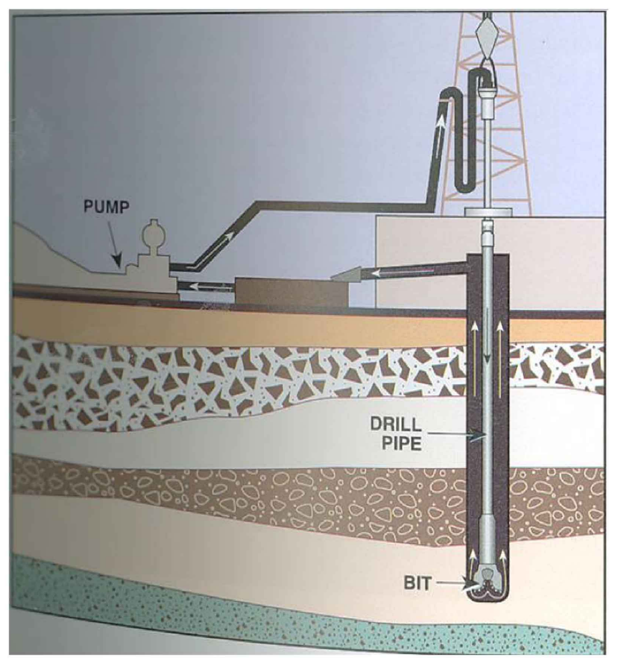
Down-Hole Energy Generation

The Olin College Schlumberger SCOPE team was tasked with investigating methods of energy generation in an oil-well. By generating energy down-hole to supplement or replace the use of one-time battery packs in 'slick-line' tools, a class of tools run without power from the surface, costly tool extractions for the purposes of battery replacement may be avoided.

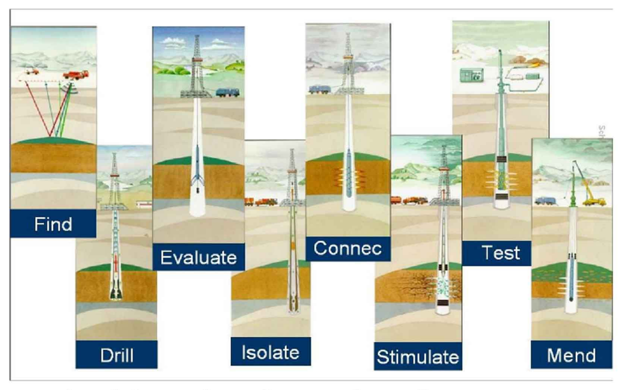


▲ Schematic of a typical drilling operation

Oil-wells are typically 2-5 miles deep, with a horizontal component as long as 10 miles. As wells fill with fluid, it's not uncommon to see pressures over 20,000 psi and temperatures over 475F.

Over the lifetime of an oil well a client may wish to perform measurements designed to ascertain the condition of the well and surrounding oil field. Oftentimes these wells are too remote or cannot afford to be supplied with the surface powered 'wire-line' tools, in which case the lighter infrastructure slick-line tools are employed.

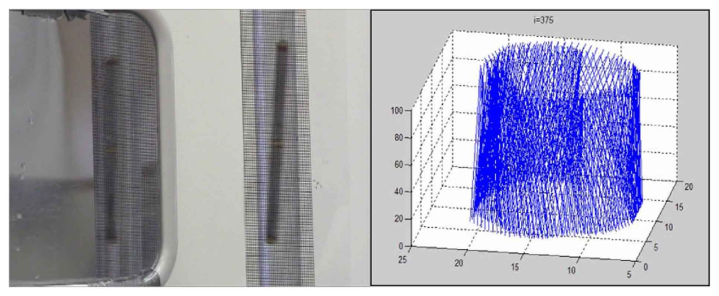
Slickline tools are distinguished by the fact that they are not dependant on electrical power from the surface. Instead, they carry a lithium-ion battery pack onboard. As these are non-rechargeable batteries, at the end of their lifespan, they are disposed of for additional cost.



