# GEOTHERMAL ENERGY PROGRAM

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VENTURE CAPITAL TECHNOLOGY SHOWCASE
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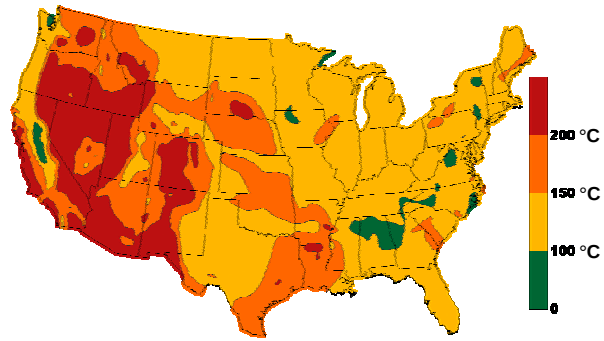
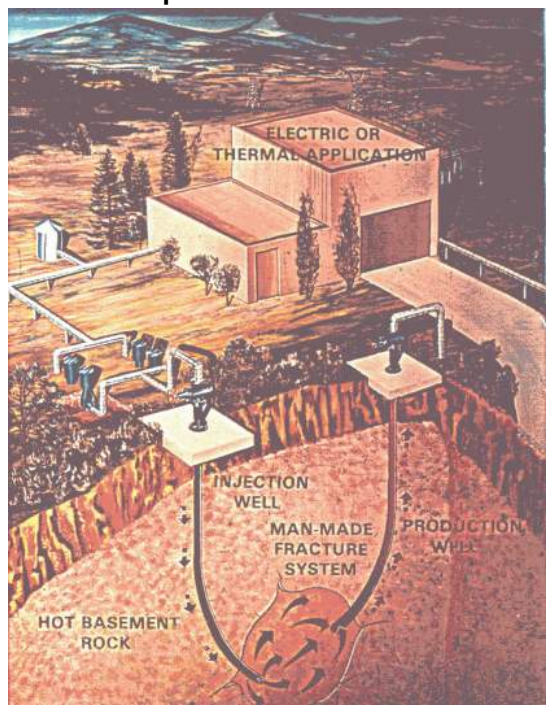
# Enhanced Geothermal Systems (EGS) for Electricity Generation

- **Problem Technology Addresses:** Base load power generation with few or no emissions.
  - **Size of Problem:** Significant shortfall in projected U.S. power generation. Coal may not be able to meet the deficit.
- **Description:** EGS involves engineering a hydrothermal reservoir via fracturing and injection of water to extract heat from the earth.
- **Impact:**
  - Up to 10% (100 GWe) of the current power generation capacity can be from EGS, with potential to install much more.
  - There are essentially no carbon or other gaseous emissions and the geothermal resource is sustainable.
  - The resource exists across the nation.
- **IP Position:** Public domain, with the opportunity for many inventions.
- **Status:**
  - The EGS concept has been shown to be technically feasible at sites in several countries, including the United States.
  - The challenge is to improve EGS technology to ensure economic viability at commercial sites.
  - Field tests are required, starting with improving existing hydrothermal reservoirs, proceeding to expanding existing hydrothermal reservoirs, and ultimately creating reservoirs in challenging conditions.
  - For full-scale EGS development, about $50M to $100M/site.
  - Although the current working fluid is water, there exists the potential for other working fluids such as supercritical carbon dioxide, with attendant sequestration of the carbon. The carbon dioxide working fluid concept is patented and available for licensing, but field testing is required.




