



## **High Power Laser for Rock Drilling**

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# DRILLING TECHNOLOGY HISTORY

More robust materials, designs, systems for higher WOB and torque



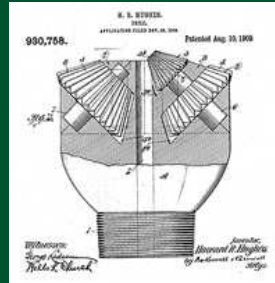
## Pre-1909 Cable drilling

- Use a cable (was manila now steel) to “bang” against rock percussively
- Used since ~2000 BC



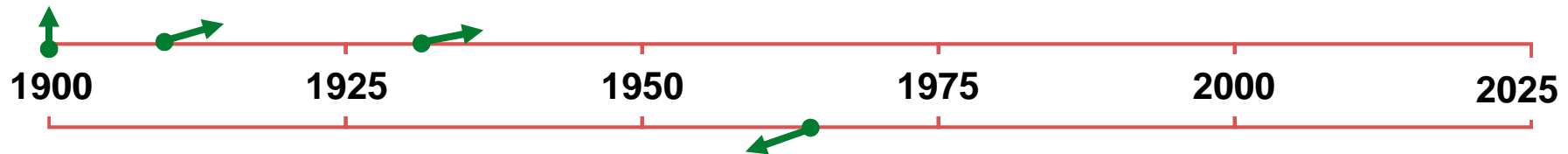
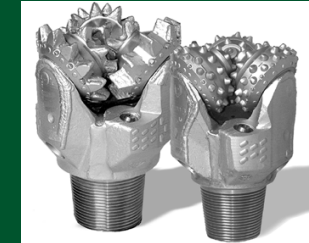
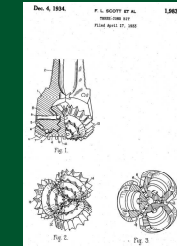
## 1909 Roller cones

- Howard Hughes invents two cone bit and rapidly dominates drilling market



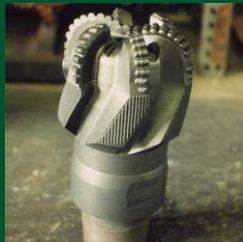
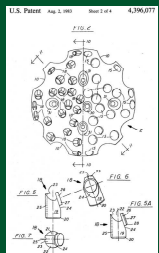
## 1933 Tricone roller cones

- Hughes Corporation adds extra cone
- Still dominant bit for hard rock drilling



## 1980 PDC bit

- Use advanced diamond materials to shear (instead of crush) soft rock
- Still dominant bit for soft rock drilling



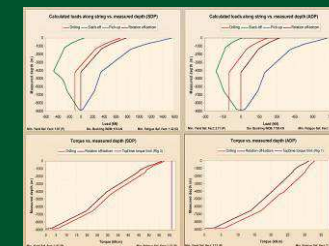
## Impreg turbodrills, hammers

- Impreg: spin a diamond abrasive bit as fast as possible until you wear bit away
- Hammer: “bang” on rock percussively



## 2000s Drill string management

- Computational methods to increase weight on bit and torque as physically possible without breaking drill string or bit



# Laser Drilling for Oil, Gas and Geothermal Wells

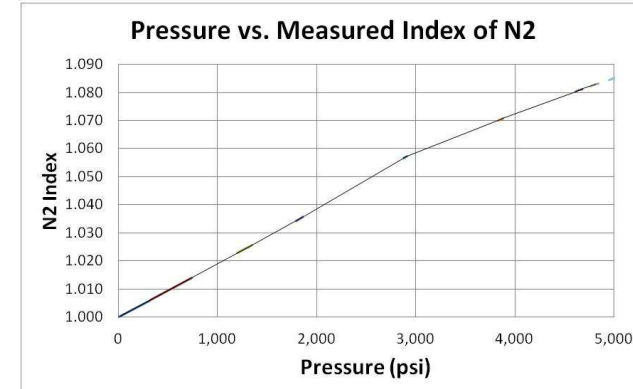
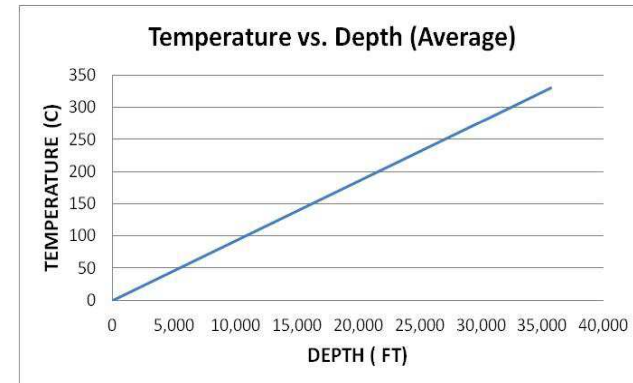
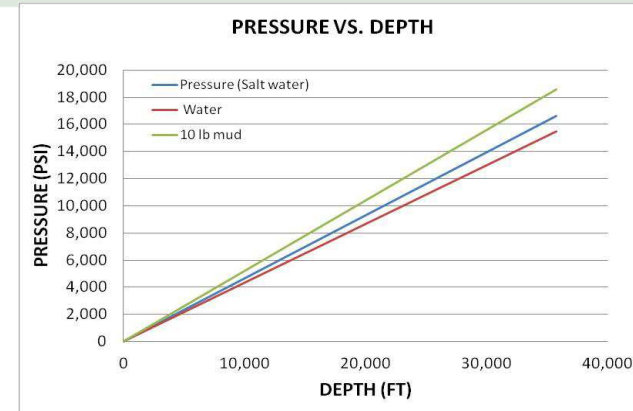


