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## Statement of the Problem

The goal of this competition is to design a system to transport equipment and materials to drillsites in environmentally protected areas, with a focus on minimizing the environmental impact. The aim is not to encourage drilling in these areas, but to foster interest and dialogue in the education community regarding these areas.

## Introduction

When drilling within environmentally protected areas, it is desirable to minimize the impact, so that the area is preserved and wildlife is able to live normally. In order to accomplish the development of a field within a protected area, it is proposed the use of a skylift system, similar to those adopted in mining operations (where they are often referred to as aerial tramways), that would be installed via helicopter. Pairing the skylift system with pipelines to transport drilling and production fluids outside the area would significantly minimize the environmental impact, especially when compared to using a traditional road. The team members believe that any form of site access by road may impair the environment by creating a preferential path for people to enter the area. Our recommendation is for fields that are outside the goals of extended reach drilling. This will be the case of a field located in the Chihuahuan Desert Province, in which extended reach drilling would prove to be less environmentally friendly than a skylift system.

The objective of this competition is focused on the use of a “Disappearing Road” to transport materials, equipment, and personnel for drilling operations for a one-year time window. However, when considering environmental impact, this window will be insufficient. We have chosen an integrated perspective that spans over the entire field life, ten to thirty years, assuming that the field has already been appraised and it is ready for the development phase. For the drilling operations, a hybrid coiled tubing rig would be transported onsite via the skylift. The generators, mud tanks, and other equipment would be located outside the protected area. Horizontally drilled pipelines would transport the drilling fluids from the rigsite to the facilities located offsite. Power would be delivered to the rig via powerlines running on top of the skyway. The only area impacted would be the extremely small rig footprint and that of each skyway tower. To allow for maximum exploitation, the wellsite would be used to drill deviated wells, allowing 40 wells to be drilled from a single drillsite.

After drilling, the rig would be removed and the skyway could be used for various purposes, including well-related work, tourism, alternative energy generation, and scientific studies. At field abandonment, a rig could be transported back to the wellsite to plug and abandon the wells. The skyway towers would be removed and everything would be returned to the way it was before drilling commenced.

## Analog Field Data

For this competition, field data from fields located at the vicinity of the Chihuahuan Desert Province is used to assess some of the subsurface conditions that affect the selection of equipment used normally in oil and gas operations. As instances, the type of rig will be selected according to the target depth and type of wells to drill; and pipeline and separation units will be chosen according to the expected type of fluid and flow rates; among other things. **Table 1** shows the general data of the Dineh-bi-Keyah field, located in northeastern Arizona.

Type of Fluid	Oil/Gas
Depth Range, ft	2800-5000
Pressure Range, psia	1200-2200
Reservoir Type	Carbonate
Avg Pay Thickness, ft	95
Age of Formation	Pennsylvanian
OOIP, MMstb	680

## **Rig Selection**

For this competition two state-of-the-art technologies known for reducing environmental impact have been identified: Extended Reach Drilling (ERD) and Coiled Tubing Drilling (CTD). These technologies have been proved to be technically successful and many service companies are available to provide them. The rig selection and the recommended technology are based on minimizing the impact of the environment of the Chihuahuan Desert Province.

## **Extended Reach Drilling and Environmental Concerns**

A way to develop oil and gas fields in environmentally sensitive areas is through the use of ERD. The use of ERD has made it possible to drill wells with extreme step-out. Many extended-reach wells have step-out lengths of 5-6 miles with more than 35,000 ft of measure depths. Vertical depth, step-out, and subsurface environment will determine the feasibility of drilling and completing extended-reach wells<sup>1</sup>.

The use of ERD for the development of fields is driven by economical and environmental objectives. However, much emphasis is sometimes given to the environmental advantages that ERD might bring while the real reason of using this drilling operation is the savings in millions in development costs. For instance, in offshore fields the elimination of artificial islands or production platforms along with subsea equipment and pipelines will upset the high risks and costs that ERD projects bring. This goes together with the certainty that extended reach wells are drilled where high production rates are achievable. Lack of subsurface data and the uncertainty of available reserves in the Chihuahuan Desert Province will make an ERD project risky and probably unprofitable.