Temperature at 6 km





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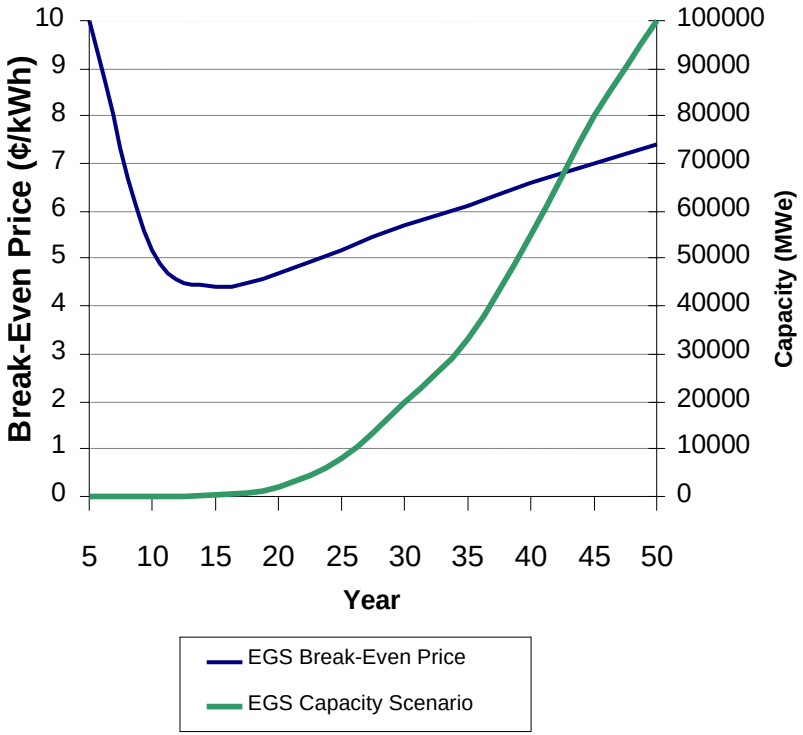
# Enhanced Geothermal Systems Have Significant Potential




The geothermal resource can be used to generate electricity via enhanced geothermal systems (EGS), where hydrothermal reservoirs are created and heat is mined for conversion to electricity.

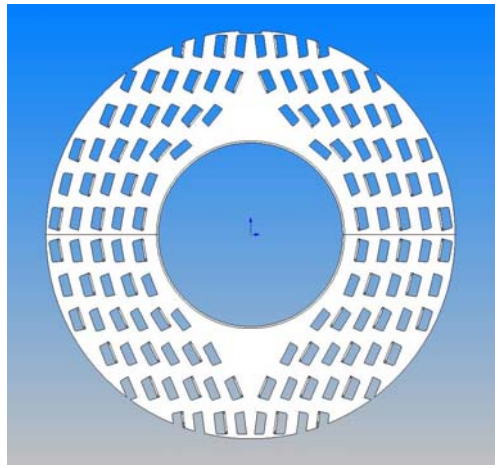
A commercial EGS project is under development at Cooper Basin in Australia using private sector funding.

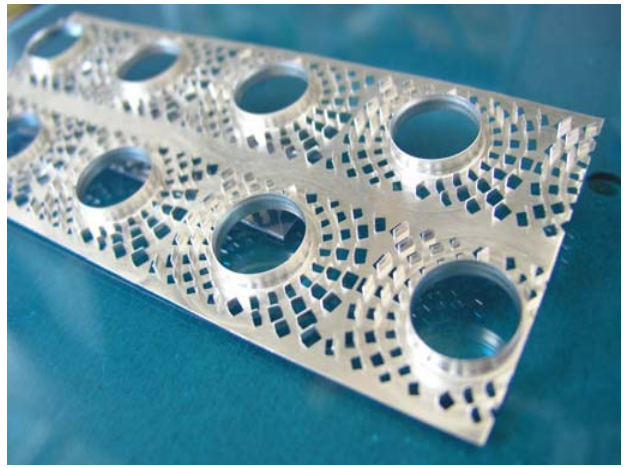
MIT led an analysis by a panel of 18 international experts who concluded that it is possible to install 100 GW of EGS generation by 2050, with costs competitive with coal generated electricity. Geothermal generation is base load and has essentially no carbon emissions. DOE and national labs are performing an evaluation to define the technology developments required to enable private industry to commercialize enhanced geothermal systems.

