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

Fort Point Associates

What Does This Mean?

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

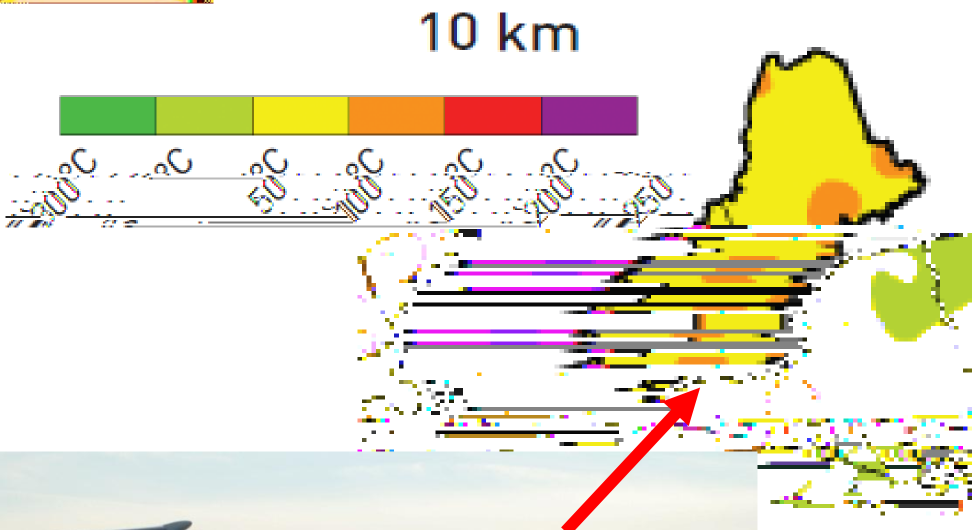
Today, we will tell you the preliminary results, for 50 MW EGS Cost in a <u>really</u> challenging environment (Western MA)

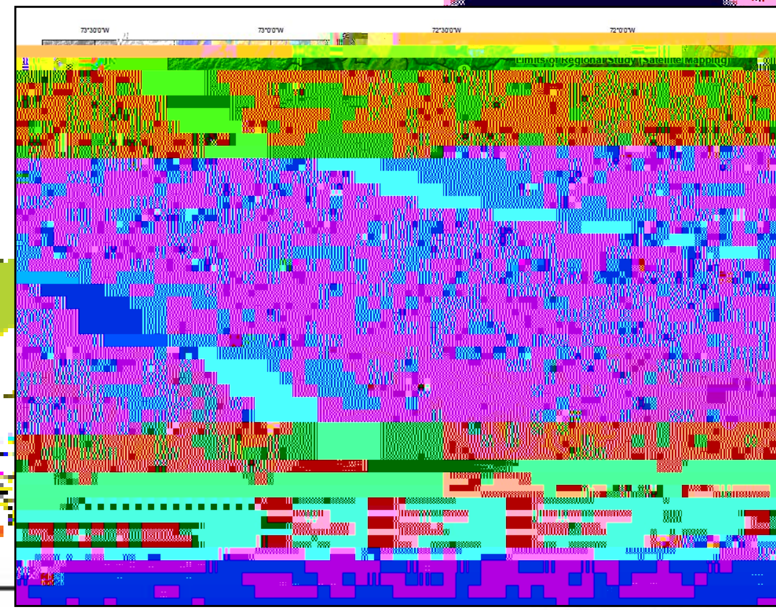
- **50 MW Net Water-EGS (70 MW Gross)**
- **50 MW Water-EGS Diesel / CNG Hybrid (20 MW Water Pumps)**
- **50 MW CO_2 EGS ï Today's Cost --- No Magic**
- **50 MW CO_2 EGS ï Cost with reasonable application of CO_2 Generation and Drilling Technology**

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





Westover:

