NitroTube

A New Solution for Fighting Forest Fires.

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Executive Summary

NitroTube is new and an integrated set of methodologies and equipment designed to more efficiently fight wildfires. The occurrence and severity of forest and other wildland fires have dramatically increased in recent years and are a growing threat to our national and state forests.

A number of reasons have been hypothesized for these increases. These reasons include climate change and pine beetle infestation, both of which have resulted in a large amount of "fuel" accumulating on the floor of many of our nation’s forests. Currently efforts are underway to reduce this large amount of fuel in various forests, particularly in the vicinity of areas inhabited by people. It has been shown that 90% of the ignition of these fires is related to human activity. Once ignited, fire suppression has been conducted using the same tools that have been available for decades. These include, but are not limited to, airborne tankers which drop water or fire suppressant materials, and firefighters, who cut fire breaks and, when applicable, employ backfires.

NitroTube modifies and utilizes a number of tools which have historically been employed in the oil and gas industry. One of these tools is "coiled tubing", which is used in coiled tubing drilling. This technology utilizes thousands of feet of tubing of various diameters that is stored on and deployed from large, transportable spools. Other technologies from the oil and gas industry integrated into the NitroTube system include high-capacity pumping and nitrogen completions technologies.

The NitroTube methodology would deploy a permeable tube from the coiled tubing unit hundreds or thousands of feet parallel to, and in front of, a wildfire front utilizing a human operated dozer or a remote-controlled dozer unit. The positioning of this tube would be facilitated by remote-controlled aerial drones which would also help to establish a communications grid across the area for controlling remote controlled vehicles. Once the fire front had advanced to a position determined optimum, nitrogen, in the form of gas or cryogenic liquid, would be pumped down the tube and distributed over a wide area along the fire front. It is believed that the wildfire midframe winds, which draw air towards the fire, would draw in the nitrogen and choke off its oxygen supply, thereby, extinguishing it. The NitroTube would then be recovered and reused to fight the next wildfire.

The NitroTube technology is a more cost-effective approach to fighting wildfires than the employment of aerial tankers and fire retardant materials. Nitrogen is available as a cryogenic liquid from a number of companies and a number of sites around the US. An additional consideration is the environmental impact of the materials used. Recently a number of concerns have been raised associated with the use of fire retardant materials, particularly in proximity to rivers and lakes. Since nitrogen is a normal component of air it would have little environmental impact and would dissipate rapidly.

Background / Description of "Need"

Climate change is resulting in warmer, drier summers in the west which in turn has caused an increase in Pine Beatles. A large number of trees throughout the west have been killed resulting in high amounts of fuel being left on the forest floor. Fires have become more common, larger, more destructive and more costly to suppress. The Union of Concerned Scientists in their publication entitled "Playing with Fire", 2014, indicates the impact of this on western US will be extremely significant by mid-century, including Wyoming. Figure #1, shown at right, is taken from this same publication and shows the increase in costs of forest fire suppression between 1985 and 2013.

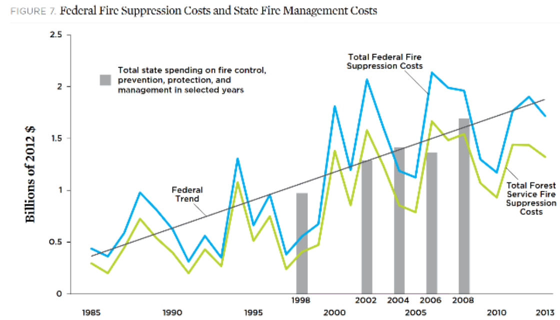

Figure #1: Increase in the Cost of Forest Fire Suppression between 1985 and 2013, (Union of Concerned Scientists).

The share of the FS budget devoted to fire management rose from 13% in 1991 to more than 40% in 2012 (Tidwell 2013). Since 2002, of the $3.3 billion average annual federal wildfire funding, 91% has been used for protecting federal land, 7% for wildfire protection assistance to local and state governments, and the remaining 2% for other activities, such as fire research (Gorte, 2013).

Together, emergency appropriations to fight wildfires and budgeted fire suppression dominate the other categories of expenditure for wildfire protection on federal lands. The Wyoming Governor's Task Force on Forests identify wild fire prevention, preparedness and response as one of the highest priorities for forest management. Multiple tools and methods exist in various industries that could adapted for fighting forest fires. NitroTube is a methodology which integrated tools from the oil and gas industry and the cryogenic industry.