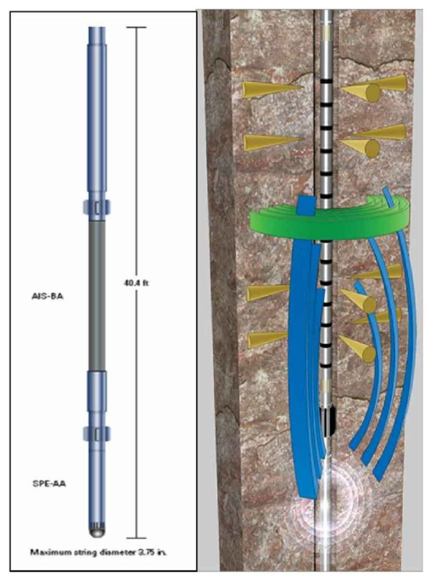
▲ The lifecycle of an oil-well

Casings
For a variety of reasons, sometimes oil-wells are given a 'casing'. A casing is a series of cascading steel tubes that are cemented into place. This provides a nice smooth, hard surface for things to roll on, but also a series of sharp corners for tools to be caught on.

The largest and easiest source of energy was determined to be gravitational potential, harvested either by wheels along the well casing or by turbine. To determine which method of downhole energy generation is more ideal, a series of experiments were designed and executed. The first two were to determine a further path of development between wheels and turbines. The third was a continuation and refinement of the

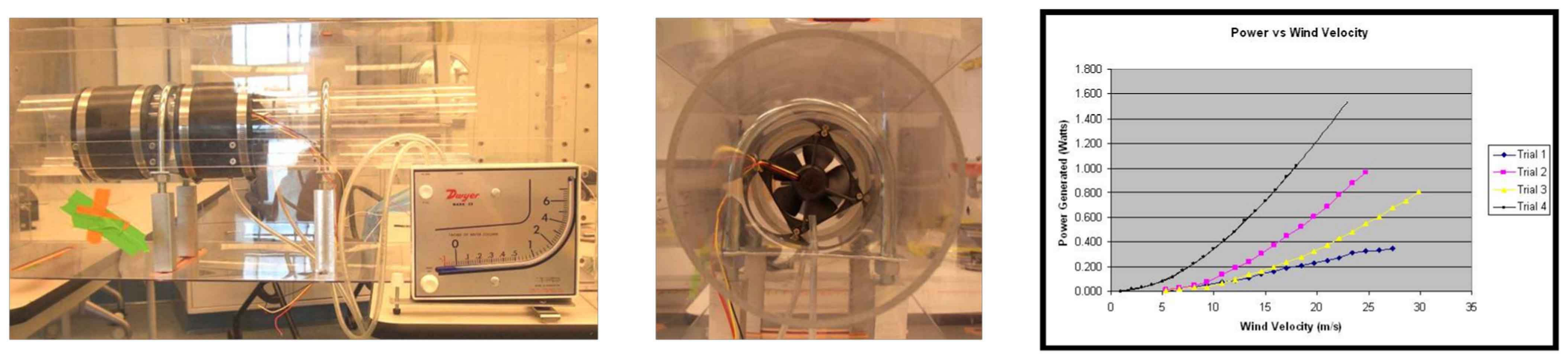


▲ Over the summer prior to the school year, work was done to limit the scope of the school year's project. This involved reasearch into energy storage, a series of fluid dynamics experiments, and the development of a mathematical model of the tool as it decends through a fluid. From this work, it was determined that the most promising methods of energy harvesting were wheels and turbines.