~400 F @ 30,000 ft

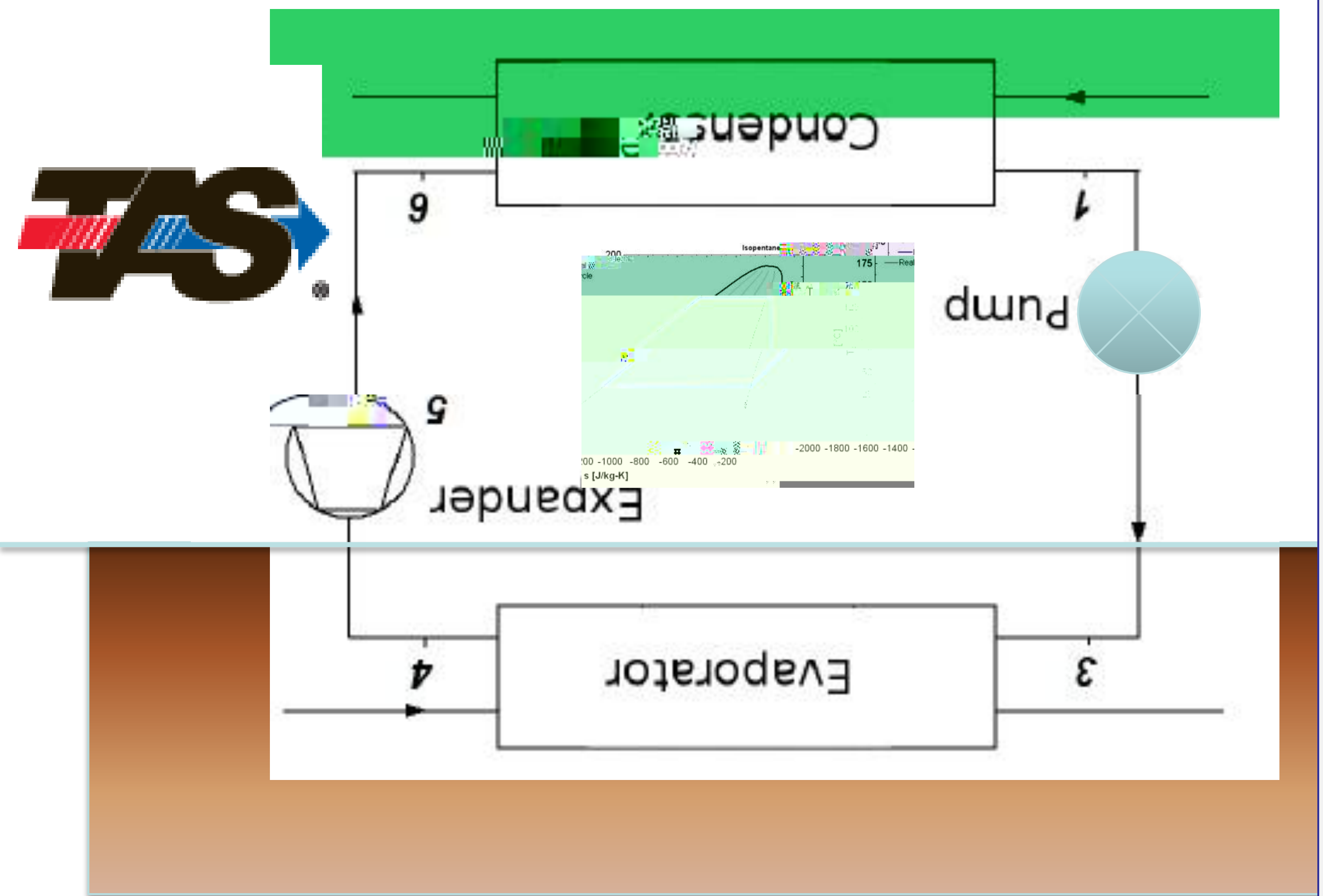
~300 F @ 21,000 ft

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_2 Direct Expansioné 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

ñEarth Cycle Efficiencyò -- Technical Observations -- Surprises

Summary for 50 MW Net Power	Depth	Massflow

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 <u>lowest</u> machinery / auxiliary costs