# Technologies Related to Energy Conversion

# Tabbed-Fin Heat Exchangers

- **Problem:** The performance of air-cooled heat exchangers typically decreases in the summer with increased air temperatures.
- **Description:** Tabbing produces “fins-on-fins” to disrupt air flow, enhancing air-side heat transfer with very little air-side pressure drop. Pictures show a flat plate fin and a round fin that would be attached to tubes. This invention allows a closer approach to air temperature for a given exchanger size, resulting in additional power generation for a power plant.
- **Impact:**
  - Heat transfer is increased by up to 30% with a slight increase in air-side pressure drop. This equates to about 3% annual improvement in power output.
  - The device is applicable to any air-cooled heat exchanger, ranging from household air conditioners to large-scale air-cooled power plants. This is a billion-dollar market.
- **IP position:** Patents pending.
- **Status:**
  - NREL has tested small-scale bundles to prove the concept and reduce it to practice. Some additional improvements are possible.
  - The flat plate fin is ready for application, while the round fin requires additional tooling and manufacturing process development.
  - Tooling will be required to produce either product. Development of the round fin will require indexing to assure proper alignment of the tabs relative to the tubes.



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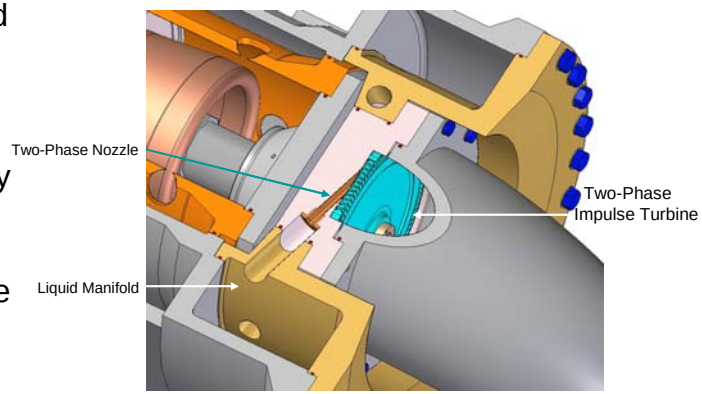
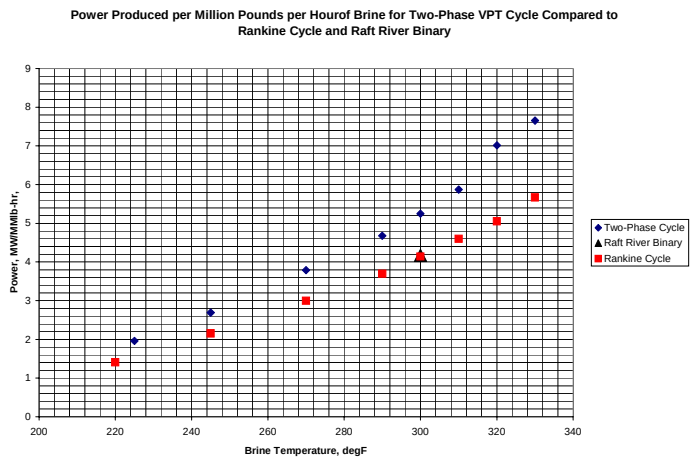
# Variable Phase Turbine

- **Problem:** Organic Rankine Cycle systems for power generation or waste heat recovery are limited economically by heat exchanger cost, power generation limitations and gearbox and seal reliability.
  - **Size of Problem:** Low-temperature heat that is currently unused could generate 10 to 34 gigawatts of power using this technology.
- **Description:** The Variable Phase Turbine enables a hermetic power system with the highest thermodynamic efficiency using a compact liquid heat exchanger and a direct drive generator. This turbine uses a proprietary nozzle to expand hot, pressurized liquid to vapor or two phases with high kinetic energy. The kinetic energy is transformed to power by axial turbine blades, directly driving a generator which is cooled by the working fluid. The turbine uses a trilateral working cycle to maximize efficiency.
- **Impact:**
  - **Basic to Geothermal:** Decrease in total cost of power generation from low-temperature resources by up to 40%.
  - **Beyond Geothermal:** Same benefit to waste heat recovery. Can increase output of industrial refrigeration processes, such as LNG, by more than 10% by substitution for two-phase Joule-Thompson valves.
  - 10 to 34 GW of power from low-temperature heat can be generated using this technology.
- **IP Position:** Inventions: U.S. Patent No. 7,093,503, August 2006; owned by Energent Corporation.
- **Status:**
  - Reduction to practice: Two-phase power system in operation in lab
  - Available immediately, host site committed (Coso)
  - Special needs: None
  - Capital needs: $1.3 million for 1 MW demonstration system