NitroTube System Components

Coiled Tubing

Figure #2 shows a Schlumberger coiled tubing drilling unit deployed in an oil and gas field. The unit shown has the capability of carrying and deploying a single, steel tube that is 14,500 feet in length and which is 1 1/4 inch in diameter. Typically, for drilling operations, this coiled tubing deployment system is connected with a drilling mud system used to clean drill cutting from the borehole. Instead of drilling into the subsurface this type of technology can be used to deploy a similar tubing system across the Earth's surface in a forest ahead of the fire front. Connected to this tubing system, instead of the drilling mud system, would be a source of nitrogen or CO2 (see Figure #3 below).

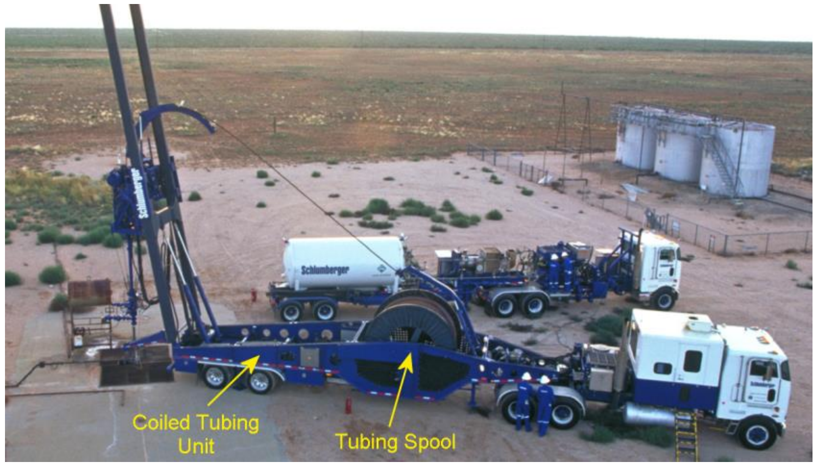

Figure #2: Typical coiled tubing unit deployed in oil and gas operations.

Figure #3 shows a close-up of the coiled tubing spool. Typically, for oil and gas operations, it is made from low carbon alloy steel. These spools range in diameter from 8 feet to 12 feet. Coiled tubing can be straightened prior to being inserted into the wellbore and recoiled back onto the spool following the drilling of the borehole. The tubing employed by NitroTube may be composed of a different material other than steel. This material may be aluminum or a plastic. This material will be identified through experimentation during the testing phase of this system.

Figure #3: Coiled tubing on spool.

Liquid Nitrogen Transporter

Figure #4 shows the second primary component of the NitroTube system, a liquid nitrogen transporter. These transport tractor-trailers can haul over 8100 gallons of liquid nitrogen at a time. This amount of liquid nitrogen can expand to 750,000 ft.^{3} of nitrogen gas at mean sea level. This amount of gas would cover of volume 500 feet in length by 100 feet in width and 15 feet high. Multiple tankers could be daisychained together to provide a larger volume that could cover a greater length of the fire front or deploy the gas for greater length of time. This will be explained in the next section.

Figure #4: Liquid Nitrogen Transporter

Tubing Deployment System

Figure #5 shows a potential tubing deployment system for NitroTube. In order to deploy the tubing a vehicle of sufficient power, preferably tracked, would need to pull the tubing from the spool/reel across the forest floor approximately parallel to the fire front. Bulldozers of various sizes are often used in forest fire fighting, when practical, in order to cut fire breaks. These have the advantage of being powerful enough to push through vegetation on the forest floor. A tracked vehicle also has the advantage in uneven terrain. The NitroTube system would initially employ a manned bulldozer for the deployment of the gas dispersal tube. However, the environment in which system would be deployed is inherently dangerous for the operator. Additional research is planned to determine if a remotely guided vehicle could be used for this purpose, which would increase the safety factor associated with the system.

Figure #5: Tubing Deployment System, a manned or remotely piloted bulldozer, to pull the tubing into place in front of the fire front.

Reconnaissance and Communication system

Figure #6 shows a typical quad-copter or drone that would be utilized to scout the location of the fire front prior to the deployment of the NitroTube system. These drones would transmit real time images back to the NitroTube operators, helping them ascertain the current conditions of the fire front and layout of the surface terrain. Additionally, a matrix of these drones would help establish a communication system across the operational area which could be utilized to remotely pilot the tubing deployment system. These drones would also help to identify the most appropriate time for the release of the nitrogen gas.