Even though ERD seems a better option to drill in very sensitive areas such as the Chihuahuan Desert Province, ERD also brings environmental disturbance that can be even greater than if a low impact road is built through the desert. First, emissions of CO<sub>2</sub> will be greater due to more power requirement for hoisting, hydraulics, and rotary systems. For the ERD of a well with a horizontal displacement of five miles, a rig rated for a hook load greater than 750,000 lbs with drawworks of 4,000 to 5,000 HP will be required<sup>2</sup>. Also, extra pumping capacity is essential to be able to lift the cuttings in the long, high-angle extended reach wells. This extra pumping is obtained by increasing the number of pumps from two to three or more, increasing the power rating of the pumps from 1,600 to 2,200 HP, and increasing the pressure rating of the pumps and surface system from 5,000 to 7,500 psi<sup>2</sup>. Furthermore, top drive rotary systems with torque capabilities in the range of 50,000 to 60,000 ft-lb will be needed<sup>3</sup>. Thus, to obtain this required power more generators will be used on-site polluting the local air, or if enough electrical power is available in the wellsite the CO<sub>2</sub> will be produced elsewhere.

Second, although state-of-the-art rigs occupy smaller footprint than previous generations of drilling rigs, the wellsite area for an extended reach well must have enough space for all surface equipment and materials, personnel facilities, and storage capacity for more than 30,000 ft of drillpipe and more than 16,000 ft casing<sup>4</sup>. Thus, this implies that at least an area of a few acres will be disturbed if not destroyed in the wellsite location.

Third, Oil Based Mud (OBM) is chosen in ERD due to lubricity and inhibition advantages over Water Based Mud. High friction factors and the length of the wellbore constrain ERD operations to OBM in order to reduce torque and drag, and minimize pipe sticking. Potential pollution problems and environmental incompatibilities are typically associated with OBM in both surface and subsurface environments. For instance, a formation bearing fresh water can be easily contaminated even if a low-toxicity OBM is used to drill through this formation. Furthermore, the quantity of fines and

cuttings produced in ERD is far greater than a normal drilling operation, bringing the concern of how to properly dispose the solids produced. The proper disposal of the drilling mud and oil-soaked cuttings will be needed to reduce the impact that they might bring to the environment and nearby communities.

Finally, reduction of visibility and noise pollution, along with the concerns of possible water, land and air contamination from drilling and transportation activities might bring potential conflicts with local and adjoining land users. Therefore, given all the reasons above, the ERD will not be environmentally friendly in the Chihuahuan Desert Province.

**Hybrid Coiled Tubing Drilling**

As Coiled Tubing Drilling (CTD) is well known and has proven to be smaller in size and cause the least environmental impact, it is strongly recommended to use a hybrid coiled tubing rig (HCTR) unit for the drilling operations. As identified by looking at analog fields, the depth of the projected reservoir is fairly shallow with pressures reasonably low; therefore, the HCTR can efficiently drill and complete the wells with minimal impact on the environment.

In comparison with conventional drill pipe rigs, an HCTR is by far more environmentally friendly. After drilling and completing a well, due to its smaller structure and overall space occupancy, an HCTR usually leaves small to no footprint when it moves off the location. In addition, HCTR units produce relatively low noise during operation while having less visual impact. In terms of space, the module of a conventional drill pipe rig can occupy a much bigger space than an HCTR and might require the use of additional equipment such as a crane to rig up. An HCTR can handle hook loads up to 200,000 lbs at the top drive and 120,000 lbs at the injector. Depths up to 7,000 ft with 3 1/2 in coiled tubing or drill pipe can be accomplished with HCTR. **Table 2** shows the general specifications of the HCTR proposed for this competition. However, not all the equipment will be at the wellsite since it is desired to reduce the footprint. Instead, most of the equipment like mud tanks and generators will be set outside the protected area. The connection between the wellsite and the equipment outside the protected area will be through power lines and pipelines.