- A major portion of the world's energy is trapped beneath and in very hard rocks
- Foro Energy is developing a revolutionary drilling process which combines high power laser energy with oil field “dumb” iron to enable drilling of ultra hard crystalline rocks
- System tests at up to 20 kW successful in initial trials
- Foro Energy has demonstrated the optical and mechanical components for the successful deployment of laser energy in remote locations under high g loads, high temperatures and high pressures



# The Challenges of Laser Drilling

- The pressure can exceed 10,000 psi for the optical system at depths up to 20,000 feet
- The temperature can exceed 150 C for the optical system at depths up to 20,000 feet
- The laser must be transmitted through a transparent “fluid” or gas
  - Liquid nitrogen is readily available and can be delivered at pressures up to 10,000 psi on site
  - Gas becomes supercritical at these pressures and begins to behave like a liquid
    - Optical systems no longer perform as designed due to refractive index variations with pressure
    - Not feasible to have adjustable optical systems due to the high g environment which can exceed 250 g rms and 500 g shock



# Laser Power Transmission System



Laser

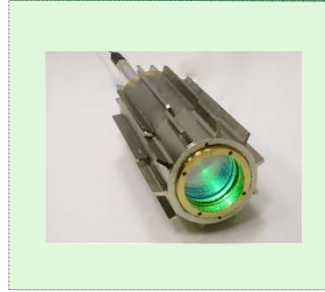
Optical Slip Ring

Fiber Optic Cable

Down-hole Connector

Optics Package

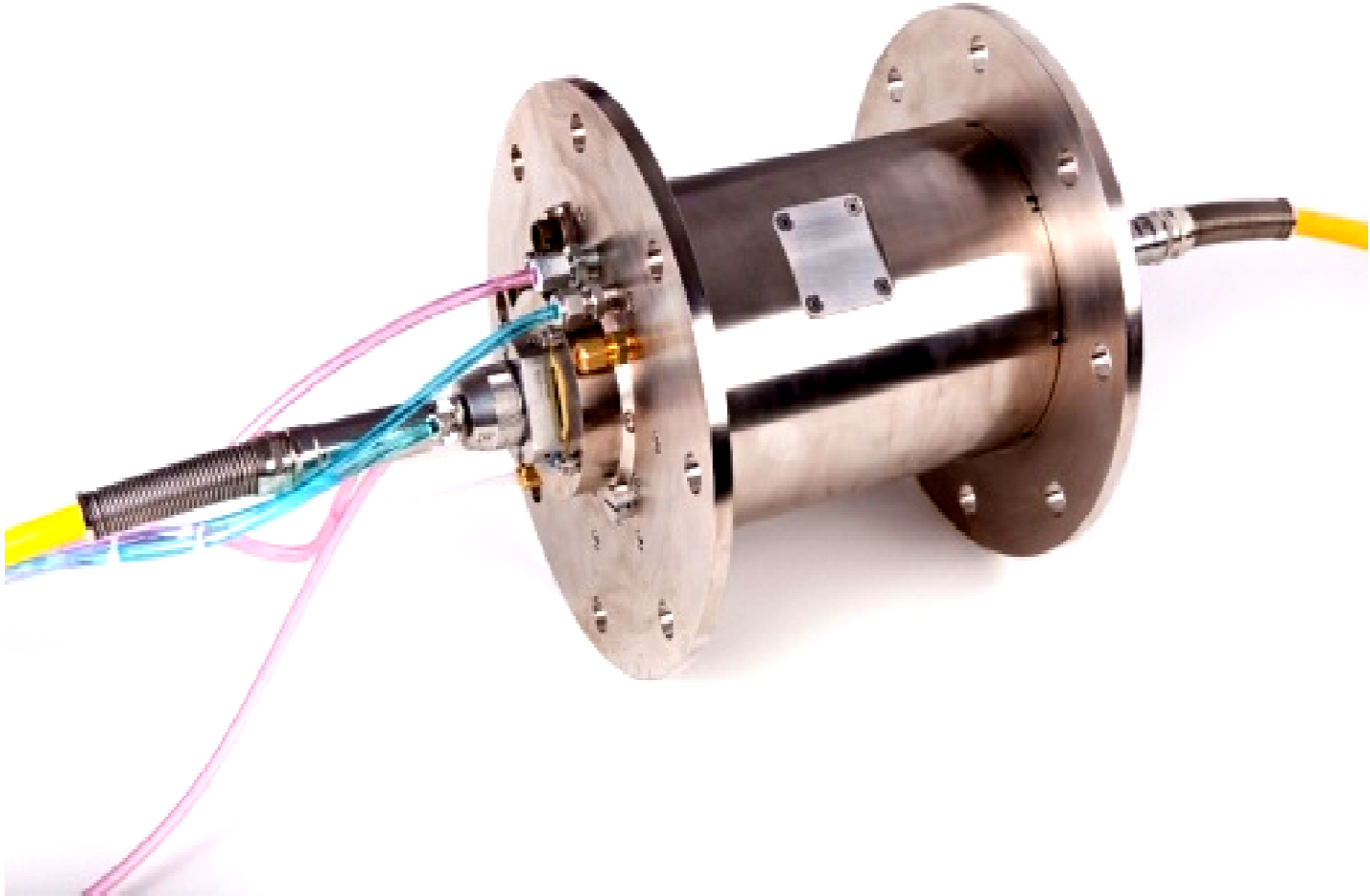
Rock Face



# High Power Optical Slip Ring



Prototype

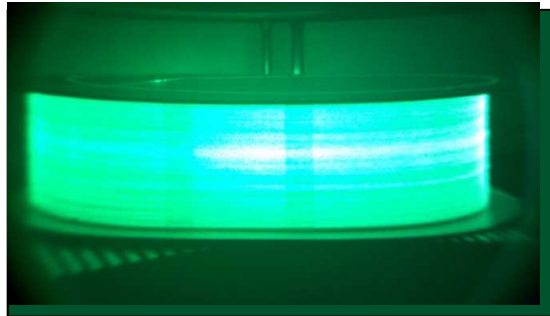




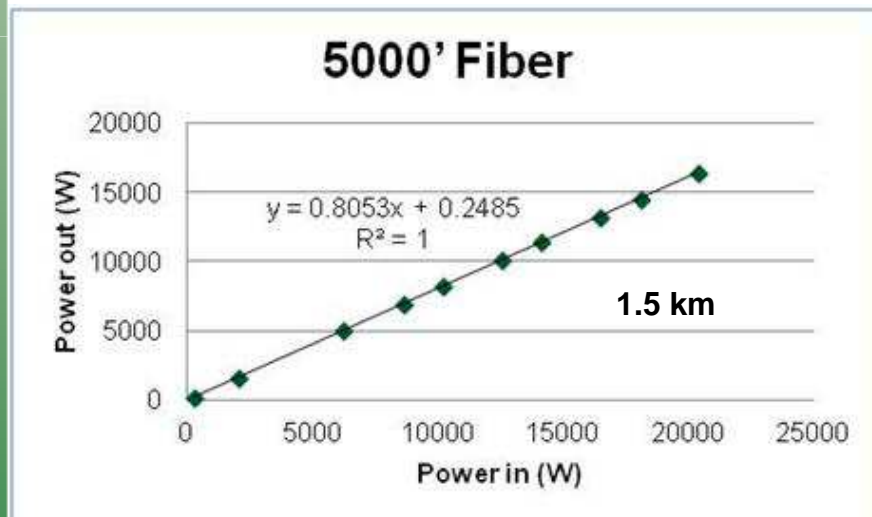
# High Power Fiber Optic Power Transmission

## 20 kW 1.5 km Transmission Test

Fiber Packaged in SS tubing designed to minimize fiber strain



Down-hole Packaged Fiber



- *>20 kW launched into 1.5 km long optical fiber with minimal non-linear effects*
  - *Highly Linear Power in /Power out curve*
  - *No significant SRS spectral signature*