Technology Concept




Results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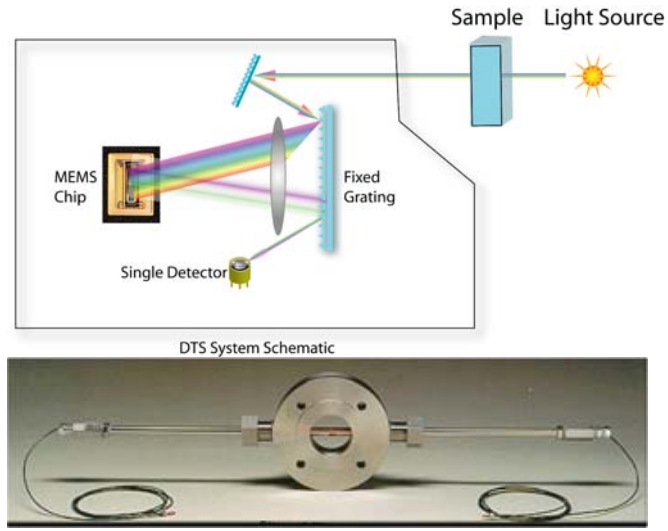
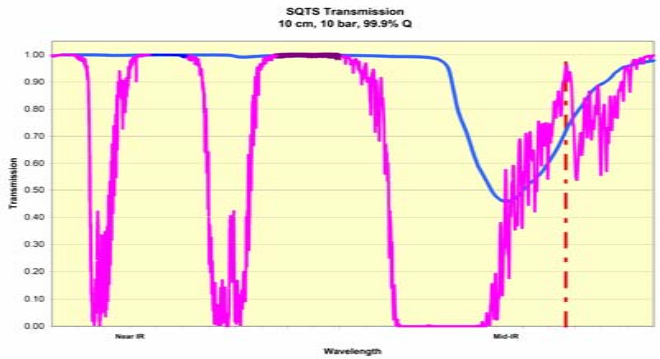
# Advanced On-Line Steam Quality Sensor

- **Problem:** Accurate measurement of moisture in steam is difficult.
  - Moisture causes damage and efficiency reduction in steam turbines. Accurate on-line measurement allows better process control. Other industries that use steam (chemical process facilities, heating systems, steam flooding for advanced oil recovery, etc.) also require this measurement. The market for power plants could be tens of thousands of units (tens of millions of dollars).
- **Description:** Newly developed Mid-IR Laser Diodes and Digital Transform Spectroscopy allow real-time detection of low-levels of moisture in steam: <0.1% moisture ( > 99.9% steam quality). Currently all steam quality measurements rely on throttling steam calorimeters (1930s technology). Recently patented optically-based measurements in the Near-IR do not provide the required sensitivity.
- **Impact:** This technology can impact virtually all baseload electric power plants and industries utilizing steam energy, including enhanced oil recovery (EOR) operations, by improving process efficiency and/or reducing turbine wear.
- **IP position:** Related technology intended for Near-IR use is patented by INEEL and exclusively licensed to Thermochem. The patent is under review to determine whether additional patents are needed for Mid-IR.
- **Status:**
  - The basic concept is patented and licensed (Near-IR version)
  - A ruggedized version must be deployed for long-term tests.
  - A prototype will be available in 12–18 months.
  - Commercial Mid-IR laser diodes at specific wavelengths are needed (currently under development).
  - Capital Needs: ~$500k