Figure #6: Reconnaissance and Communication Quad-copter

The NitroTube Method

Once a forest fire is detected and determined to be one in which NitroTube may be deployed, the NitroTube equipment will be prepositioned where it could be deployed quickly once its use is authorized. A supply of liquid nitrogen will be obtained from nearby commercial suppliers and trucked to the prepositioning site. Figure #7 shows the locations for commercially available liquid nitrogen from just one company, Air Products.

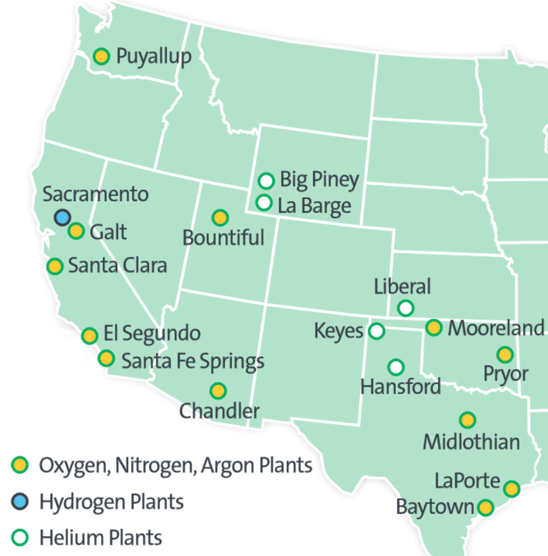

Figure #7: Locations of sources of liquid nitrogen through one commercial supplier, Air Products, in the western US.

While the NitroTube equipment and the liquid nitrogen is being moved to the prepositioning site the NitroTube crew chief will begin communication with the local fire commander in order to be up to date on the evolving fire conditions. Once all equipment is located at the prepositioning site the NitroTube crew chief will coordinate the deployment position of the NitroTube equipment and the timing of its deployment with the local fire commander. At the appropriate time the equipment will move into the designate position and deploy.

At the deployment site the remote controlled drones would be released in order to reconnoiter the fire front, only as long as these drones would not interfere with airborne tanker operations. In addition to this reconnaissance these drones would set up the communications array. This is shown in Figure #8

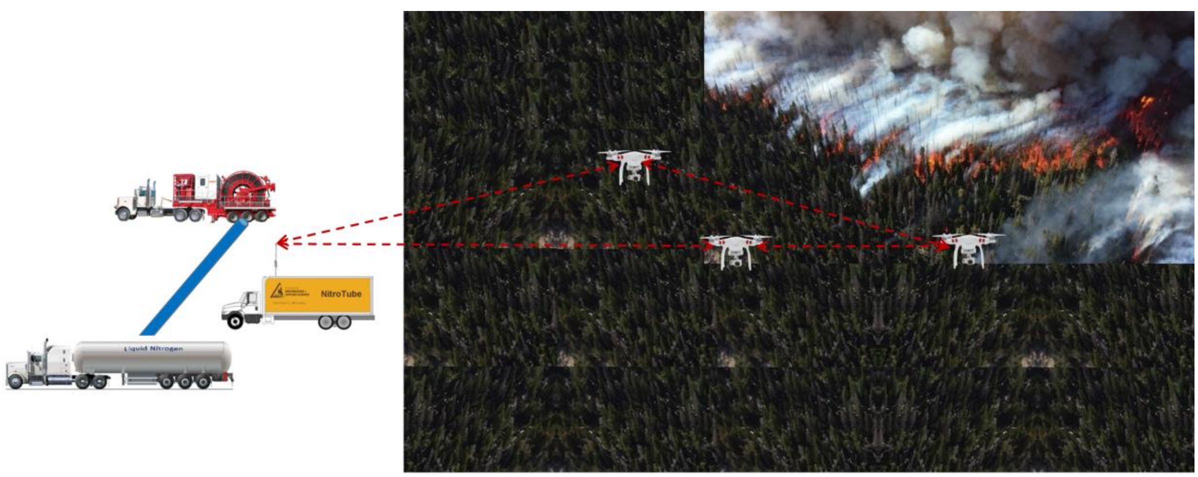

Figure #8: Establishing the reconnaissance and communications array.