# Fiber Optic Cable Performance Data



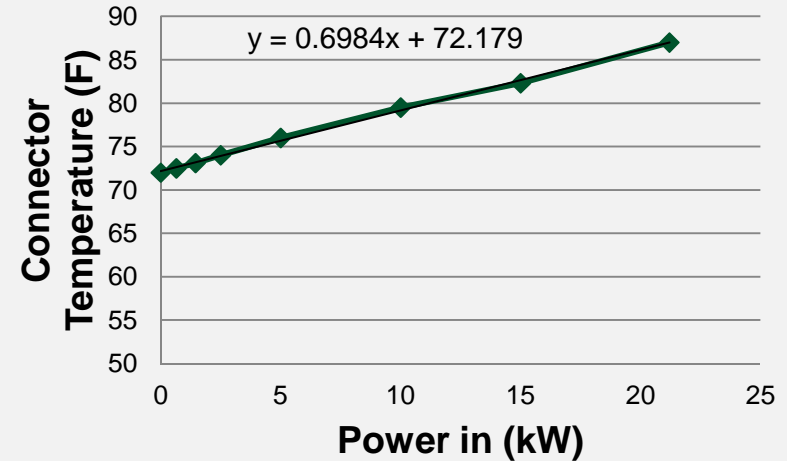
- **Fiber optic packaging tested to 250 g and 200 C (400 F)**
  - **Output power and mode quality monitored during testing**



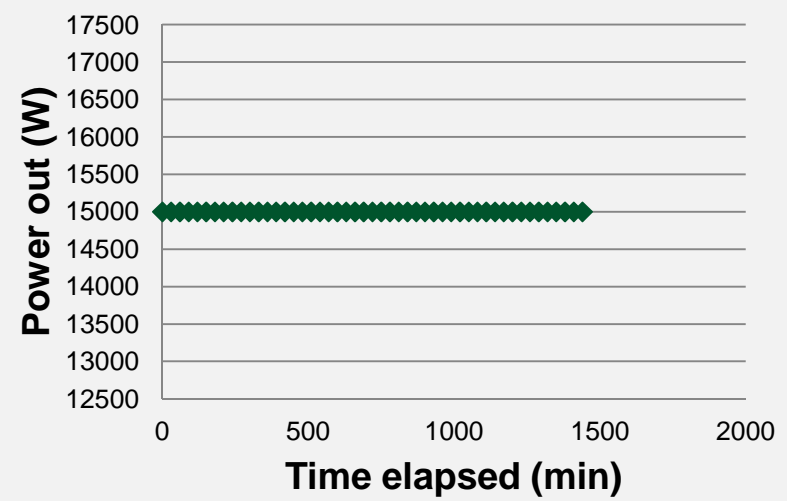
# Down-hole Connector Test Results



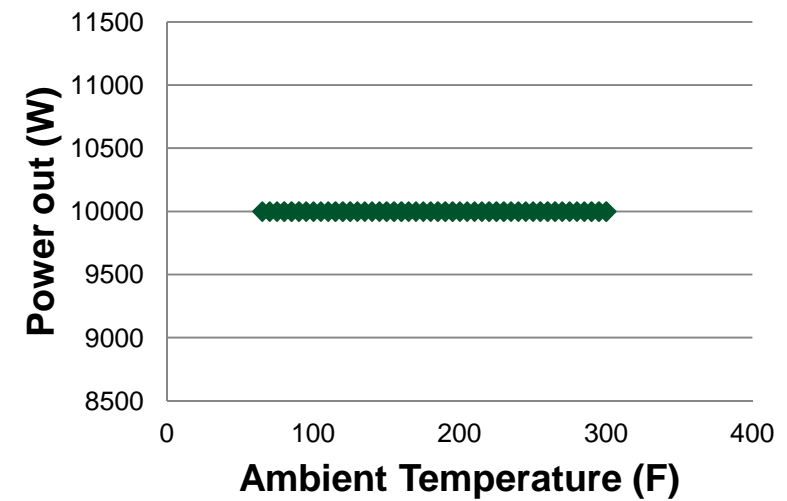
## Temperature Scaling w/ Bit on Dolomite