Technology Concept




Results

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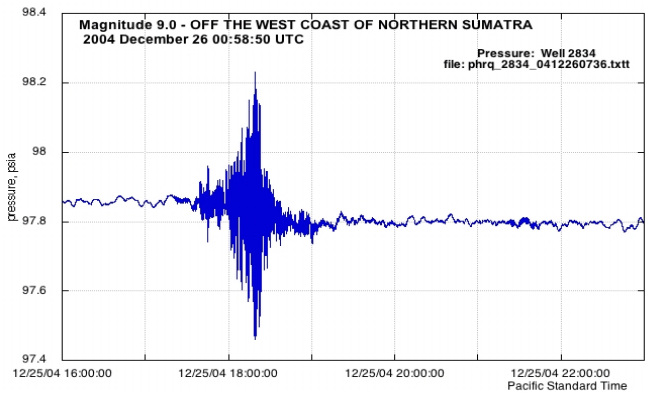
# Technologies Related to Drilling and Well Completion

# High-Temperature Chip Set

- **Problem:** Geothermal wells are too hot for conventional electronics.
  - **Size of Problem:** Few electronic monitoring and control systems are available for high-temperature environments. This technology enables remote monitoring and control solutions for geothermal and deep oil & gas wells, aircraft engines, hybrid automobile motor controls, and other harsh applications.
- **Description:** 8051-based chip set (processor, memory, I/O, and boot up and operational instructions) with proven reliability of 5.2 yrs at 200°C; system can operate at 300+°C.
- **Impact:**
  - Allows the manufacturing of downhole tools not previously available.
  - Other potential markets include motor controls for hybrid & electric cars, ultra-deep natural gas wells, earthquake warning systems, aircraft engine monitoring systems
- **IP position:** Copyrighted (code is burned into the chip set).
- **Status:**
  - Fully developed including educational materials
  - Used in Sandia's 250°C Pressure, Temperature & Spinner tool
  - Available now
  - Used to monitor a 193°C well for over 800 days (the geothermal industry standard is 400 hours at 175°C)

Monitoring a Geothermal Well




High sensitivity of tool using chip set captured hydro-seismic response of Sumatra earthquake from site in a California well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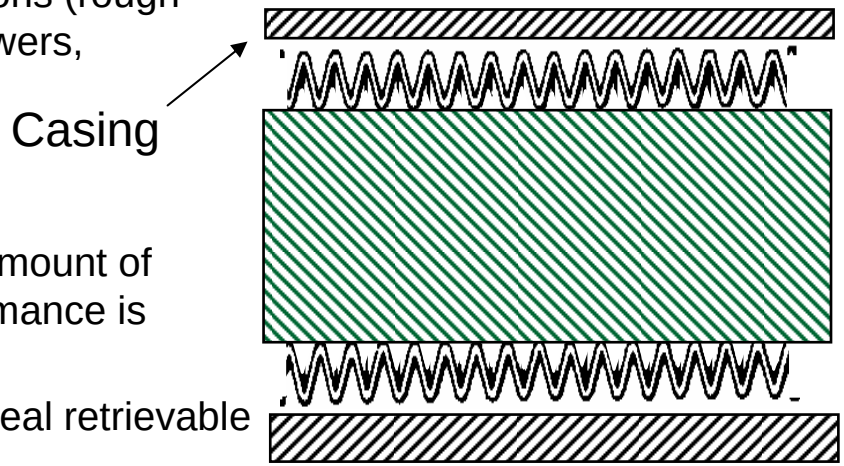
# Bellow Seal and Anchor

- **Problem:** Blocking off a portion of a well requires creating a removable elastomeric seal inside an irregular rough opening.
  - **Size of problem:** Intervention in boreholes (open and cased), sewers, gas distribution lines is frequently required. Isolating sections is often problematic. This technology provides a simple, robust solution to the problem.
- **Description:** The unique properties of a bellows allow sealing, insertion, retrieval, and anchoring: bellows shrink when stretched and can be made to fold when compressed.
- **Impact:** The technology allows an “o-ring like” seal to be made in difficult locations (e.g. inside a hole) and conditions (rough surfaces). The technology works in boreholes, sewers, pipelines, etc.
- **IP position:** Patent 6,182,755 issued 2/6/2001.
- **Status:** A visual demo has been built and tested.
  - The cost is comparable to other seals (same amount of materials), but application is easier and performance is better.
  - Designs have been developed that make the seal retrievable and reusable (some retrofit may be required).
  - The next step is to market the device.