3. **ñCleverò CO2 cycles probably not so bright**

   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**

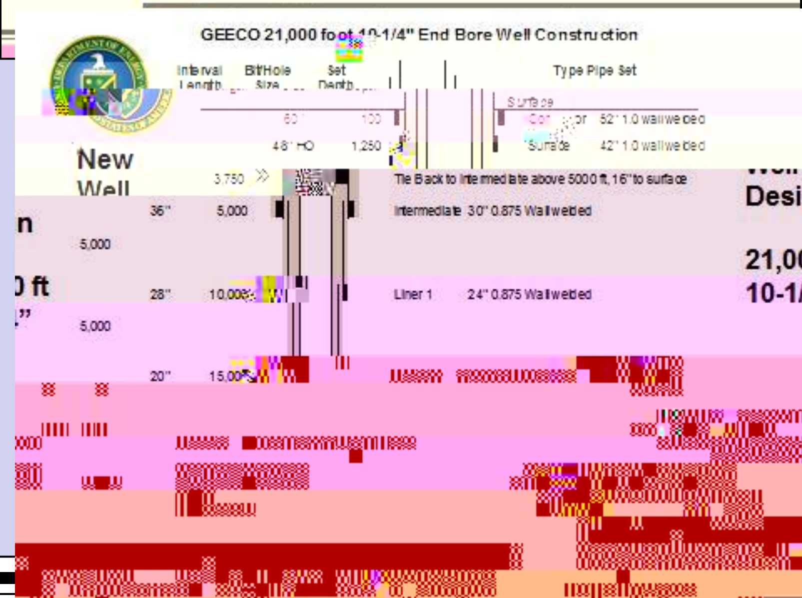
The hybrid diesel pump version (next page) is better than all electric pumps

- **Lower capital cost**
- **Better ROI**

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

Ne1 37949e7(W0 0 1 2.25 3123630280 175 349.3$1]T61]T7]T/F721]T2]T5]T/F721]T0]T6 Tc[($13)]T275 Tf1 0 0 1280 175 349.3)8

SOPO 1.0 (H2O Baseline) Capital Cost Tab



SOPO 2.0: Impact of CO_2

CO_2 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 nowé

Parameters:			Comment
Geothermal Power (Net)	50		Geothermal Net Power
	50		Yearly Total (Not Including Filling)
	0		
	$167		
	$81		
	$13		
	4.0%		
Cost Item	$		
			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 ï and lower price of CO_2 enabled shallower depth design (21kft)

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

Net result:

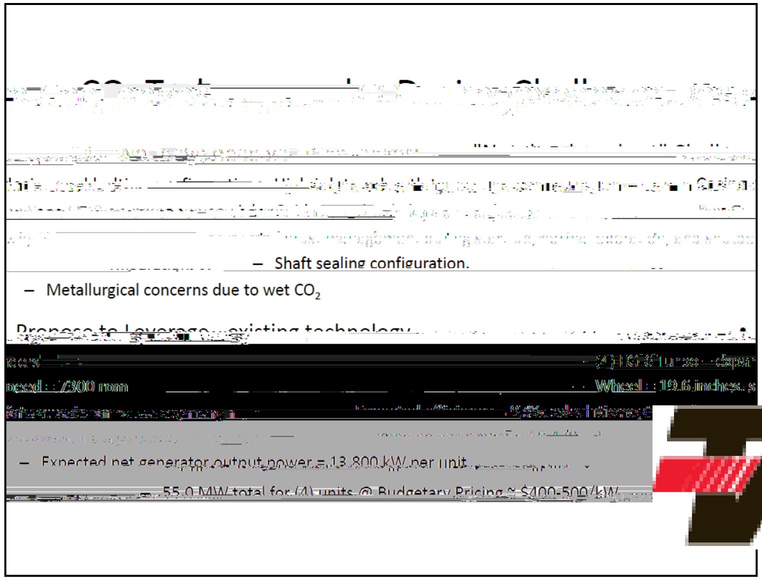
- **60ish% of the costs**
- **125ish% of the revenue**