## Performance Constant with 250 g vibration

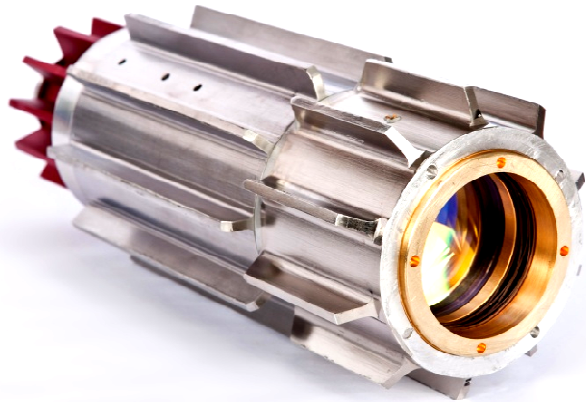


## Performance Constant with Temperature

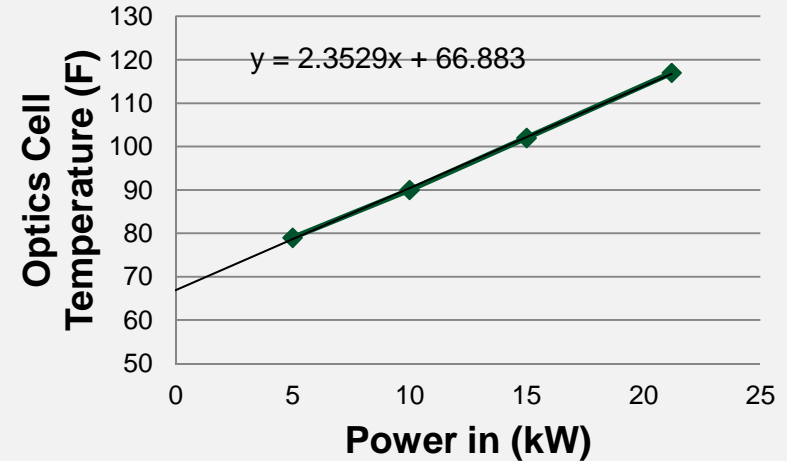


\*All optical testing performed using IPG 20 kW 1070-1080 nm laser source

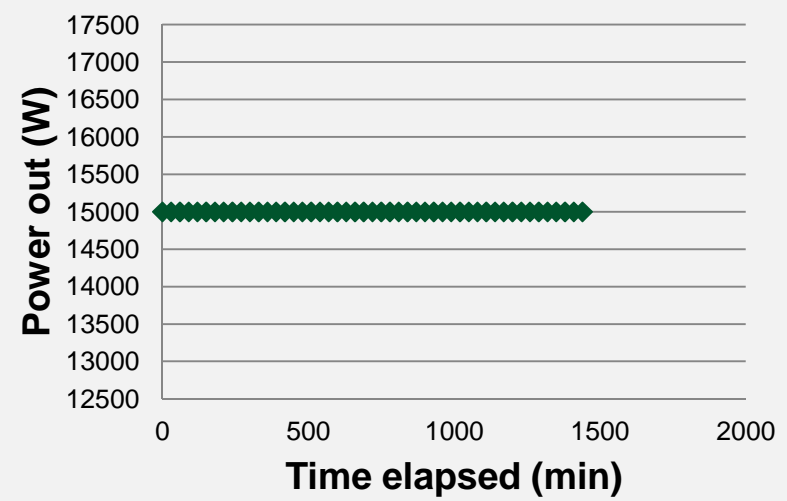
# Down-hole Optics Package Performance Data



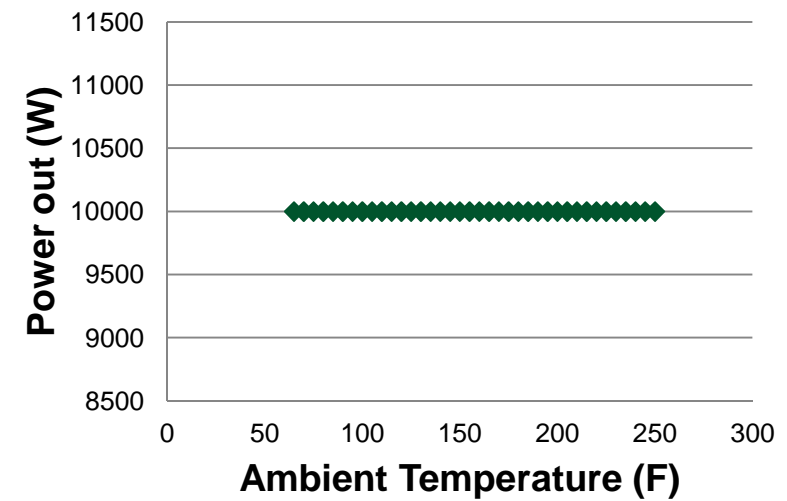
## Temperature Scaling w/ Bit on Dolomite