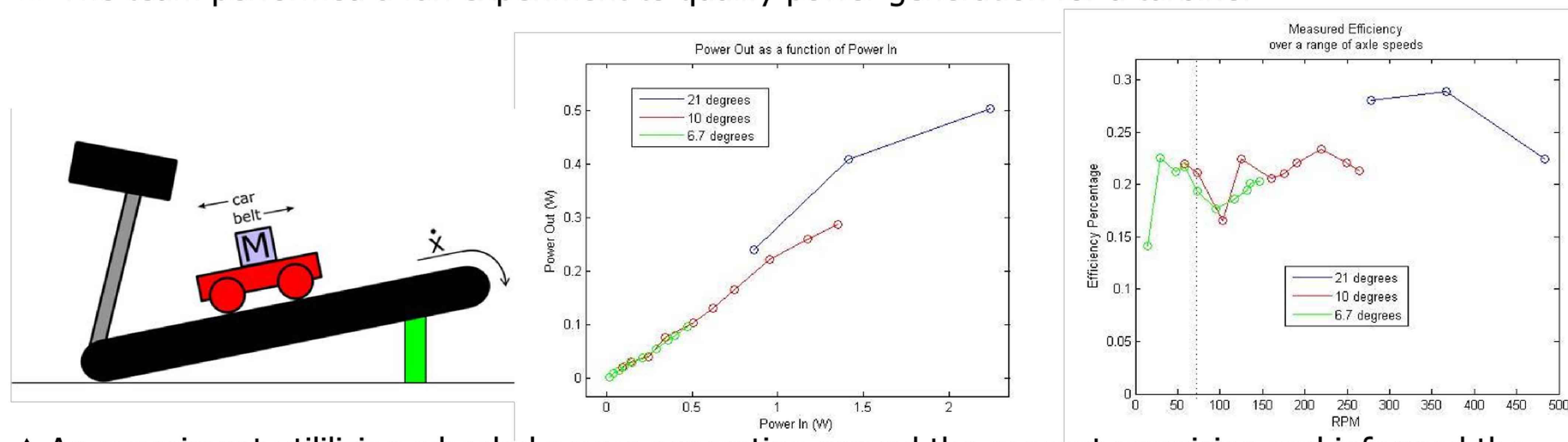
◀ Tools are anything that is sent downhole with the intention of gathering information or manipulating the well. The range of tools is huge, bothin physical dimentions (40' long 8" diameter to 6' long 2" diameter) and in function (blowing holesthrough the casing and surrounding rock to using ultra-sound to measure caracteristics of the rock).

▶ In the first experiment (right top), an equipment fan was inserted into a test section within the wind tunnel. Internal circuitry was removed, and the fan run in reverse as a turbine generator. Power was dissipated across a resistive load, and the efficiency calculated based on the pressure drop across a known area.



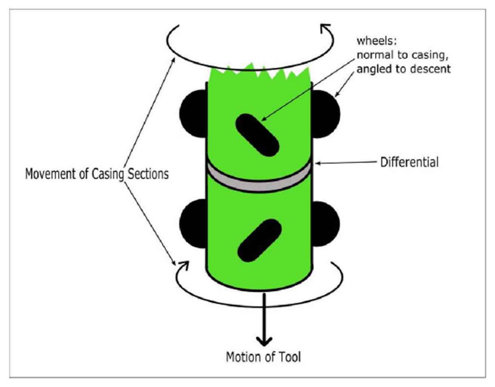
▲ The team performed a fan experiment to qualify power generation for a turbine.

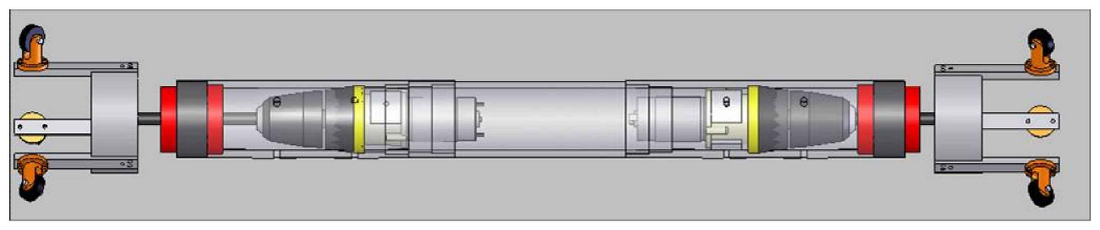
▶ In the second experiment (right middle), an RC car was run down down an inclined treadmill, and dissipated power measured at steady state. Given a higher measured efficiency of the wheeled experiment, the team decided to design a full-scale wheeled prototype in the Spring semester.