Table 2—General Specifications of HCTR <sup>5</sup>		
	CTR type	Hybrid Coil/Single
<b>General</b>	Typical Application	Intermediate Drilling
	Total Loads (excluding boiler)	11
<b>Coil Tubing</b>	Typical Penetration Rates	300+ ft per hr
	Maximum Coiled Tubing Size	3 1/2"
	Drill Pipe Size	3 1/2"
	Typical Coiled Tubing Size	3 1/2"
	Reel Capacity with Above Tubing	7,200 ft
<b>Top Drive</b>	Maximum Injector Pulling Force	120,000 lbs
<b>Top Drive</b>	Pipe Handling Range	46 ft (Range III)
	Hydraulic Rotary Table	13 7/8"
	Depth Capacity with Drill Pipe	7,200 ft
	Drawworks Type	Electric
	Drawworks & Top Drive Rating	200,000 lbs
	Tool Joint Make-up and Break-out	Back-up Wrench
	Bails and Elevators	Hydraulic

**Table 3** shows the configuration and other specifications of the HCTR. The configuration given here for the HCTR is not the best available in the market. Rather, it is a typical size that is commonly used nowadays in sensitive and environmental protected area. Deeper drilling and higher capacity in terms of hook loads, pressure handling, pump efficiency, and other important factors to the drilling operation can be handled with the more advanced CTR available in the drilling industry. This usually depends on the specifications and requirements provided by the customer. **Fig. 1** depicts a picture of typical HCTR where it can be seen its size as well as its visual impact.

<b>Table 3—Configuration of an HCTR<sup>6</sup></b>		
Trailer Dimensions (approx)	L × W × H	70 ft × 11.5 ft × 14.5 ft
Trailer Weight (approx)	Without Coil	160,000 lbs
Work Reel Capacity	2.875 in Coiled Tubing	18,000 ft
	3.5 in Coiled Tubing	10,000 ft
Work Reel Diameter	13 ft	
Work Reel Core Diameter	11 ft	
Work Reel Width	9 ft	
Spooling Force	8000 lbs	
Injector	Pull Capacity	200,000 lbs
	Push Capacity	100,000 lbs
	Max Speed	100 ft/min
Utility Winch Rating	7250 lbs	
Lubricator Winch Rating	2200 lbs	
Derrick Pipe Handling Range	46 ft (Range III)	
Derrick & Substructure Rating	300,000 lbs	
Rotary Table	Rating	3000 lbs A.P.I.
	Opening	13.875 in
	rpm	125 rpm
	Torque	1600 ft-lbs
Top Drive	Rating	140,000 lbs A.P.I.
	Max rpm	Up to 220 rpm
	Max Torque	Up to 250,000 ft-lbs
Substructure with B.O.P. Handling System	10,000 lbs	
Annular Preventer	7.167 in (180 mm)	3000 psi
Single Gate RAM Preventers	2 × 7.167 in (180 mm)	3000 psi
H.P.U.	Diesel	Up to 500 hp