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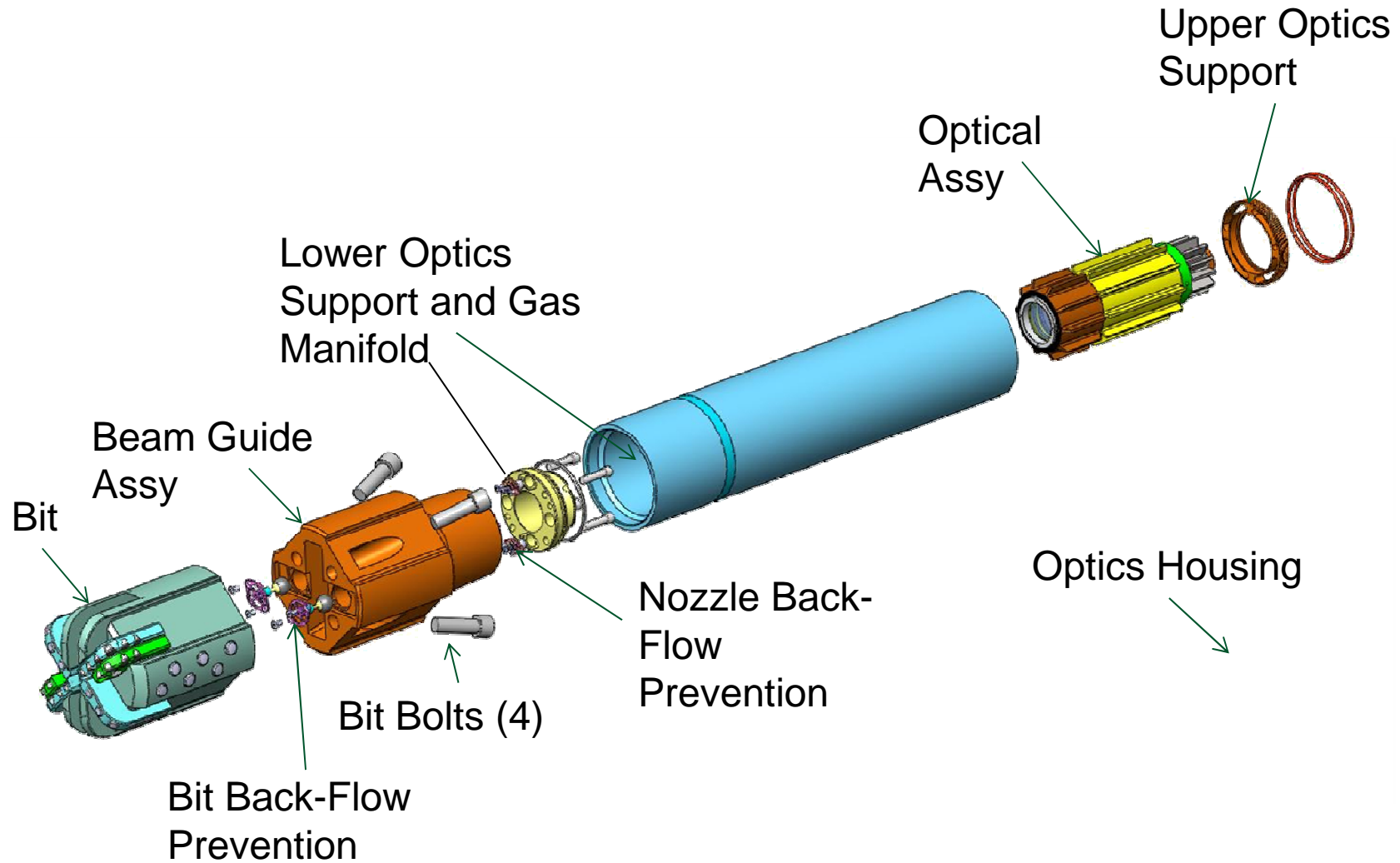
## Performance Constant with Temperature



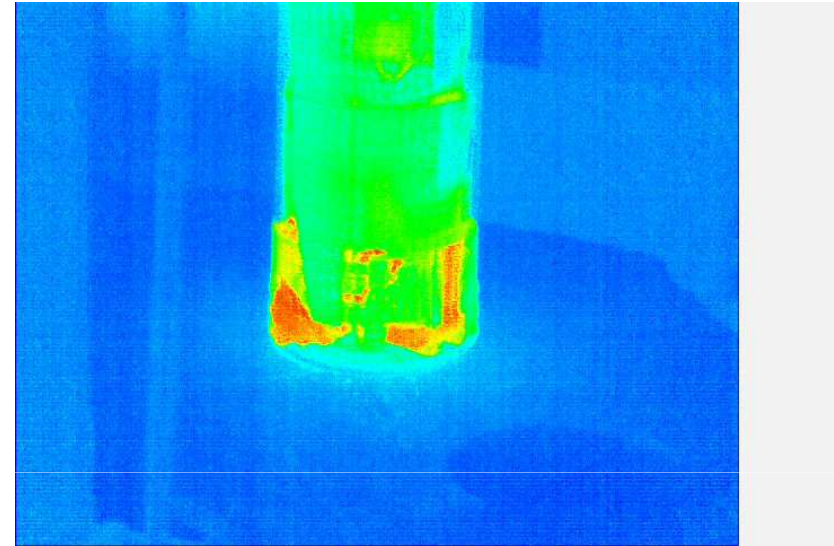
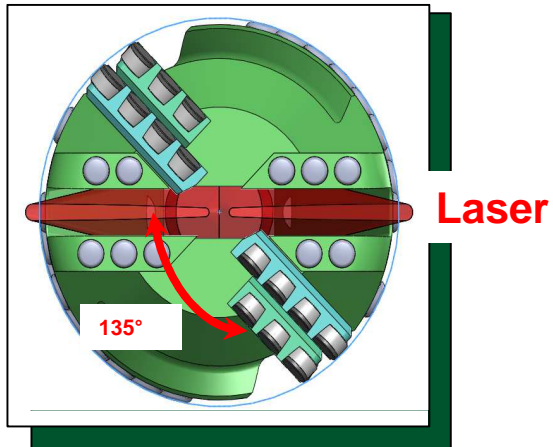
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# HIGH POWER LASER DRILLHEAD, BIT ASSEMBLY