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# Encapsulated Lost Circulation Material

- **Problem:** Lost circulation during drilling is costly, especially if multiple plugs are needed, because it requires stopping operations to trip the drillpipe and set a plug.
  - **Size of problem:** Typical "flat-time" (all time spent not making new hole) ranges from 60% to 80% of the time a rig is over a hole. In some wells lost circulation can be a significant fraction of flat time.
- **Description:** The "perfect" solution is encapsulating a reactive lost circulation material in a chemical barrier to allow the plug to be pumped through the drillpipe without having to remove the drillpipe from the hole.
- **Impact:** A robust way to plug lost circulation zones would reduce trouble costs, and would also allow less conservative well designs (e.g. longer sections between casing points), reducing steel & cement costs. In deep wells, decreasing the number of casing strings can reduce the total well cost by 10% to 20%.
- **IP position:** A Technical Advance (the first step in the patent process) is on file.
- **Status:**
  - Reactive lost circulation plugs have been demonstrated as effective even in the presence of underground blowouts. They fill a vital technology gap because they can be set, compacted, and self-divert before there is time for the plug to wash away.
  - The difficult aspects of using reactive plugs are delivering the plug and properly timing the setting of the plug. The concept of encapsulating reactive lost circulation material has been demonstrated in the lab.
  - The next step is designing and prototyping field tests.

Laboratory simulation of sealing a lost circulation zone with a reactive plug

Consolidation of rubble loss zone


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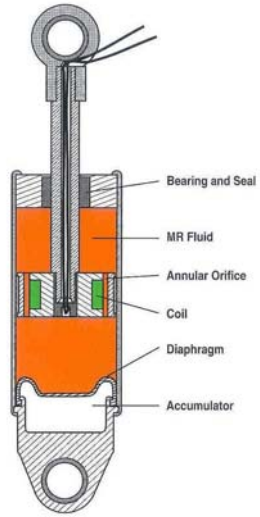
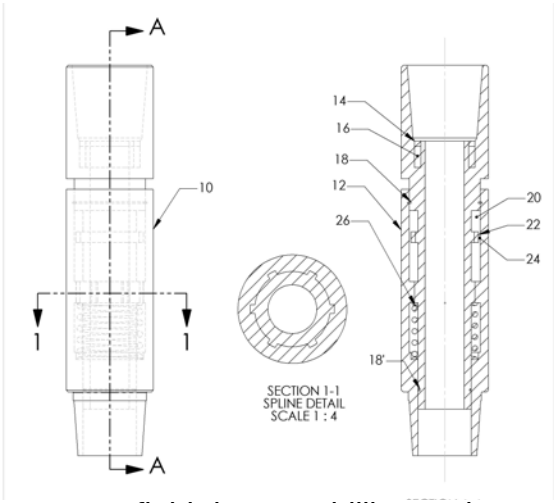
# Magneto-Rheological Fluid Damper

- **Problem:** Drill bits and downhole tools are susceptible to failure when subjected to excessive vibrations.
  - **Size of problem:** Drilling for energy purposes is an enormous industry, with more than 150 million feet of development hole drilled in 2005. Trouble during drilling can exceed 50% of the cost of drilling a hole; this technology reduces trouble time.
- **Description:** An active control system mitigates downhole vibrations using Magneto-Rheological (MR) fluids consisting of a suspension of micron-sized iron particles in a carrier fluid that is housed in a downhole tool. The effective viscosity is controlled internally by modulating a magnetic field in response to drilling conditions. The system can be remotely powered and autonomously self-controlled.
- **Impact:** Mitigating vibrations can save millions of dollars in drilling costs by reducing tool failures and rig down time. Controllable damping is applicable to drilling as it can be self-controlled and provides fast response to unanticipated formation changes and other variability in drilling processes.
- **IP position:** United States Patent No. 7036612, for drilling applications.
- **Status:**
  - A prototype tool has been developed and tested in a laboratory drill rig; significant reductions in vibration levels and related bit damage were observed.
  - A field tool is ready to be developed and tested.
  - A high-temperature MR fluid will eventually be needed.




