High Power Laser Tool & System for Unique Geothermal Well Completions

FORO ENERGY

Design, build, and field test a high power laser tool and system

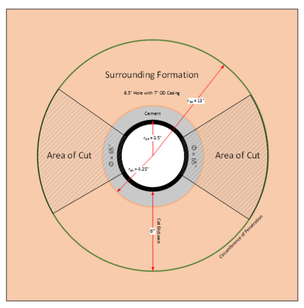
- Enables 10x+ control to orient and engineer wellbore-formation connectivity in near wellbore region where wellbore stress, regional in-situ stress, perforations / other geometries, choice of fluid properties, fluid rates, the pumping schedule and other design properties, strongly influence heat extraction potential

Project Phases & Timeline

Phase I Front End Engineering Design	Phase II Build & Surface Test, Prelim Downhole Tests	Phase III Field Test (Pending "Go")
Jul / Sep 2013 (~9 mo)	2014-2015 (~15 mo)	*2015-2016 (~6 mo)*
Deliverable: Front End Engineering Design with supporting lab tests and laser hardware builds / tests	Deliverable: Laboratory surface test of tool and system & detailed field test plan, prelim downhole tests	*Deliverable: Successful unique geothermal completion operation at predetermined geometries and depth*

Technical Barriers & Targets

- Target to perform oriented slot operation in 7" casing with Initial proof of concept stage operating parameters:
  - 6,000 ft
  - 3,000 psi
  - 150C



- Achieving target requires "world first" developments:
  - > 500 ft downhole environment
  - Circumferential cut with penetration
  - Right angle operation at <10" tool diameter
  - Optics package designed for high pressure
  - Deeper depths / umbilicals
  - High pressure downhole environments
  - Mobile splicing
  - Downhole high power laser downhole connector
  - Onshore workover-style supporting surface spread

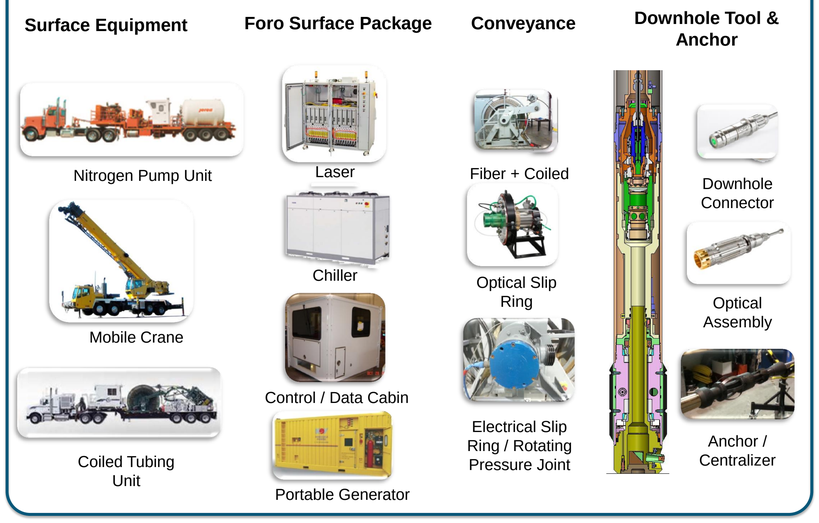
Technical Accomplishments

- **World first design of a high power laser cutting tool for well completion applications**
- **World first tests of high power laser downhole**
- **World first 12,000 ft packaged high power fiber cable: fiber optic, break detection, 3-wall stainless**
- **World first installation of packaged high power fiber cable & conductor into 2,000 ft coiled tubing**
- **World first high power laser hardware (optics package & fiber connector) tested to >5,000 psi**