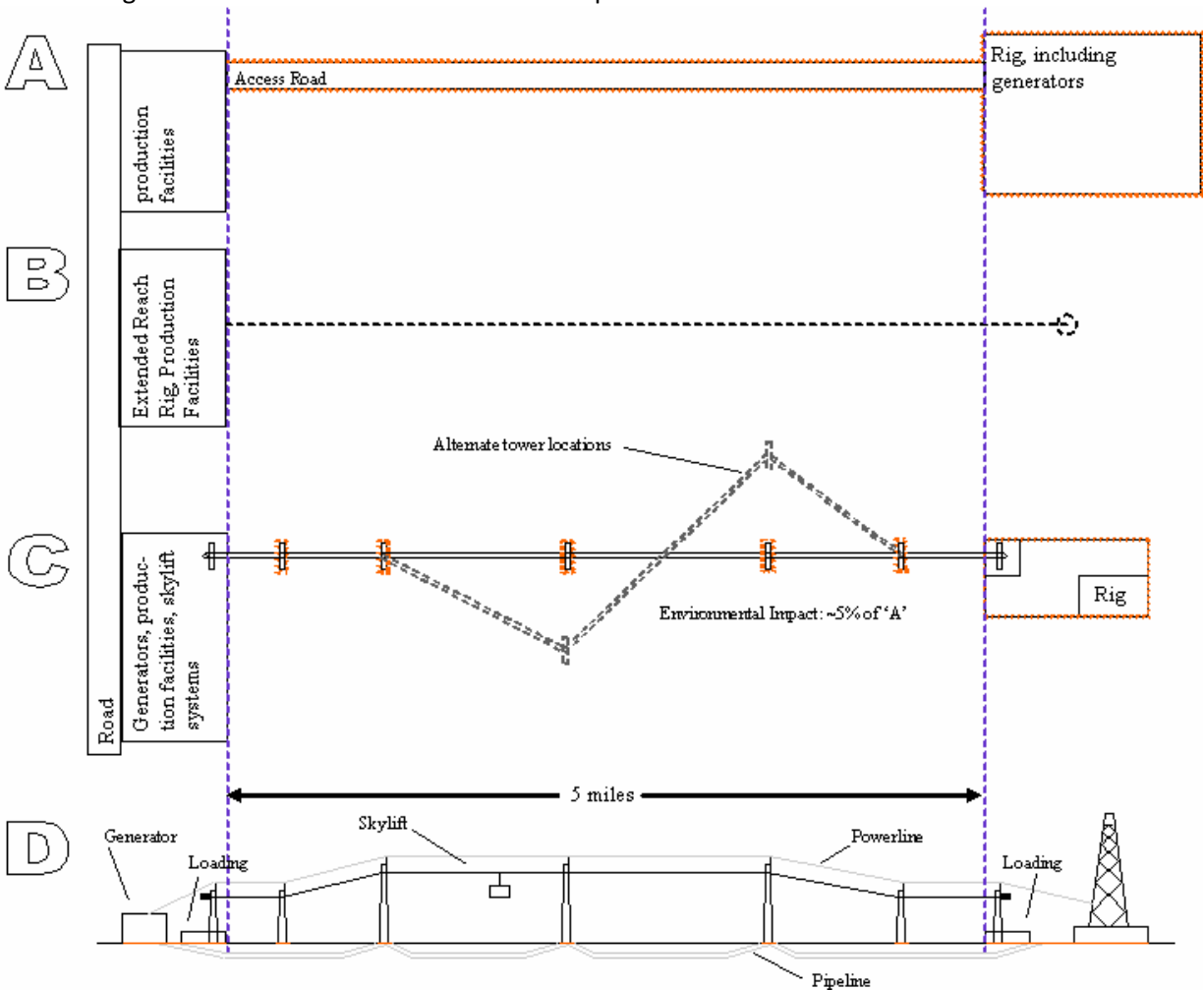
**Fig. 1 – HCTR units have a relatively small size compared to a conventional drill pipe rigs, thus reduce environmental impact.**

### Skylift Design

The skyway system proposed is a more robust version of what is used in mining and was used in the construction of the Hoover Dam. During literature search of mining publications, we found four aerial tramway builders – Garaventa AG, Global Technologies & Manufacturing, Interstate Equipment Corporation, and Reliance Barker Davies - but were unable to find capacities and dimensions. We suspect this lack of information is due to the fact that every installation must be custom built. However, we were able to find mentions of a wooden aerial tramway built in 1914. This system carried 2200 pounds and was reported to be significantly cheaper than building a traditional road<sup>7</sup>. Using modern materials and building techniques, it would be easy to build a system that could carry the desired loads. When examined aerially, as in **Fig. 2A and C**, the footprint of the skylift system is significantly less than a more traditional road.

The basic design consists of two loading/unloading platforms – one located at the wellsite and the other outside of the protected area. In between these platforms would be a series of towers that would support the two cables necessary to complete a skyway circuit. These would need to be tall enough to ensure that the tram was always above the local vegetation and wildlife. The cable between the towers will ‘sag,’ with the overall amount of sag related to the tram load and the cable material selected.