Conventional MR Fluid Damper (truck shock absorber)




MR fluid damper drilling tool


Well wall surface before (rough) and after damping (smooth)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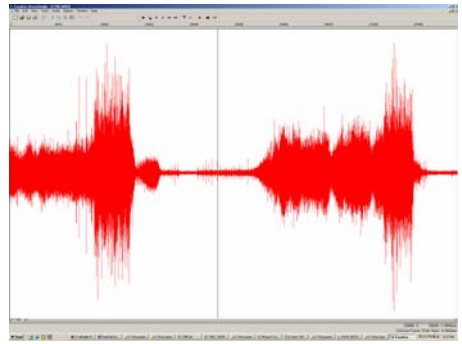
# Hearing Inaudible Drilling Noise

- **Problem:** Drilling problems can be mitigated if the driller can hear what is happening downhole. When a well is several thousand feet deep, downhole drilling sounds become inaudible.
  - **Size of problem:** Experienced drillers use their ears as one tool to diagnose drilling problems. As holes deepen, that connection to the bit is lost. This technology allows drilling to “hear” the bit and bottom-hole assembly using advanced processing of downhole signals.
- **Description:** A method allowing the driller to hear downhole drilling noise that is inaudible on the surface by selectively listening for/ detecting sounds, blocking out background noise, and making the drilling noise audible has been described in a Technical Advance.
- **Impact:** Development of a way to hear deep downhole drilling sounds using only surface equipment would significantly aid the driller.
- **IP position:** Technical Advance SD#10275 on file (first step in patent process).
- **Status:**
  - Correlation of downhole sounds and drilling problems has been demonstrated using downhole hardware, and transmission of sound through the drillpipe to the surface is understood.
  - Surface hardware for listening to downhole sounds has been developed.
  - The next step is to prototype a complete system (hardware and software) and test it in the field.



Drilling sounds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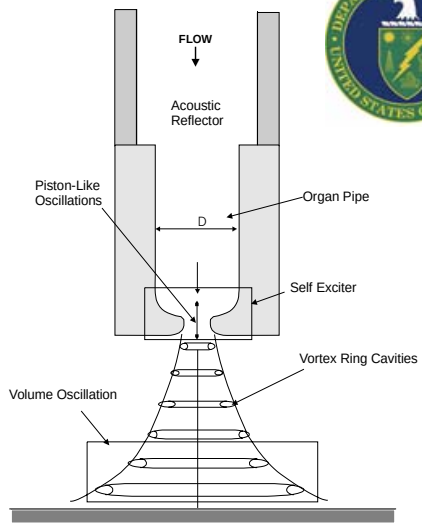
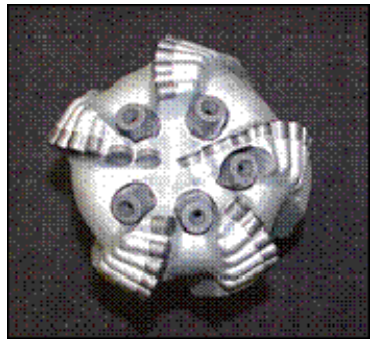
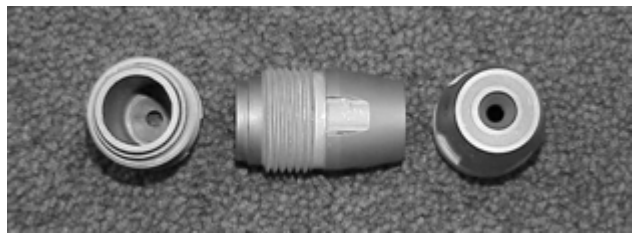
# Mudjet-Augmented Bit