The deployment of NitroTube may take advantage of existing firebreaks, roads or meadows. Or the NitroTube crew may be required to cut a new firebreak, if timing permits, or attempt to deploy across the forest floor as best as they can without cutting a break. Figure #9 illustrates this concept. Additionally, depending upon the terrain, it may be possible to remotely pilot a vehicle through the forest, which would pull the NitroTube into place. The communications array, established previously by the drones, would be utilized to transmit the signals between the driver and the remotely piloted vehicle. This would have a significant safety advantage as the vehicle's driver would be at less risk.

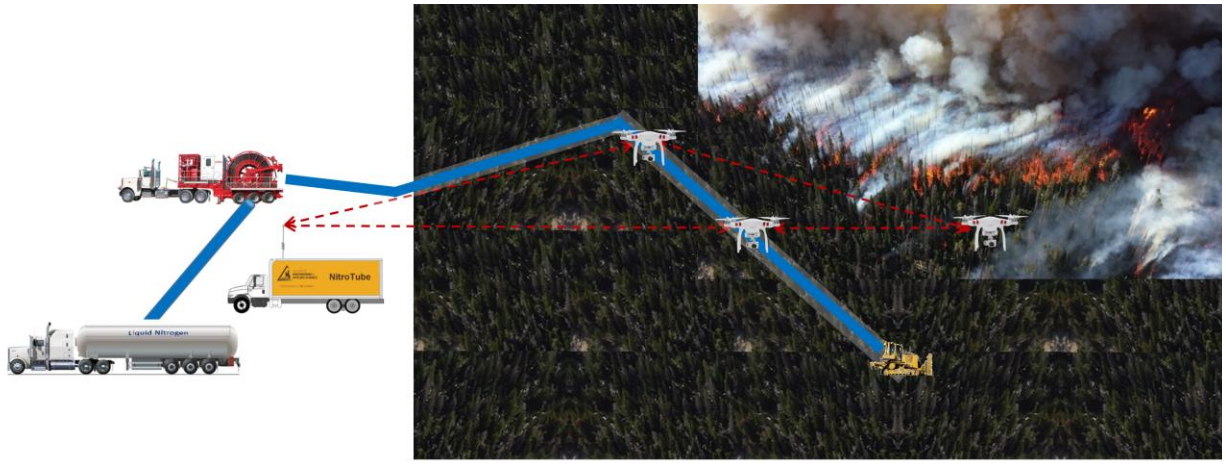

Figure #9: Cutting a new firebreak and deploying the NitroTube using a manually driven bulldozer. This may also be possible using a remotely controlled vehicle.

Once the NitroTube is in place the NitroTube crew would monitor the approach of the fire front and the direction and intensity of the local winds. Depending upon the local weather conditions wind direction close to the surface of the earth can float towards the flame front as the fire pulls air towards it. These are referred to as mid – flame winds and they are dependent upon the height of the flames. These are utilized by backfires, which are set by traditional fire suppression crews in order to eliminate fuel directly in front of the fire.

Should these mid flame winds develop at the optimum time for impacting the greatest length of the fire front the NitroTube crew would access the store of liquid nitrogen, charge the NitroTube and release the nitrogen. As the pure nitrogen gas has nearly the same density as air the mid flame winds would pull the nitrogen into the fire front, denying it oxygen and extinguishing it. Should local weather conditions prevent the development of the mid flame winds the NitroTube crew would wait until the fire front was at the NitroTube location before releasing the nitrogen. Figure #10 illustrates this concept.

Traditional fire suppression crews, which would've been withdrawn to a safe distance prior to the release of the gas, could then enter the area to combat any remaining hotspots that may still exist. This would depend upon a number of factors including the movement of the fire front following the deployment of the NitroTube. Once the

NitroTube had returned to ambient temperatures it could be recovered for use at the next wildfire.

