HDIAC Journal

The Journal of the Homeland Defense and Security Information Analysis Center

Volume 2 • Issue 4 • Winter 2016

ON DEMAND:

UAVS IN DISASTER AND REMOTE COMMUNICATIONS

HDIAC
Homeland Defense & Security Information Analysis Center
JOURNAL
Volume 2 • Issue 4 • Winter 2015

DoDIACs
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Message from the Director

Department of Defense operations are far reaching and touch on each of the eight Homeland Defense and Security Information Analysis Center focus areas. To this vein, it is important to discuss and understand the non-traditional, yet still essential, missions of the DoD.

The DoD charge is more than boots-on-the-ground, as the department is essential in aiding humanitarian and disaster relief efforts and leading the endeavor to utilize renewable energy resources. The articles in this issue of the HDIAC Journal explore potential developments in biofuel production and water filtration, as well as potential applications for unmanned aerial vehicles.

The first article highlights the use of unmanned aerial vehicles for communication infrastructure. In remote locations and emergency or disaster situations, the military and first responders may not have access to reliable fixed communication infrastructure. Researchers at the University of North Texas propose using a drone-carried Wi-Fi system for on-demand communications. An on-demand communication infrastructure is essential for military communication and networking systems for situational awareness, especially in remote environments. In addition, an on-demand communication infrastructure would facilitate the recovery of existing infrastructure in emergency or disaster situations.

Next, access to safe, clean water supplies is essential for the military in remote and disease-prone locations. The United States Army issues purification tablets containing iodine, halazone and chlorine to deployed soldiers to treat individual water supplies. A Carnegie Mellon postdoctoral researcher developed a filter paper that purifies water. This paper was turned into a book, which can provide water filtration for a single person for up to one year. While geared toward providing safer drinking water in developing countries, this technology could be used by the military for easier water purification.

Finally, researchers at the University of California, Berkley are considering alternative plant sources for creating liquid fuels. Although biofuel production has intensified in the last decade, liquid fuels derived from oil remain the largest contributor to transportation. This research could be essential to the DoD, which aims to power at least 25 percent of any DoD facility through the use of renewable energy sources by 2025. Academic, public and private research primarily focused on generating ethanol-based fuel utilizing corn, the Berkley researchers are studying the use of fungus to degrade the structure of perennial plants for fuel. These developments could potentially support the Department of Defense's renewable energy transition, as well as future military deployment fuel needs.

In addition, this issue highlights one of HDIAC's technical inquiries. HDIAC received a question regarding the cultural aspects of pipeline surveillance in Nigeria using unmanned aerial vehicles. HDIAC's response to this request looked at the UAVs for resource protection and discussed the cultural implications of UAVs in Nigeria.

HDIAC provides analytic, scientific and professional research in the eight focus areas. HDIAC offers up to four free hours of information services including literature searches, product/document requests and analysis to academia, industry and other government agencies.

Stuart Stough
HDIAC Director

HDIAC Focus Areas

- Alternative Energy
- Biometrics
- CBRN Defense
- Critical Infrastructure Protection
- Cultural Studies
- Homeland Defense and Security
- Medical
- Weapons of Mass Destruction

Communicating in Remote Areas or Disaster Situations Using Unmanned Aerial Vehicles

By: Shengli Fu, Ph.D. &
Yan Wan, Ph.D.

Introduction

A reliable communication infrastructure is crucial for an efficient and successful emergency response system. As stated in the Disaster Resilience Framework (work-in-progress) developed by the National Institute of Standards and Technology for the United States Department of Commerce; communication infrastructure in natural disasters is important for "relaying emergency and safety information to the public, coordinating recovery plans among first responders and community leaders, communication between family members and loved ones to check on each other's safety, and communication between civilians and emergency responders." [1] In this framework, communication is addressed as one of the seven critical facilities along with buildings, transportation, energy, water and waste water.

Despite well-known conveniences introduced by telecommunication infrastructures, such as high-speed Internet and wireless cellular phone service, populations may not realize the fragility of these infrastructures, especially during disasters. Communication infrastructure disruptions may be caused directly by damage to cables and cellular towers, or indirectly through shutdown of power and water. Massive disasters, like 9/11 and Hurricane Katrina, teach the unreliability of the fixed communication infrastructure. [2,3] Reliable communication infrastructure is also not available everywhere.