Our design calls for using a circuit skyway path, as opposed to a straightline path. Utilizing a circuit, we are able to transport more supplies within a shorter period of time. The straightline method only allows for one tram that travels from the dock to the wellsite and then returns before a second load can be sent. The circuit method allows for multiple cars, with no waiting for a car to return before the next can proceed.



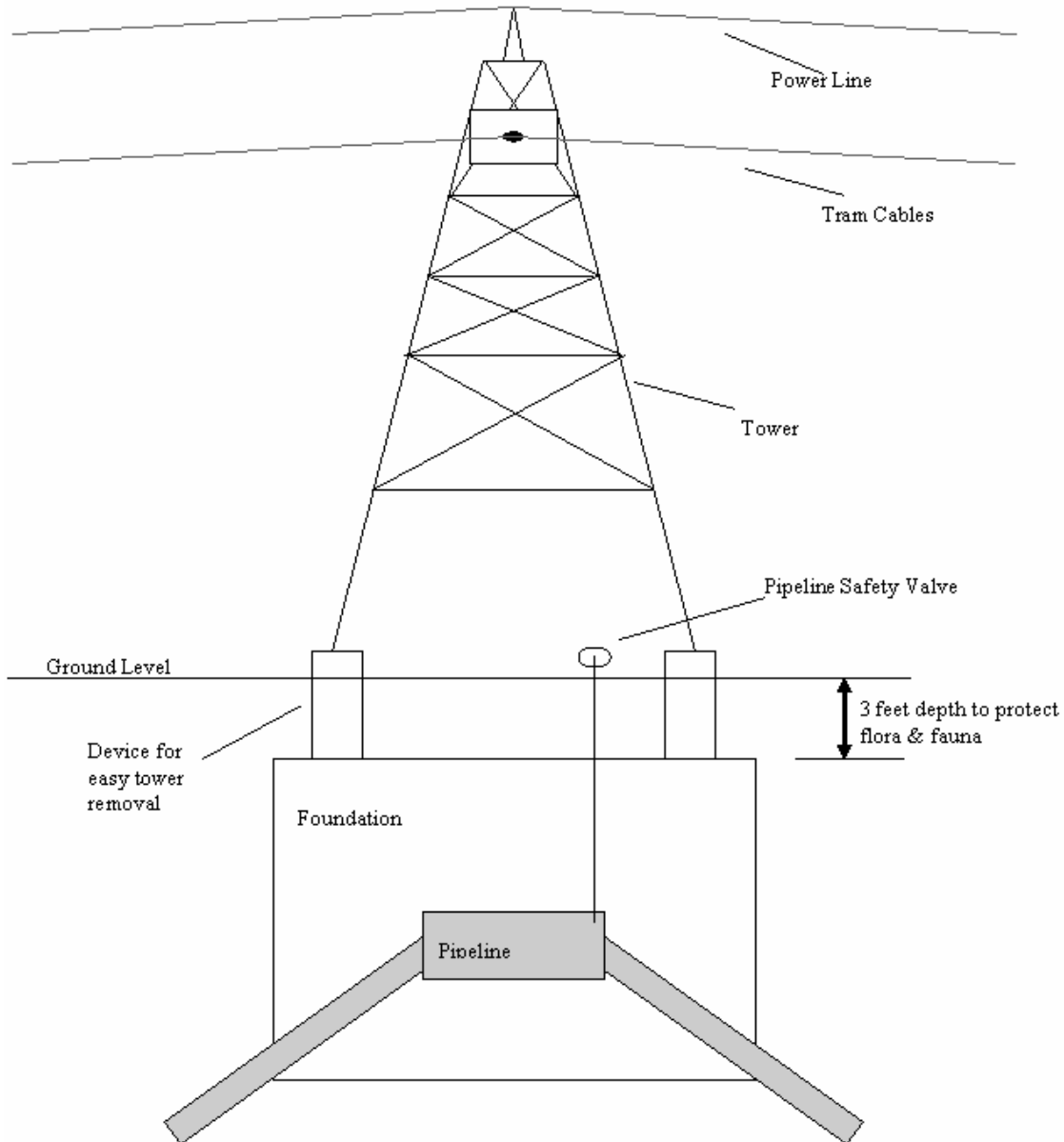
**Fig. 2 – Comparison of footprints for a traditional road (A), extended reach drilling (B), and the skylift system (C). The orange lines represent the footprint of each method. Figure also shows side and aerial views (D) of the skylift system.**

The recommended tram design is an open air cargo platform, roughly the size of a shipping trailer. This would facilitate the transport of the rig, tubulars, crews, and any other necessary supplies.