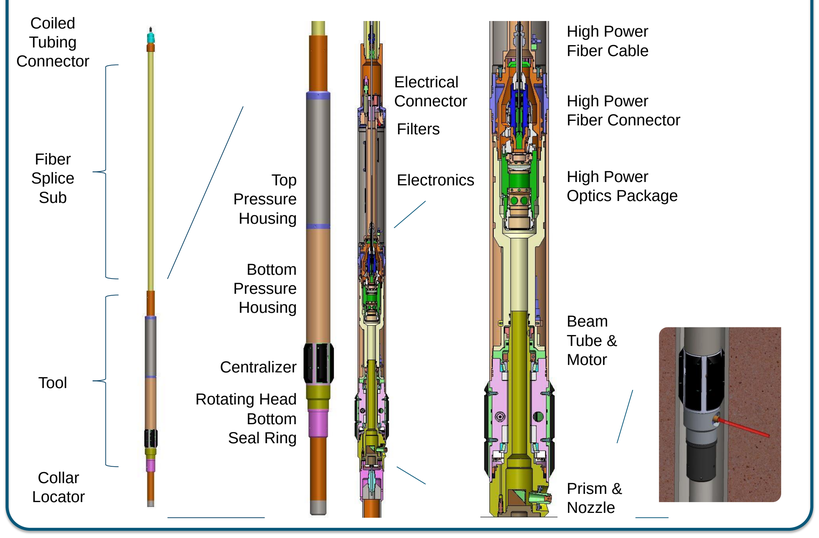
Conclusions & Lookahead

- Prelim success on interim technical milestones but true value will not be apparent until field testing data
- Foro Energy has moved aggressively to conduct earlier and more frequent field testing to maximize the probability of a successful unique geothermal completion operation in a dedicated test well

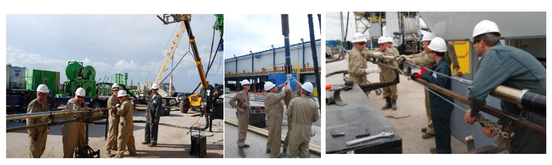
Proof of Concept System Overview



Proof of Concept Tool Overview

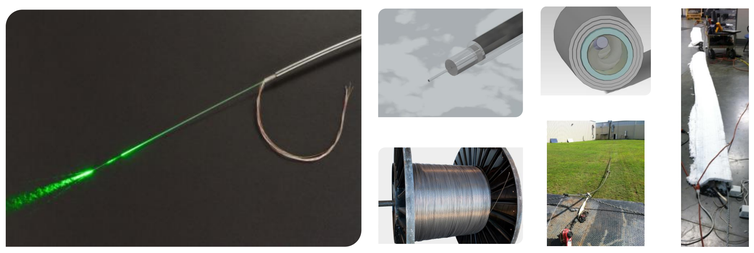


Challenge: Preliminary Field Tests



- Executing on significant lessons learned in improving conveyance reliability, debris management, operational procedures & ruggedizing surface system
- Dedicated test well created through re-entry of plugged and abandoned well near Galveston, TX to allow rapid iteration & downhole / conveyance tests

Challenge: High Power Fiber Cable

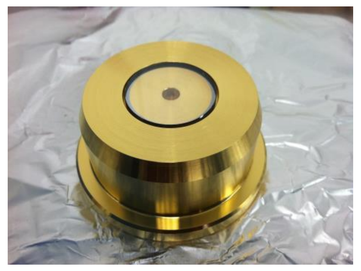


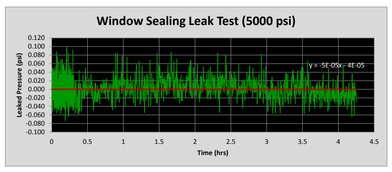
- Packaging of fiber optic in cable, installation of cable in conveyance structure, and mechanical stresses caused by hanging weight and tool operation

Challenge: High Power Connector

- Incorporating updated hardware versions into the tool design while using packaged fiber cable to deliver not only fiber but also telemetry and power for motor

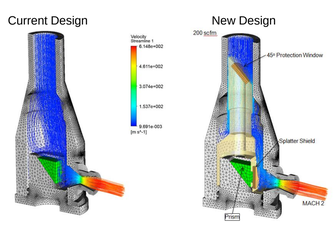
Challenge: Windows & Seals





- Achieving reliable, consistent materials and glass-to-meal hermetic seals that meet mechanical requirements to 3,000 psi and beyond

Challenge: Nozzle Flow Path



- Achieving proper flow around High Power Optics Package, Prism Assembly, and Nozzle as supported by computational fluid dynamics
- *Successful proof of concept R&D for transitioning to water-based jet and nozzle*

Foro Energy, Inc. – Littleton, CO & Houston, TX | Principal Investigator: Dr. Joel Moxley, Founder, joel.moxley@foroenergy.com | Project Start and End Date: September 2013 – March 2016