▲ An experiment utililizing wheeled power generation proved the concept promising and informed the team's decision to move to a wheeled prototype in the next stage of the project.

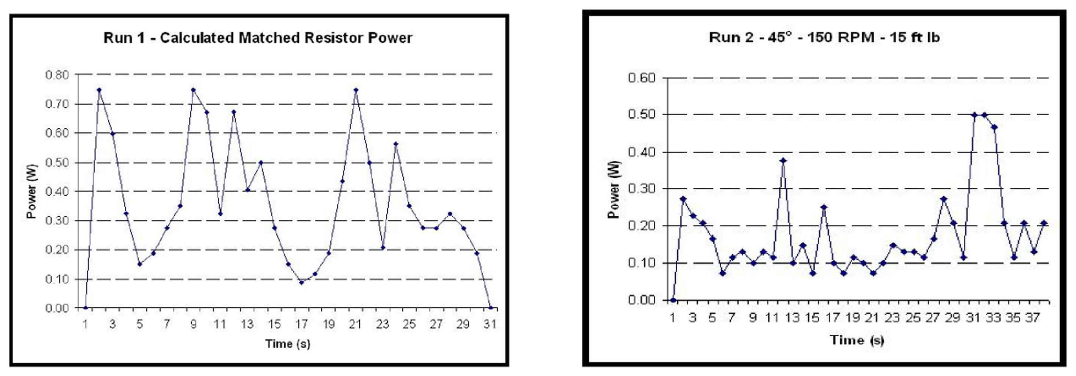
▶ From the results of the previous experiments, and the percieved ease of mathematically modeling the system, it was determined to further develop the wheel based system. The experiment was designed to mimick a tool moving in a cased section of the well, and generate power.





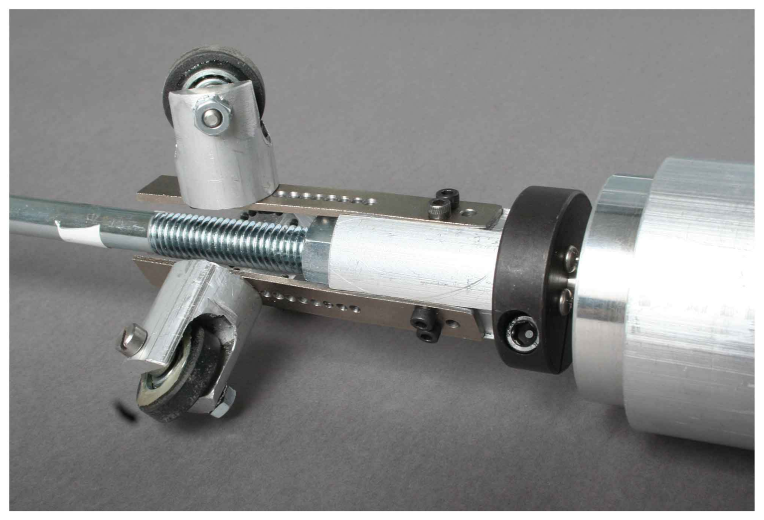
◀▲ The team's prototype of a wheeled energy harvesting mechanism, described in more detail below, was utilized in a simulated test section to gather power data

▲ Experimental setup for testing the prototype.



