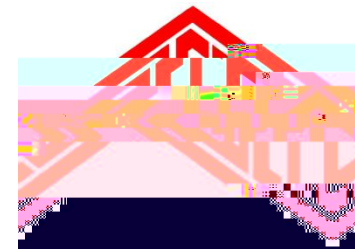
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We would also like to thank the DOE Geothermal Technology Program, in particular Ms. Arlene Anderson, for her support

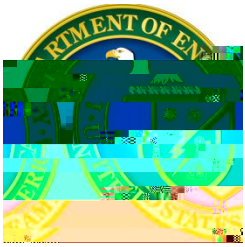


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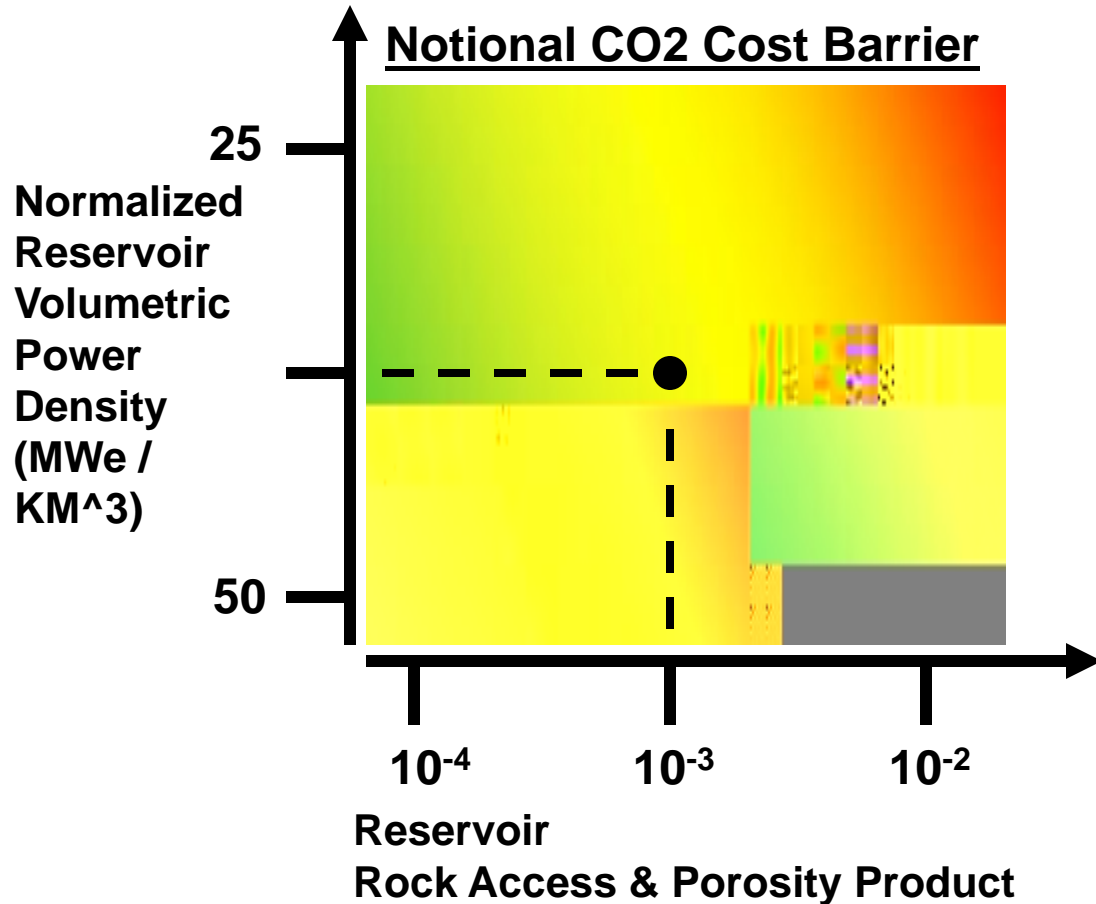
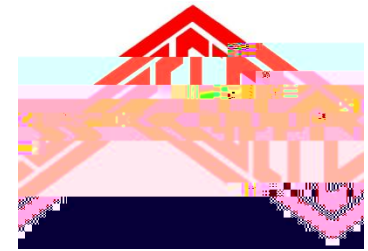