Simultaneously satisfies mechanical and laser specifications

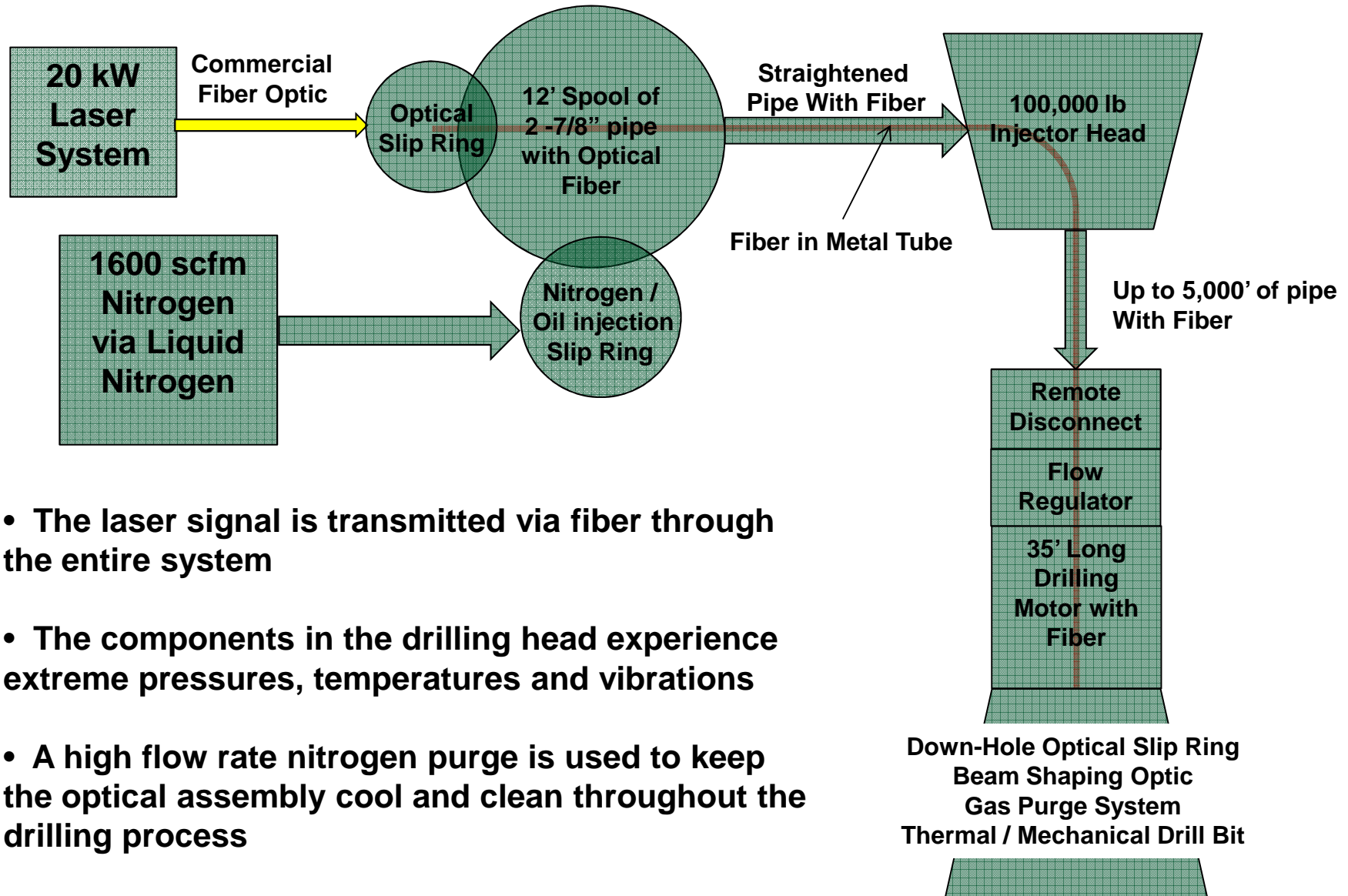


## Laser-Mechanical Drill Bit



- Laser based drilling process developed for most ultra-hard crystalline rock:
  - Granite: >25 ksi
  - Basalt: 45 ksi- 60 ksi
  - Travis Peak Sandstone: 35 ksi
  - Dolomite: 35 ksi
  - Limestone: 35 ksi
  - Quartzite: 40 ksi
- Mechanical cutters scrape away the “soften” layer
- Conventional drill bit: 20,000 lbs weight on bit, 1,000 ft. lbs torque
- Laser drill bit: <1,000 lbs weight on bit, <100 ft. lbs torque