On-demand communication infrastructure to quickly recover communications in a disaster area is of critical need to coordinate emergency response operations. The on-demand communication infrastructure needs to permit information sharing via text, voice, image and/or video. It can be used to share information critical to the military, first responders, emergency control centers and also survivors. The United States military could rely on unmanned aerial vehicle Wi-Fi as a backup communication method when outside communication is impeded, such as enemy forces cutting off outside communication methods. Warfighters in the field could also utilize roaming UAV Wi-Fi support in order to maintain connections with field bases in the event of similar communication outages without having to carry any additional equipment.

In addition to facilitating recovery of existing infrastructure, the on-demand communication infrastructure is valuable for temporarily setting up high-speed networks in places outside of the range of fixed infrastructures. The U.S. military needs communication and networking systems for situational awareness, especially in remote environments. Researchers say there is a gap in communications coverage in some locations where the military is operating. [4] The Defense Advanced Research Projects Agency created the "Fixed Wireless at a Distance" program to develop better military communications for warfighters deployed to remote areas without the need for fixed infrastructure. [5]

Wildfires, which often occur in rural and mountainous areas without the availability of fixed infrastructures, are a national threat to the United States. The solution of dispatching high-cost manned airplanes to collect fire condition, and planning resource allocation solutions based on data retrieved from these airplanes after they are back, is highly inefficient due to the information delay. A high bandwidth, on-demand communication infra-

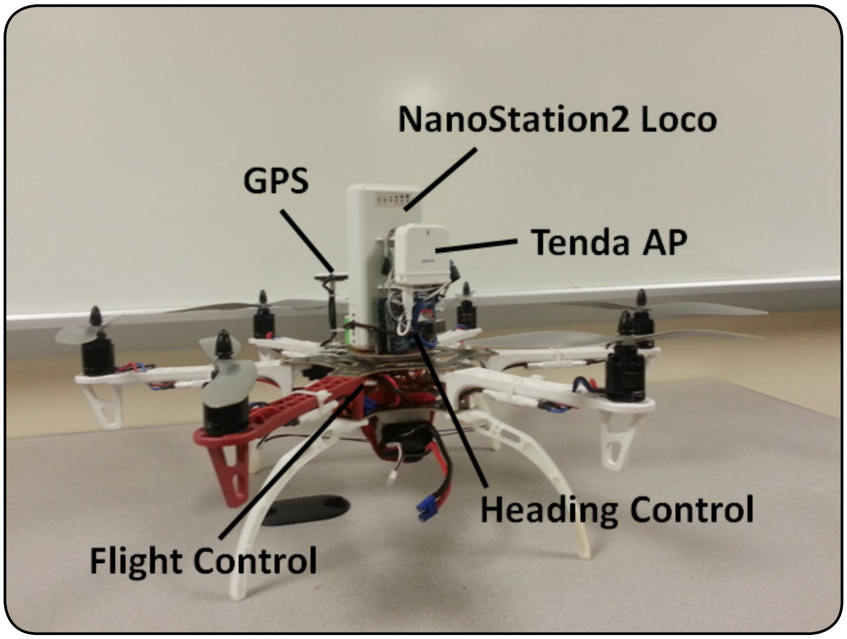

Figure 1: Drone-carried Wi-Fi prototype system. [1] (Image courtesy of Shengli Fu and Yan Wan, University of North Texas/Released)