Before the skylift is built, the area should be examined so that the towers minimize environmental impact. One of the significant benefits of our plan is that the towers do not need to be located in a straight line, as shown in Fig. 2C. The towers can be located in the areas where there is no, or minimal, vegetation and animal life.

The implementation of this system is straightforward. Individual towers will be constructed as shown in Fig. 3 and outlined below. Tower height would be dictated by local vegetation and would be limited by local wind speeds.

All construction is done with cargo airships to transport crews, equipment, and materials to and from any locations. Cargo airships come in varying sizes and are used around the world to successfully transport heavy loads. For construction work, they are superior to helicopters because they produce less noise and pollute less. Their downside is that they can be slower than a helicopter.



**Fig. 3 – Side view of basic tower construction. Foundation is located three feet below ground level to protect local wildlife and vegetation. Also it is shown how tiny is the footprint that impacts the ground after installation.**

The first step in construction is to excavate the footprint of the tower. A crew and equipment are placed on the site and the ground is removed. The removed soil is stored outside the protected area. Next, a concrete base is built that starts one meter below the ground. The base should be sufficiently deep so as safely support the towers. By keeping the top of concrete deeper than one meter, we are able to easily revert the footprint area back to its natural habitat at field abandonment. Flora and fauna exist within the first meter of the ground – they would not notice or be affected by the base. Once the concrete base is installed, horizontal pipe installation equipment would be placed upon the base and the pipeline would be installed. This setup allows using horizontal directional drilling techniques to install the pipelines and to inspect them during the lifetime of the project.

The next step is to install the towers into the base and fill the remaining hole with some of the excavated soil. This process is repeated for each tower. After all the towers are built, cables and power lines would be strung and the skyway access platforms would be installed. The final step is to install the skyway motor outside the protected area and to attach the trams. The system would now be operational. It must be noted that this type of installation is widely used to install towers in mountainous regions.

Once the skylift is no longer needed, at field abandonment or once the alternative uses are finished, it can be removed and the environment restored to its original conditions. The wellsite would be returned to its original condition using standard oilfield practices. Then the skylift would be removed, with the assistance of cargo airships. The trams, cables, and power lines would be removed from the towers. The footprint of each tower would be excavated down to the base; the tower would then be detached from the base and removed. The original dirt would be brought back in to fill up the hole. Once removed in this manner, the local environment would be unable to tell that anything had ever occurred in their area.

### **Pipeline Design**

Two methods were chosen to transport hazardous material from drilling and production phases through an environmentally sensitive area. The large amounts of hazardous materials in question are from a production stream of a typical natural gas and oil reservoir. Surface separation systems will be set with the facilities outside of the protected area; therefore, the transported fluid will be a multiphase mixture of natural gas, oil, and water. Natural gas and liquid lines are subject to different regulations. A multiphase mixture is subject to both sets of standards. For example, when calculating impact radius, the spill area would be treated as a liquid and explosion radius would be that of a gas line. This is according to 49 Code of Federal Regulations 192 and 195. The line will consist of electric resistance weld steel pipe, and it will be cased for corrosion and leak protection. The critical integrity issues for this line to operate in an extremely sensitive environment are corrosion protection and leak detection. For this competition, the following Department of Transportation guidelines will be adopted: computational pipeline monitoring leak detection system must be in accordance with API 1130 (49 CFR 195.444), pressure/flow sensors and remotely operated valves must be tied to a control center, and right of way patrolling via skylift.