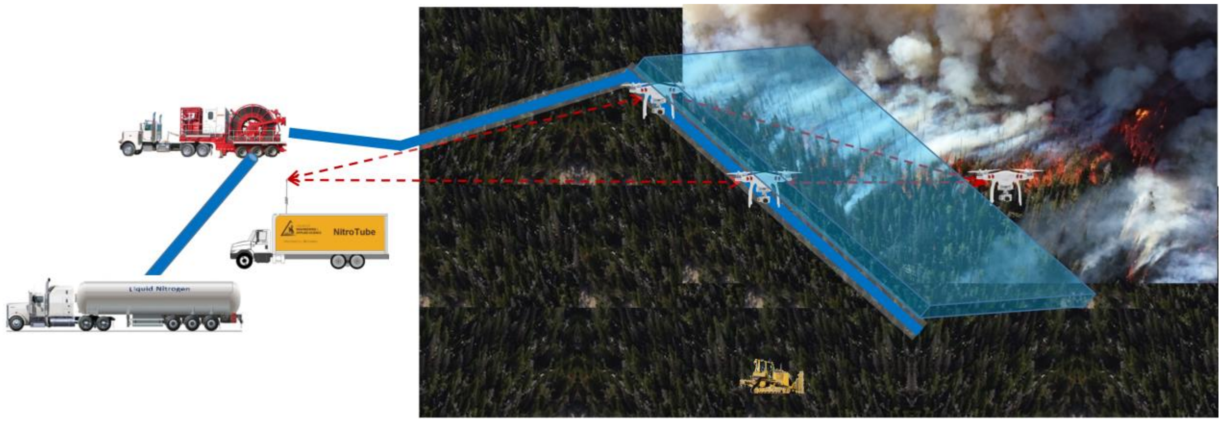

Figure #10: Release of the nitrogen (or CO2) gas along the NitroTube approximately parallel to the fire front. The nonflammable gas is then pulled into the fire front by the mid-flame winds and the fire is denied oxygen and is extinguished.

A major advantage of the NitroTube concept is the ability to daisychain potential nitrogen sources together in order to increase the amount of volume delivered to a particular wildfire. Figure #11 illustrates this concept. In this illustration three liquid nitrogen tankers supply the nitrogen for two NitroTubes. This potential solution would increase the length over which the gas would be released and could extinguish a much longer fire front.

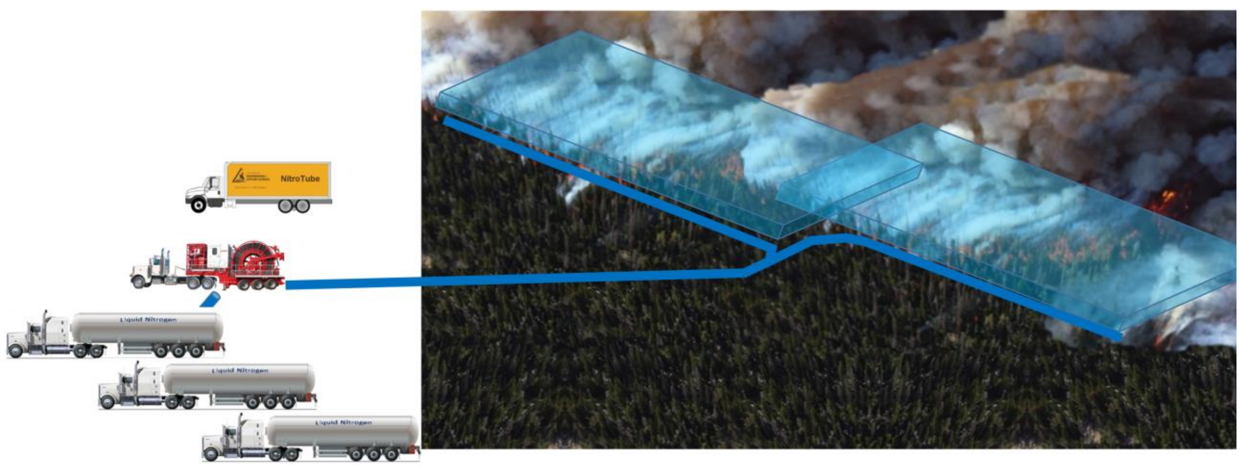

Figure #11: Daisychained nitrogen source tankers supplying two NitroTubes. This could increase the amount of gas delivered to a specific portion of the fire front and/or increase the length over which it was delivered.

Research Needed

The primary uncertainty associated with NitroTube which needs to be investigated initially concerns the type of material that could be utilized for the tubular deployment system. This may be the same material that is utilized in the oil and gas industry, a low carbon alloy steel. However, other materials may be better suited for this particular application. Research into the use of aluminum tubing or a plastic tubing system would be conducted immediately. Factors to be investigated would include the response of these materials to supercooled fluids, the time for them to return to ambient temperatures and their material properties following super cooling.