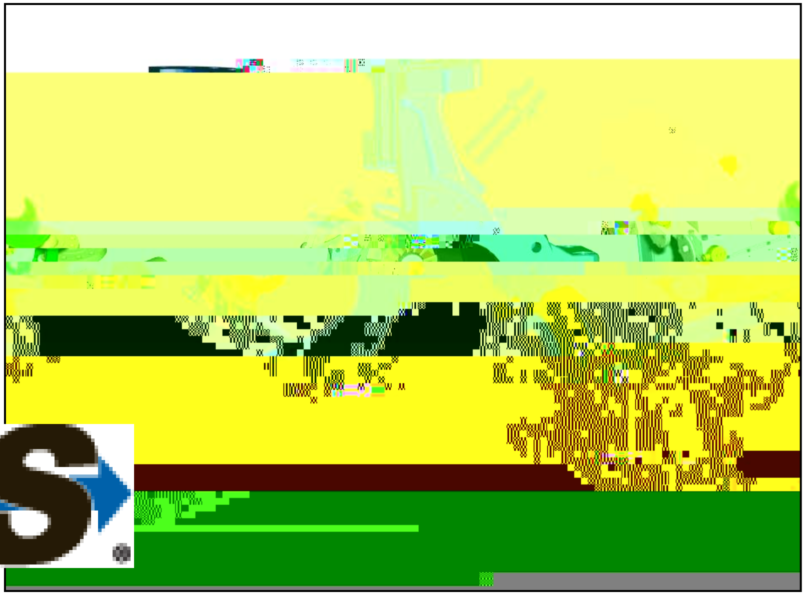
Turbines, Turbines, Turbines

Plasma reservoir filling system uses Dresser Rand Model 1

- **Semi-closed combustion turbine with captured CO2**

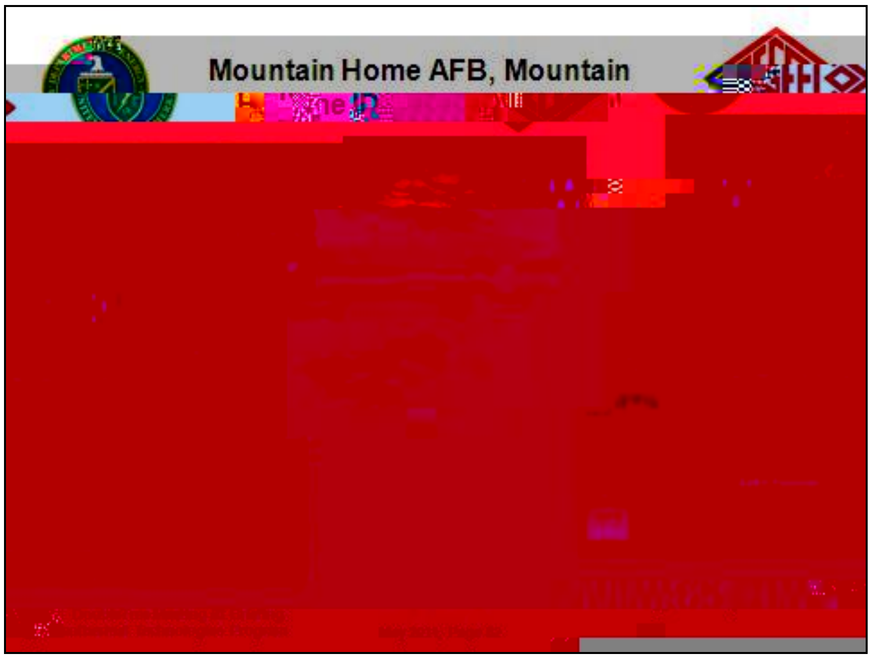
Main power turbines by TAS

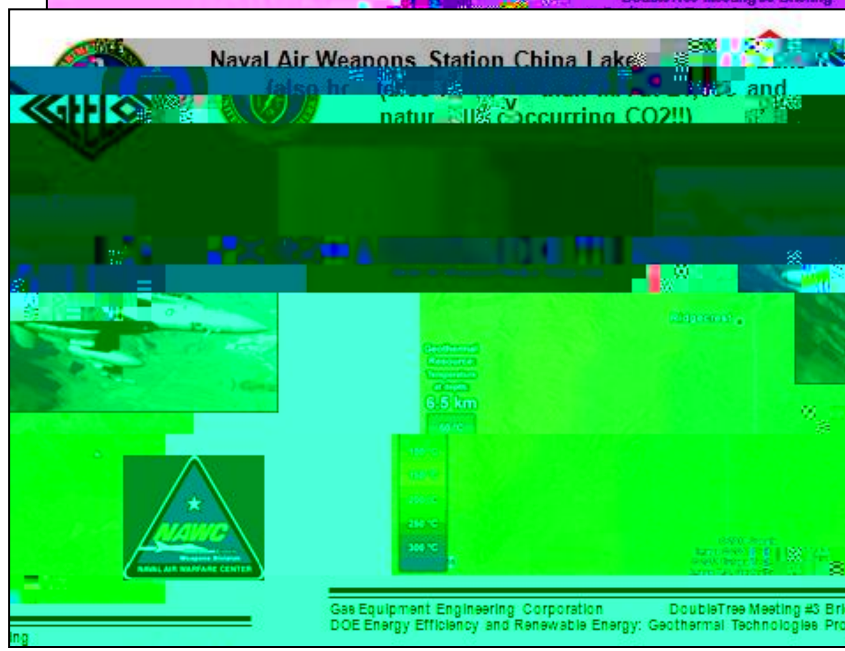




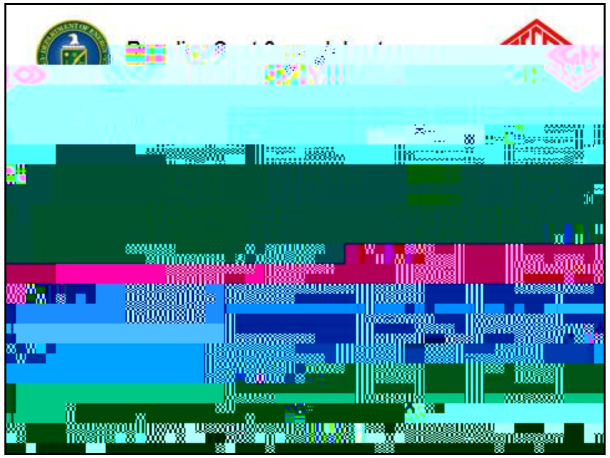
SOPO 4.0 Locations (with Technology)

- **Ft. Bliss will be a Water EGS**
  - **It might be a good site for CO_2 sequestration, but not EGS!!**
- **Others will be CO_2**
- **Net result is a range of locations, EGS designs, and costs**



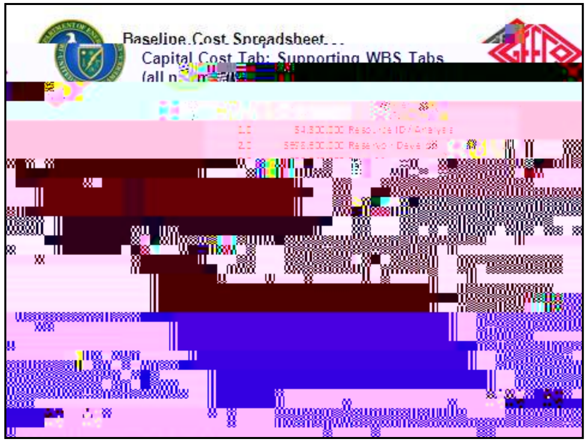


Summary



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 ï 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) ï 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