# BACKUP



**The Size of the Reservoir, and Parameters, Such as Porosity and Access, Significantly Drive Cost**

**Example Shown Below for \$240/ton Trucked In CO2 (Unaffordable!!)**

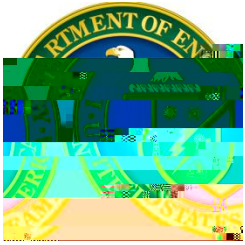


The mass of CO2 required to charge a given reservoir is a function of the density (average at temperature and depth), volume, and porosity

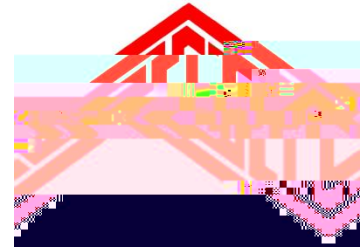
per MWe, e.g.

- 50 MW, 1.3 km<sup>3</sup>
- 0.1% Access / Porosity Product, e.g.
  - 5% is accessible
  - 2% porosity
- 50 lbm/ft<sup>3</sup> density
- ~1.1 Mega Tons CO2
- \$264M @ \$240/ton





# **SOPO 1.0 Water Bottom Depth 21,000 ft**



**70 MW Case (50 MW Net); 2703 MMBTU/hr heat removal rate**

**25 Production Wells and 16 Injector Wells Æ 0.5 mile spacing**

**160 lbm/sec production well; small bores OK; dual completion**

**250 lbm/sec injection well; big bores required**

**3.2 km<sup>3</sup> reservoir volume**

**50 MW Case (Diesel driven pumps)**

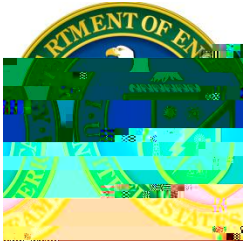
**Proportionally lower heat removal rate and well count (5/7th)**

**20 Production Wells and 12 Injector Wells Æ 0.5 mile spacing**

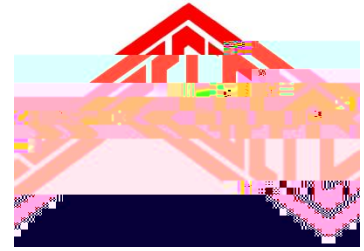
**Same casing sizes, nominally the same per well flow rates**

**Other than dual completion on production wells, this is conventional construction**

**DfcXi Wjcb'di a dg'gYh]b`%Î `X]Ua YhYf`4 `bca ]bU`m' \$\$\$Zh**



## **SOPO 2.0 (CO<sub>2</sub>: Purchased, Existing Technology (SS))**



**50 MW requires 799 MMBTU/hr heat removal rate (@ 30kft)**

**12 Production Wells and 6 Injector Wells @ 0.45 mile spacing**

**System flow rate is down to 2700 lbm / sec (H<sub>2</sub>O was 4000 lbm/sec)**

**450 lbm/sec per injector well**

**225 lbm/sec per production well**

**Big Bore Injector Wells to 30,000 ft @ no exotic materials needed**

**Manageable pressure drop ~150 psig  
(nothing compared to siphon)**

**Small Bore Production Wells, Dual Completion, in STAINLESS!!**

**Manageable pressure drop ~700 psig  
(still ok compared to siphon)**

**Reservoir Size 0.94 km<sup>3</sup> (vs. 3.2 km<sup>3</sup> for SOPO 1.0)**

**At 44 lbm/ft<sup>3</sup> bottom (hot) density, this is 730,000 tons of CO<sub>2</sub>**

**5% of reservoir is accessible to CO<sub>2</sub> flow**

**2% porosity in this area**

**\$175M delivered (initially!!) @ then that much again over time**