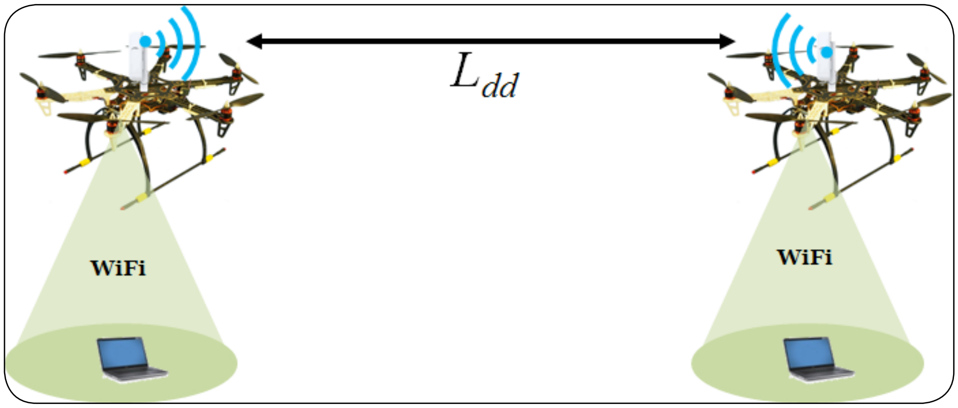

Figure 2: Field experiment setup. [11] (Image courtesy of Shengli Fu and Yan Wan, University of North Texas/Released)

structure is of significant value by providing real-time fire information to increase the safety of firefighters and their effectiveness in rescue missions.

Due to their low cost and high flexibility, UAVs recently gained significant interest as a platform to provide on-demand communication infrastructure. UAV features, such as high speed, controllability and capability to reach dangerous zones, all make them promising solutions for fast on-demand provision of communication infrastructure. Providing communication from the sky is not new. Satellites have been widely deployed in the last 50 years for broadcast, emergency response and personal communications.

The Challenges

Some key challenges, ranging from technical to operational issues, need to be addressed before UAVs can be widely adopted for emergency response operations.

High mobility is one main challenge for robust airborne networking. The wireless communication channel between a pair of UAVs is very different than channels in wireless communication networks on the ground. Typical wireless commercial channels have at least one stationary terminal. For example, in the 4G cellular system, despite the movement of users' cellphones, the base station (the other side of the channel) has no mobility. In establishing communication channels between flying UAVs, however, the uncertainty of UAV mobility introduces vastly different channel characteristics, which are not fully understood. In fact, the mobility characteristic of UAVs itself has not been systematically studied. A majority of existing research on UAV-to-UAV communication borrows mobility models from traditional mobile ad hoc networks, which have been used by the military, [5] such as random walk and random waypoint. While these simplified models provide invaluable insights into airborne networking, there is critical need to understand UAV mobility and develop mobility models dedicated to aerial networks that realistically capture the unique attributes of aerial links. [6,7]

Frequency changes introduced by the high cruise speed is another challenge for establishing robust communication between UAVs. The relative speed is doubled if the two UAVs cruise in the same speed but opposite direction. The high speed introduces severe frequency changes, known as the Doppler shift effect. The frequency changes directly impact link quality and result in lower data rate or even loss of connection. To compensate the Doppler shift, more advanced techniques need to be developed for UAV communication, including faster channel equalizer, agiler receiver design and prediction of mobility changes to prepare for potential frequency changes in advance.

The connectivity of an aerial link between UAVs is also affected by the non-line-of-sight effect. The quality of wireless communication relies heavily on the line-of-sight path to ensure the proper propagation of signals from the transmitter to the receiver. The non-line-of-sight effect in ground wireless communication networks is typically caused by obstacles (such as high building, trees and mountains) standing within the wireless link. The signal block for UAVs, however, is typically caused by the aircraft body blockage. [8] UAV-carried antennae are typically small and installed on one side of the aircraft. As such, wireless signals are