We have an amazing teamé

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

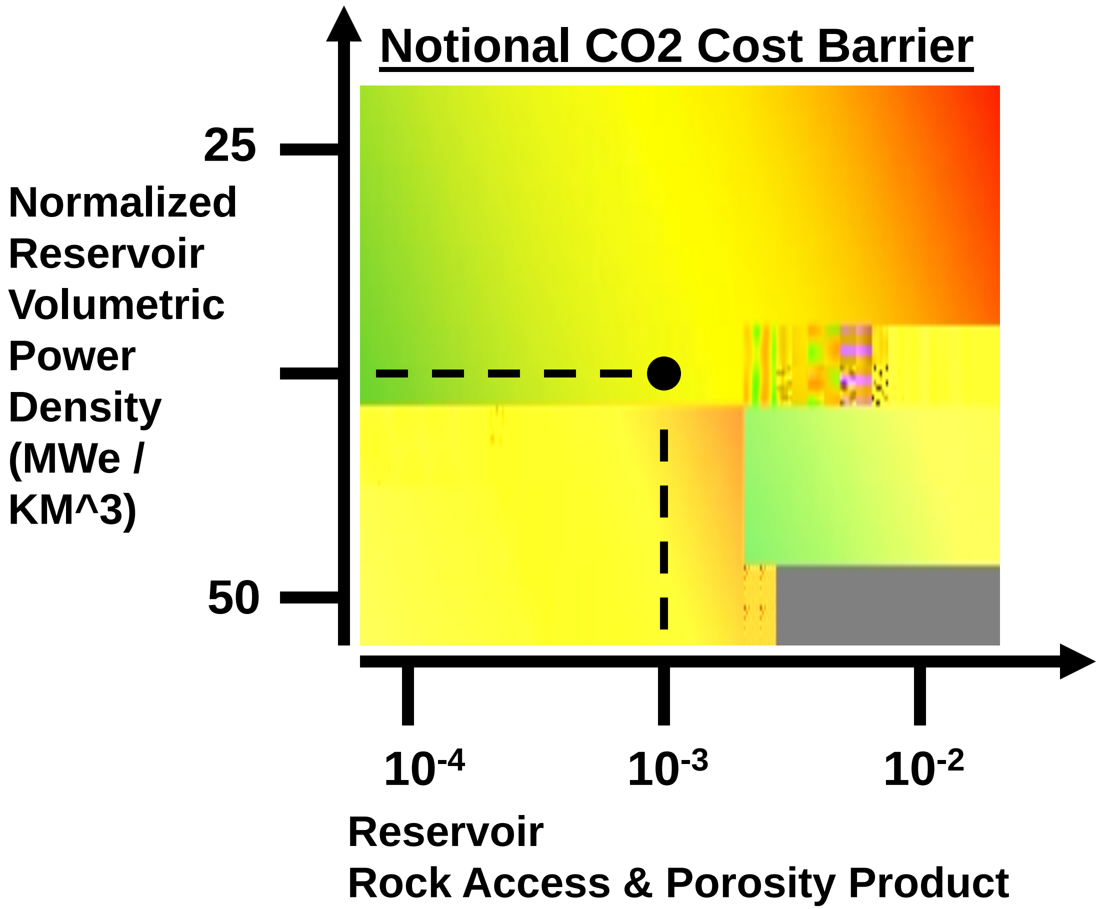
Impact Technologies LLC

Fort Point Associates

BACKUP

Reservoir Size Implicationsé

The Size of the Reservoir, and Parameters, Such as Porosity and Access, Significantly Drive Cost Example Shown Below for \$240/ton Trucked In CO_2 (Unaffordable!!)



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 ñdotò is at ~\$5.3M per MWe, e.g.

- 50 MW, 1.3 km^3
- 0.1% Access / Porosity Product, e.g.
  - 5% is accessible
  - 2% porosity
- 50 lbm/ft^3 density
- ~1.1 Mega Tons CO_2
- \$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 ï 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^3 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 ï 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

- Production pumps set in 16ò diameter @ nominally 3,000 ft

SOPO 2.0 (CO2: Purchased, Existing Technology (SS))

- 50 MW requires 799 MMBTU/hr heat removal rate (@ 30kft)
- 12 Production Wells and 6 Injector Wells ï 0.45 mile spacing
  - System flow rate is down to 2700 lbm / sec (H2O was 4000 lbm/sec)
    - 450 lbm/sec per injector well
    - 225 lbm/sec per production well
  - Big Bore Injector Wells to 30,000 ft ï 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^3 (vs. 3.2 km^3 for SOPO 1.0)
- At 44 lbm/ft^3 bottom (hot) density, this is 730,000 tons of CO2
  - 5% of reservoir is accessible to CO2 flow
  - 2% porosity in this area
  - $175M delivered (initially!!) ï then that much again over time