The two methods of pipeline settings are shallow burial and horizontal directional drilling (HDD) installation. Shallow burial can be quickly and easily installed and removed with simple leak and corrosion monitoring; however, installation can interfere with the surface vegetation. If shallow burial is chosen, a burial of 3 to 6 ft should ensure adequate frost protection. An alternative would be to use drilling rigs located at the base of each surface skylift support to drill a horizontal path for the pipeline. The benefits of this method are minimal environmental impact and complete isolation, however, this method is costly to install and remove, and makes leak and corrosion detection more complex. Shallow burial is orders of magnitude cheaper. Using a case study of horizontally drilled pipeline, the development and implementation of this project will require funding in the order of \$250 millions for a length of 5 miles<sup>8</sup>, making this not economically viable.

If cost is no issue, drilling and running pipeline through boreholes is recommended. It would ensure that, except for the surface stations, this pipeline would be completely isolated from the environment. Power lines should be run above ground, attached to the skylift system. Operating pressures can be safety-factored down to give extra assurance of integrity.

Some of the specifications for the pipeline recommended are in **Table 4**. By regulation these specifications yields a maximum allowable operating pressure of approximately 4,900 psi, meeting all requirements for safety and environmental protection as well as meting production throughput needs.

Diameter, in	6.5
Specified minimum yield strength, psi	42,000
Wall Thickness, in	0.5
Safety Factor	0.72
Joint Factor (E), electric resistance welded pipe	1

### **Effort to minimize environmental impact**

By locating everything except for the rig outside of the protected area and by using a skyway instead of a physical road, we have minimized the impact on the environment to just the footprint of the towers and the wellsite. Noise pollution is also reduced due to the fact that skylifts and cargo airships produce little, if any, noise pollution.

### **Assessment of environmental restoration**

The guidelines for this project state the environment should be assessed one and five years after drilling ceases. As stated earlier, focusing on a one-year time window does provide a complete picture of environmental impact. Under our proposed timeframe, the impact after one and five years would be identical. After drilling, it is still necessary to visit the wellsite during the life of the field for inspection purposes and workovers. If the wellsite is not accessible, it would be impossible to catch a potential equipment failure before it impacted the local environment. It is proposed that the environmental impact after drilling and at field abandonment should be considered instead.

After drilling has ceased, the skylift will be used when wellsite inspections occur, plus when desired if an alternative use is employed, as described later on in this report. Unlike a traditional road, no cleanup work is necessary at this stage, beyond the wellsite. The environment between the towers has not been affected, and is still pristine. Wildlife and vegetation would not be hindered in any way – land based wildlife could walk between the towers and flying fauna would be able to fly around or over the towers. Unlike traditional wind turbines, the skylift would not endanger birds by being difficult to see. Had a road been built, any flora or fauna underneath the temporary road would be destroyed, and the soil would have been heavily compacted.

After the field has been abandoned, and assuming no further use of the skylift, the towers can be removed. The wellsite and the footprint of each tower will be returned to their natural state. Since tower locations had been chosen where there was no vegetation, it will immediately be returned to its original condition. The environment will function as if drilling had never occurred. Had a road been chosen, it would have been necessary to relay the road, destroying the environment after it had just started to reestablish itself after the previous road was removed.

### **Future Use & Alternative Energy**

Once drilling is completed, the skylift has several possible uses. These uses include future well workovers, tourism, science, and alternative energy exploitation. Should the well need future work, the skylift can be used to transport a rig or equipment back onto the site. The skylift can also serve as a tourist attraction by allowing visitors to view the area from a raised height. This would lead to taller towers, allowing a larger view. Scientists may also find value in the skylift by being able to study the area without disturbing it; in this case, shorter towers may be preferred to allow the scientists to be closer to the environment. Alternative energy systems can be installed as the skylift is built.

In desert environments, the three main sources of alternative energy are wind, solar, and geothermal. For this project, wind and solar could be utilized to generate electricity. This would be accomplished by designing the skylift supports to hold solar and wind generators in place. There are four main types of solar generators and two main types of wind generators that could be applied to this project. The four main types of solar generators are the standard power-plant

type (elliptical mirror focusing sunlight onto a generator), traditional solid flat panels, flexible cells, and ‘paintable’ cells. The two types of wind generators are the traditional 3 or 4 blade model and the newly developed Aerotecture turbines.