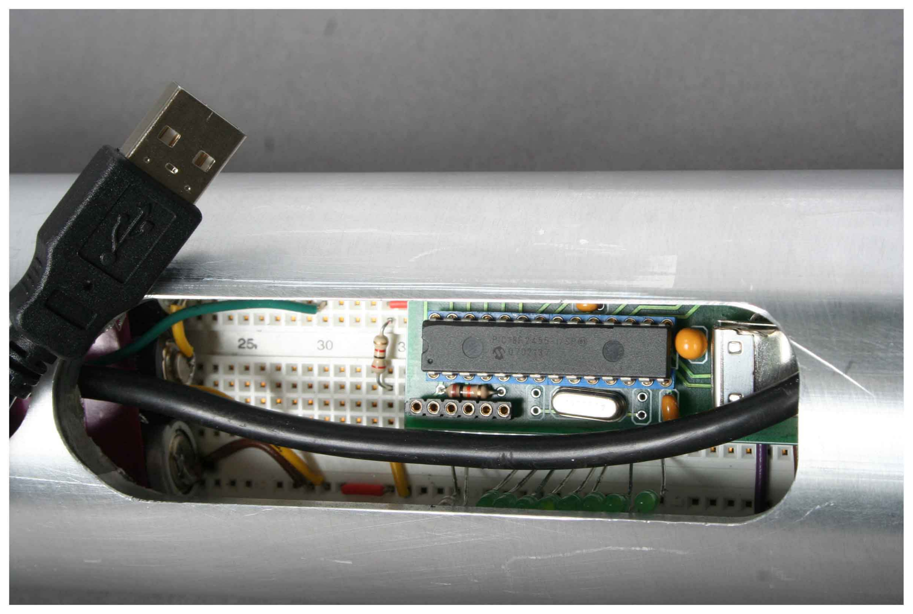
▲ Power generated from prototype test runs. There were a variety of factors artificially reducing the power produced, and the power the system could theoretically generate is 23 times the values shown here.

Tool Prototype



◀ **Wheel Holders** allow the wheels to contact tube wall at for various angles to optimize power generation efficiency. By changing the wheel angle, the rotational velocity of the rotating wheel section can be varied with respect to the pulling speed.

◀ **Spring arms** pushed the wheels against the inside tube wall, such that the wheels would be forced to spiral around as the tool was pulled, instead of merely sliding down the

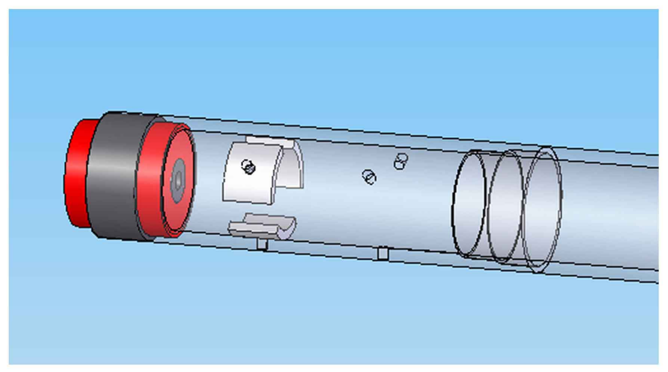


◀ The **power-tracking circuit** is battery-powered and stores necessary data about how much power the tool is generating on board. The data is then downloaded to a computer via USB.

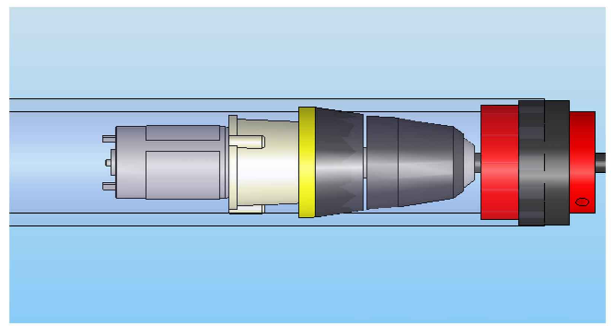
▼ The photo below is taken from the perspective of looking down the tube. This photo shows how the wheels rotate as the tool is pulled through thetube.

▼ **Bearing blocks** thread into each end of the housing to stabilize the drive shaft as it transmits rotational velocity from the wheels to the gearbox/motor.