Additionally there is a question concerning the speed at which large amounts of liquid nitrogen can be flashed into gas. In the oil and gas industry conversion of large amounts of super cooled liquid nitrogen to gaseous form is accomplished using heat or vacuum evaporators. The speed in which this occurs may not be optimum for firefighting. Should this prove correct, high pressure holding transports may need to be added to the NitroTube system in order to have enough gaseous nitrogen available at the time of release. This initial research effort would be limited to laboratory conditions and would not require a significant amount of funding.

Following this initial laboratory testing phase a "proof of concept" set of equipment would be assembled for the preliminary testing of the integrated system. A small reel of tubing and an appropriate amount of liquid nitrogen would be obtained for a small test. This test could be performed on a small, controlled, grassland burn somewhere in the Laramie basin. This test would require coordination with the local fire authorities to ensure safe and controlled testing conditions. Additionally, testing needed for the development of the reconnaissance and communication drone system would occur.

Should this test be successful a fully functional NitroTube system would then be assembled. This system would then be tested in a fully operational capacity environment with a large, controlled burn in a state or national forest area. Testing of the integration of the remotely piloted surface vehicle into the NitroTube system would also occur during this phase of testing. Upon completion of this final set of tests NitroTube could be made available for operational use.

Economics

The following economic analysis has been made with limited data and will be performed again with assistance of the University of Wyoming’s business college once the initial laboratory testing phase has been conducted.

Initial Capital Expenditure

The initial cost for a single NitroTube operating unit is estimated to be approximately $2.3 million. These costs are shown in Table #1. While a liquid nitrogen cryogenic transporter is not listed, as it would be provided by the supplier of the liquid nitrogen, three gaseous nitrogen tube trailers have been listed. The cost of these have been estimated based on the asking prices of used trailers seen on the internet, as is the cost of the High Capacity Vaporizor and Pump.

Cost of the Coiled Tubing Unit and the Coiled Tubing are both taken from a recent Oil and Gas Journal article. It should be remembered that it is unlikely that the same material used for coiled tubing in the oil and gas industry will prove to be optimum for

NitroTube. This will be determined during the initial laboratory testing phase and the cost estimates adjusted.

Cost of the bull dozer is taken from the internet. This is for a new unit for safety as the operator will be at the greatest risk during the NitroTube deployment.

Operating Expenditures

Annual salaries shown are pure conjecture and will be adjusted once additional research is performed with the aid of the Business College. It should be kept in mind that NitroTube will, most likely, only be deployed during fire season. Therefore, these salaries would be for a partial year of employment. During the off season NitroTube employees would be released.

The cost of liquid nitrogen was obtained through personal communication with an Air Products representative during phone conversation on 11/1/17. As the NitroTube application could not be described to the Air Products representative due to the current lack of IP protection the range for the cost of the liquid nitrogen is fairly large, $0.30 to $2.00 per gallon. $1.00 per gallon has been used for this initial estimate.

Transportation costs will be dependent distance from source to wildfire location, which will always be an unknown until a wildfire breaks out and is recognized as one where NitroTube could be deployed. Costs of transportation of the NitroTube equipment and the Liquid Nitrogen will, of course, be dependent upon trucking and fuel rates at the time of deployment. While exact costs for this are unknown at this time industry trends can be applied for costs estimations. Figure #12 is taken from the DAT.com website, which monitors freight costs. As indicated refrigeration units (reefers) are currently running approximately $2.30 / mile. The transport units for the liquid nitrogen are, most likely, more expensive but the coiled tubing units are also probably less. While the two may not balance out it may be close enough for an approximation.

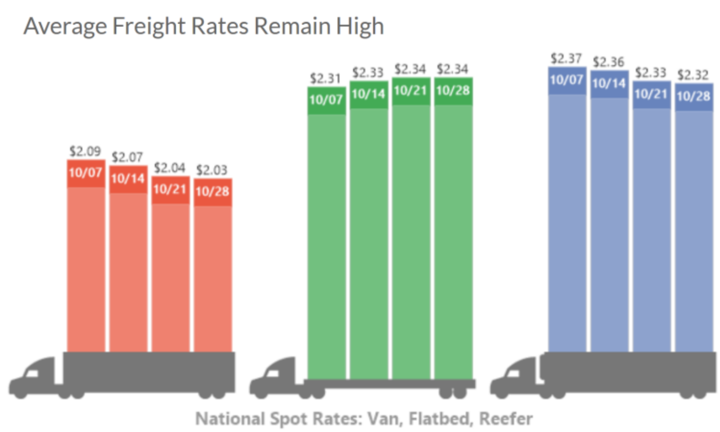

Figure 12: Average cost of freight transportation across the US.