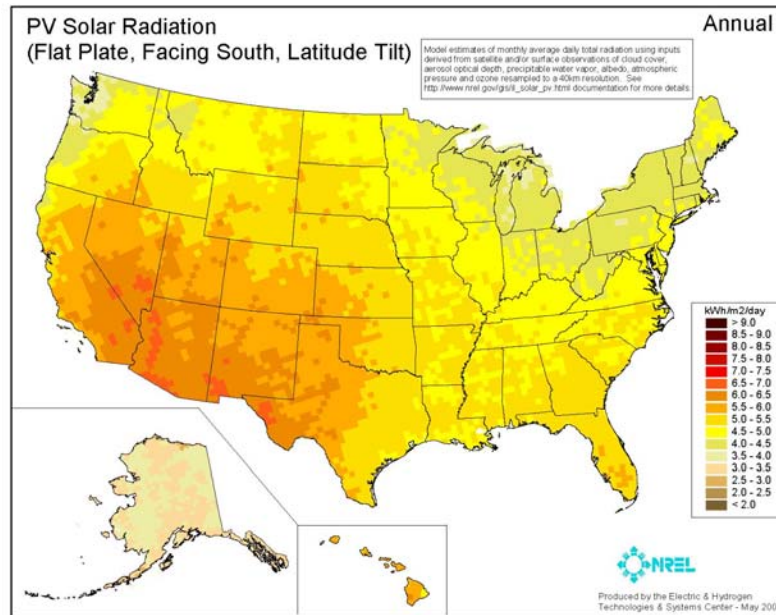
**Fig. 4 - Example of Nanosolar's flexible solar cells.**

If generating power from alternative energy is desired, our recommendation would be to use a combination of Aerotecture wind generators and either ‘paint’ or flexible solar cells. To harness the sun’s energy, using either ‘paint’ or flexible solar cells, shown in **Fig. 4**, to cover the majority of the supports would be the primary method<sup>9</sup>. To harness even more solar energy, it would be possible to install traditional solar power plants on top of each support. The Aerotecture wind generators, shown in **Fig. 5**, can operate in low wind environments and use wind from all directions<sup>10</sup>. Due to their design, they are also bird friendly, allowing us to harness wind energy without harming the local avian life. Another benefit of this type of wind generator is that they are relatively inexpensive and are transparent, allowing light to pass through – which will be beneficial for the solar generators.



**Fig. 5 - Horizontal Aerotecture wind turbine.**

Wind turbines and solar cells both require regular maintenance. Approximately once a month, the solar cells must be rinsed to remove dirt buildup that reduces their efficiency. This will require a method of bringing water to each platform – the two options are to either carry the water within the skycars or to have a water pipeline to each platform. Care must be taken to reduce the amount of water that comes into contact with the local environment. If not collected, the water could increase vegetation growth around the structures, altering the local environment. If this increase in local vegetation is considered unacceptable, the base of the platform would need a water collection vessel that would either be drained via pipeline or vacuumed into the skycar for removal from the area (The water would be nontoxic, containing only sand). The wind turbines would also require regular maintenance to keep them running at peak efficiency. Facility maintenance must be considered when designing the structures to allow personnel to work on the structure without coming in contact with the local environment. This would be easily accomplished by installation of walkways and ladders on each support that is accessible from the skycars.



**Fig. 6 - Solar energy map of the United States of America<sup>11</sup>.**

In order to install alternative energy generators, it is necessary to ensure that their installation is justifiable. **Fig. 6** shows that this area is located in the best part of the United States for solar energy. Also the use of Aerotecture wind turbines allows generation of electricity even in low wind conditions.

## Conclusion

In approaching this challenge, an integrated approach was chosen. If the goal is to protect the local environment, it is necessary to consider the entire life cycle of the field, not just the drilling window. Our plan calls for using an skylift to reach the site, locating only the rig within the protected area, placing the remainder of the drilling (and production equipment) outside the area, and using horizontally drilled pipelines to transport fluids. This plan will produce less impact on the local environment than an ERD project or a traditional road.

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