- **Problem:** Employing conventional rig pressures to promote cavitation in the drilling fluid at the interface between the drill bit and the rock aids in downhole cleaning, rock erosion, and reduction of chip hold-down forces during deep drilling.
  - **Size of problem:** Drilling for energy purposes is an enormous industry with more than 150,000,000 feet of development hole drilled in 2005. This technology improves the drilling rate.
- **Description:** Resonance is established in a tuned chamber upstream of the nozzle orifice. Collapsing cavities spawn microjets that produce very high impact pressures capable of breaking the rock.
- **Impact:** Penetration rate improved for small increase in drill bit cost.
- **IP position:** Technical Advance SD#10248 is on file (first step in patent process).
- **Status:**
  - Cavitation-resistant orifices using polycrystalline diamond have been developed. The orifices are produced by profiling them in a product consisting of synthetic polycrystalline diamond with an annular ring of tungsten carbide. Direct sintering of orifices has been demonstrated by an industrial partner.
  - A demonstration bit developed for a high pressure differential across the nozzle (5000 psi) has been laboratory tested at realistic downhole pressures resulting in significant drilling rate enhancements. The demonstration bit is available for immediate field testing.
  - The benefit must be verified at smaller differential pressures (1000–2000 psi) and field validation testing must be conducted.
  - Short-term development: Approximately 3-6 months.




Technology Concept





Demonstration Bit & Nozzles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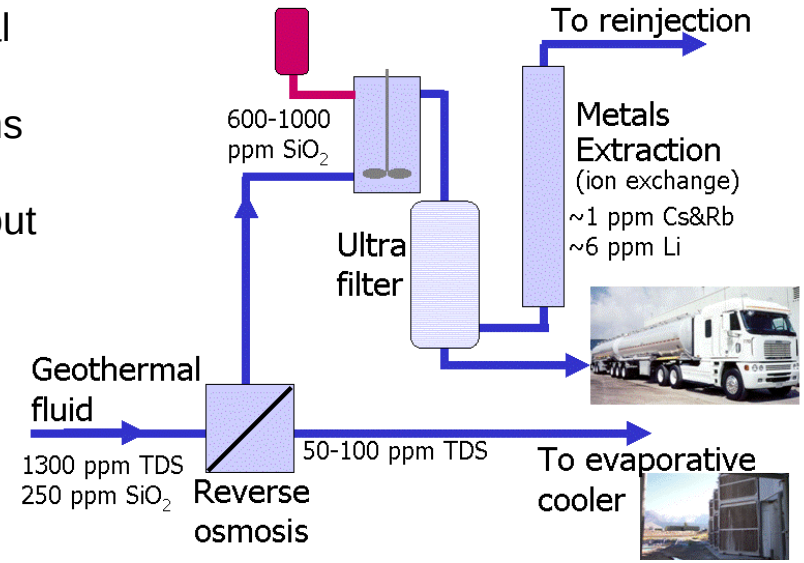
# Technologies Related to Mineral Coproduction

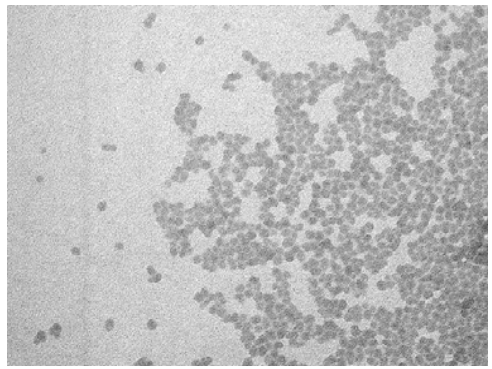
# Mineral Coproduction from Geothermal Fluids

- **Problem:** Need to produce a marketable by-product to increase the profitability of geothermal energy.
  - **Size of problem:** All geothermal systems contain marketable dissolved minerals.
- **Description:** Mineral extraction can be carried out using existing water treatment process technologies.
- **Impact:**
  - Lowers electricity production cost by ~20%
  - Provides a 'green' replacement technology

    for hard-rock mining
- **IP position:** ROI/Provisional patent.
- **Status:**
  - Pilot testing in progress at Mammoth Pacific site
  - Each geothermal system is unique and will require a unique extraction process
  - Capital costs: 4-5 times the volume of fluid treated in gallons per day (estimate)




**Reverse osmosis and cross-flow filtration is used to produce and extract colloids**



**High-quality 10 nm colloidal silica produced from Mammoth Lakes geothermal fluid**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