Based on the locations of sources of liquid nitrogen from one commercial supplier, Air Products, in the western US, which are shown in Figure #7, the following two scenarios have been used to estimate transportation costs.

Scenario #1: Fire in the Bighorn National Forest in the Bighorn Mountains, Wyoming. In this instance liquid nitrogen would be obtained from Bountiful, Utah, which is 557 road miles away. Cost of transportation would be $1,280

Scenario #2: Fire in the Lolo National Forest near Missoula, Montana. In this instance liquid nitrogen would be obtained from Puyallup, Washington, which is 487 road miles away. Cost of transportation would be $1,120.

Initial investment Estimate		
Capital Expenditure (CapEx)		
Coiled Tubing Unit	$1,500,000	Source: http://www.ogj.com
Coiled Tubing	$220,000	2" diam.
High Capacity Vaporizor and Pump	$300,000	Est.
Tube trailer transport x 3	$150,000	Used
Bull Dozer	$125,000	
Total	$2,295,000	
Operating Expediture (OpEx)		
Personnel		
Crew Chief / Coordinator	$40,000 / year	
Coiled Tubing Operator	$32,000 / year	
Pressure unit operator	$32,000 / year	
Dozer Operator	$34,000 / year	
Supplies		
Liquid Nitrogen (LIN)	$8,400	8400 gal.
Transport for LIN	$1,200	Per deployment, per trailer
Fuel for Dozer	$400	Per deployment

Table #1: Initial general costs associated with NitroTube.

Summary

Changing environmental conditions across the western US in recent years has resulted in drought conditions and a proliferation of pine beetles. This is led to an increase in the severity and number of wildfires as fuel levels within Western forests have increased. Recent events, most notably wildfires in California which have led to a large loss of human life and over $1 billion in property losses, illustrate the need for new tools, techniques and methodologies for fighting wildfires in the western US. New solutions are now being sought by many state governments, the federal government and the insurance industry to combat these wildfires.

NitroTube integrates tools and techniques from various industries, most notably the oil and gas industry, as a potential solution for more efficiently and cost effectively fighting these wildfires. Utilizing technologies previously employed in the oil and gas industry for Coiled Tubing Drilling and high-capacity pumping from hydraulic fracturing and combining these with liquid nitrogen transport systems, and remotely piloted drones and surface vehicles, NitroTube could be one of these solutions.

Trademark

The name “NitroTube” was trademarked in 1995 for “Pipes and tubes of metal for commercial and industrial uses.”, (Serial Number 74652485, Registration Number 1953409).

This trademark was canceled in 2002.

Summary

NitroTube is a new technology for fighting wildfires in our national and state forests. This system integrates multiple technologies that have historically been employed in the oil and gas industry. These include coiled tubing, used in coiled tubing drilling, as well as high capacity pumping and cryogenic nitrogen, both of which are used in completions of subsurface reservoirs.

These components can be combined in such a way that large amounts of gaseous nitrogen can be released into an advancing wildfire front in order to deprive the fire of oxygen, resulting in the fire being extinguished. Some basic research, conducted in a staged manner designed to build upon the success of the previous stage, needs to be conducted in order to determine the optimum configuration of the system components and deployment methodologies. Additionally, research into the use of remote controlled vehicles for the deployment of NitroTube needs to be conducted. This may not only result in a more efficient method for deploying NitroTube but also increase the safety factor associated with fighting these wildfires.

Bibliography

Moore, T. A. and Yamada, N., “Nitrogen Gas as a Halon Replacement”, Halon Options Technical Working Conference, 12-14 May 1998

Ruckleshaus Institute, “Final Report, Governor’s Task Force on Forests”, Laramie, Wyoming: Haub School of Environment and Natural Resources, University of Wyoming, 2015.

Union of Concerned Scientists, “Playing with Fire”, 2014

Union of Concerned Scientists, “Rocky Mountain Forests at Risk”, 2014

University of Alaska, Fairbanks, “Gaging Fire Behavior & Guiding Fireline Decisions”, S290 Unit 12, 2015

Wyoming’s State Forester – Forest Action Plan, 2013