▼ **Locator plates** inside the housing prevent the the motor/gearbox from rotaing inside the tool



As the tool is pulled through the tube, the two sets of wheels **rotate in opposite directions**, such that there is a **zero net torque** on the tool housing.

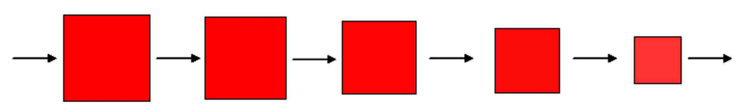


◀ A **12-V drill motor and gearbox** combination were used to generate power within the tool. The motor was then connected to the power-tracking circuit

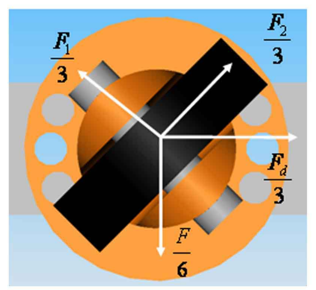
▲ In this picture of the test setup, the wheels are angled at 45° with respect to the test tube.

Math Model

Gravity ▶ wheels ▶ driveshaft ▶ gearbox ▶ generator



Wheels



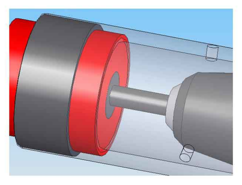
$$F_d = \frac{\tau_d}{R-r}$$

$$F_1 = \frac{F}{2}\sin\theta + F_d\cos\theta$$

$$F_2 = \frac{F}{2}\cos\theta - F_d\sin\theta$$

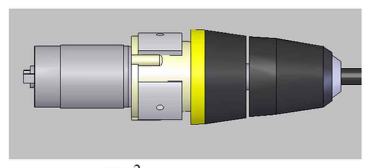
$$F_2 = \mu_r F_N + f_w\omega_w + bF_1$$

Driveshaft



$$\tau_d = \tau + f_d^*\omega = \left[\frac{(K\rho)^2}{R_g+R_L} + f_d^*\right]\omega$$

Gearbox & Generator



$$\tau_g = \frac{(K)^2\omega_g}{R_g+R_L} + \rho = \frac{\tau}{\tau_g} = \frac{\omega_g}{\omega} \longrightarrow \tau = \frac{(K\rho)^2\omega}{R_g+R_L}$$

Tool Model

drive shaft losses

$$\lambda_d = \frac{f_d/(R-r)}{(K\rho)^2/(R-r)^2(R_L+R_G)}$$

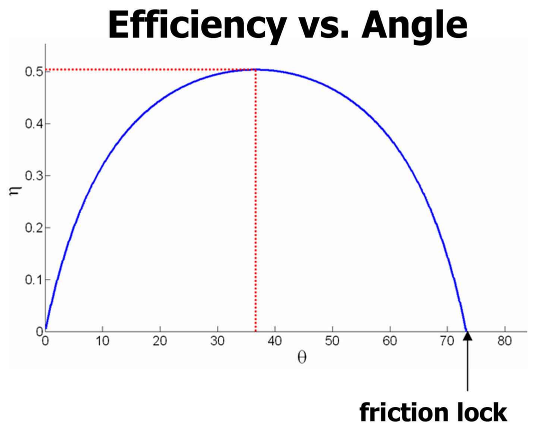
wheel bearing losses

$$\lambda_w = \frac{f_w/r}{(K\rho)^2/(R-r)^2(R_L+R_G)}$$

rolling friction losses

$$\lambda_R = \frac{\mu_r F_N/U}{(K\rho)^2/(R-r)^2(R_L+R_G)}$$

Efficiency vs. Angle



friction lock

Final Governing Equation

$$\eta = \left(\frac{R_L}{R_L+R_g}\right)\frac{(\cos\theta - b\sin\theta)(\tan\theta\sin\theta)}{\lambda_w\sin\theta + \lambda_R\cos\theta + (1+\lambda_d)\sin\theta(\sin\theta + b\cos\theta)}$$