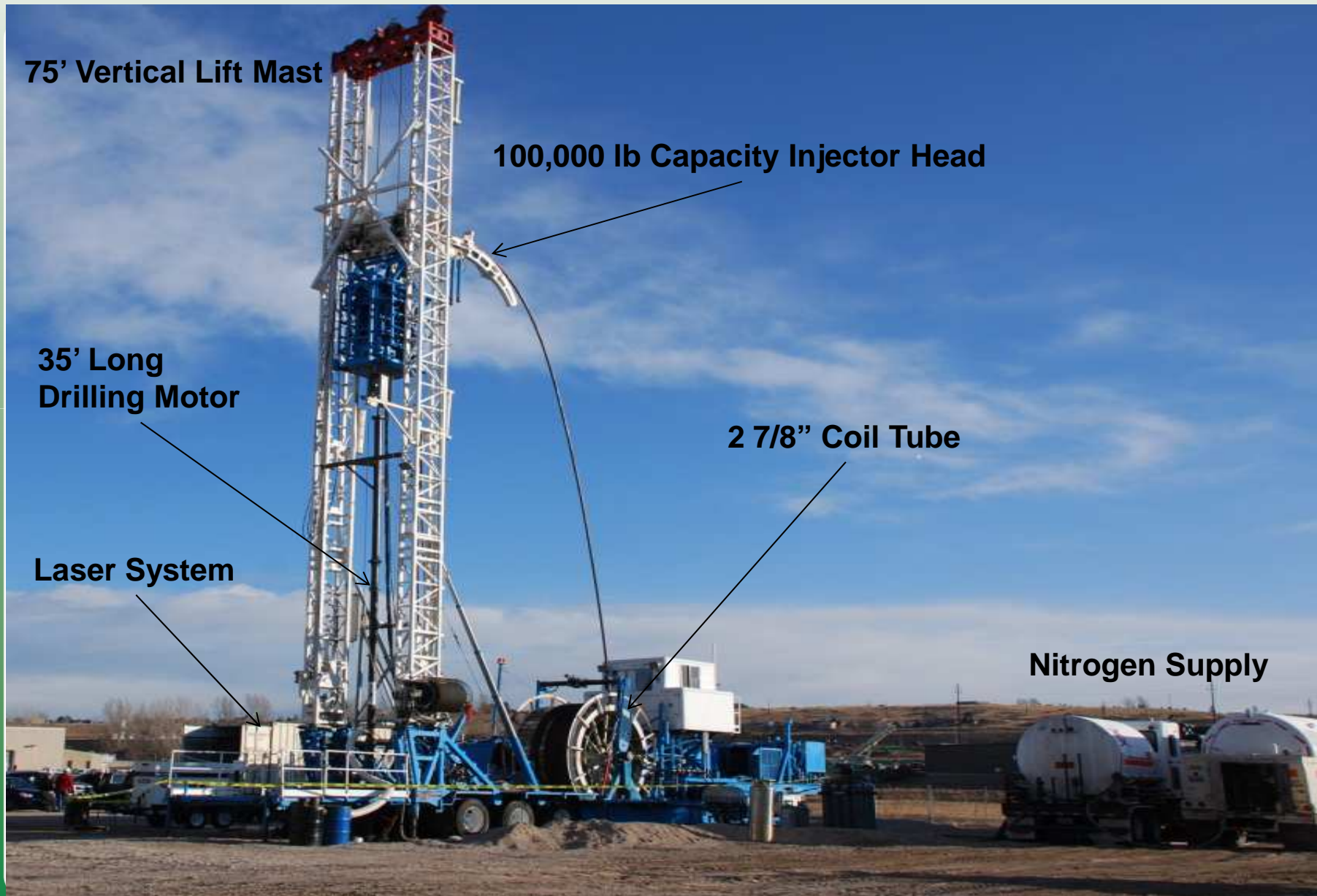
# Drilling System Schematic



- The laser signal is transmitted via fiber through the entire system
- The components in the drilling head experience extreme pressures, temperatures and vibrations
- A high flow rate nitrogen purge is used to keep the optical assembly cool and clean throughout the drilling process



# Laser System Integrated with Coil Tube Drilling System



75' Vertical Lift Mast

100,000 lb Capacity Injector Head

35' Long Drilling Motor

2 7/8" Coil Tube

Laser System

Nitrogen Supply



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