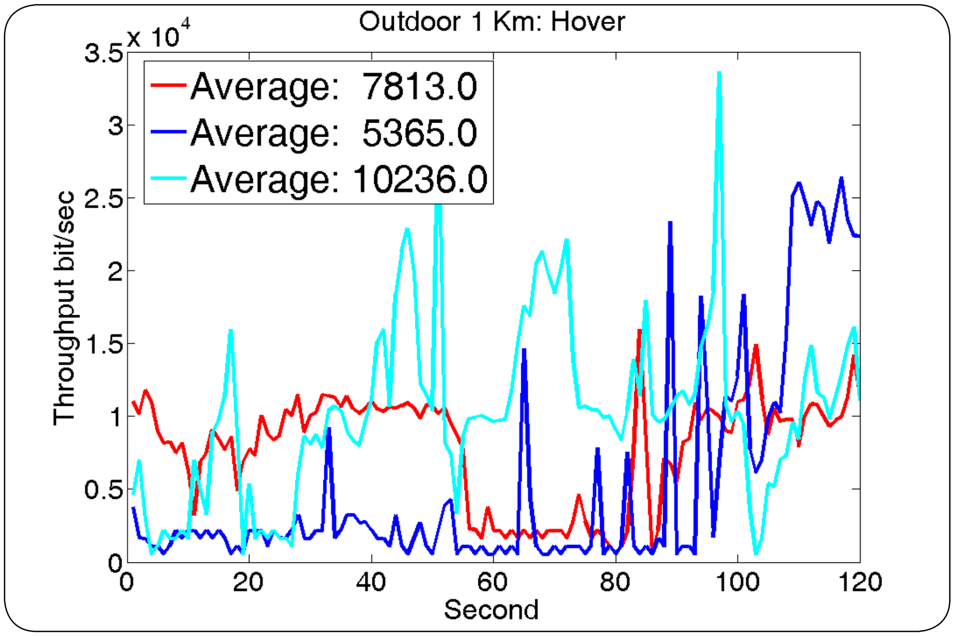

Figure 3: Throughput for the UAV-to-UAV link of 1Km. [11] (Image courtesy of Shengli Fu and Yan Wan, University of North Texas/Released)

easily blocked by the UAV body, especially when the UAV changes it gestures, e.g., during turns. One solution to resolve the effect of body blockage is to change the heading of UAVs according to their relative positions. If the position information is also transmitted through the aerial link, however, it is still difficult to maintain communication because the position information is lost once the communication link is broken due to body blockage.

Flight time is another factor that significantly holds back the use of UAVs for providing communication services. While balloons can stay long in the air (e.g., the balloon for the Google Loon project is designed for 100 days in the stratosphere), it is very challenging to have a UAV hover in the sky for a long duration. Small drones are currently mostly powered by electric batteries, and have a typical flight time of less than 30 minutes. To increase the hover time, other power sources such as fuel cell, solar, wind and hybrid energy source will be valuable. For instance, the UAV in the Facebook project powered by solar energy is expected to fly up to 90 days.

In addition to these aforementioned technical challenges, UAV applications also face non-technical issues, such as federal regulations and acceptance from the society. Under current regulations from the United States Federal Aviation Administration, academic institutions and small businesses require a very rigorous process to fly UAVs, including a request for UAV operation, certificate for the pilot and report after the flight. In addition, society is still not widely ready for UAV applications due to privacy, security and also the ownership of immediate airspace issues. [9] Convincing society of the safety and reliability of UAVs and their benefits to human lives in terms of efficiency, reduced cost and job opportunities will take considerable time. Google launched Project Loon to use balloons to connect people in rural and remote areas. [10] Facebook recently announced a solar-powered UAV project to provide Internet access from an altitude range of 60,000 to 90,000 feet. [11]

Drone Wi-Fi Prototype System

To address the urgent need for on-demand emergency communication infrastructure, researchers developed a drone-carried, on-demand Wi-Fi prototype system. [12] While a number of wireless protocols can be used for aerial communication, the commercially available Wi-Fi is considered suitable for the on-demand broadband communication infrastructure using small UAVs, due to the cost, regulation and compatibility considerations. As shown in Figure 1, on page 4, the drone-carried Wi-Fi system consists of the following main components: 1) the multi-copter UAV, 2) GPS module, 3) flight control module, 4) directional antenna, 5) heading control module and 6) Wi-Fi router.

The multi-copter UAV is used to carry the Wi-Fi terminals. Compared to fixed-wing UAVs, hex-copters are easy to control, and can stay at a fixed position in the air, making them a nice platform to provide communication services. In the prototype, researchers used DJI F550 hexacopter as the carrier platform because of its high stability in strong winds. As the drone Wi-Fi system features a modular design, it can be placed on other UAV platforms, including fixed-wing flights.

The GPS module and flight control module are standard for UAVs. The GPS information is not only used for flight control, but also for maintaining communication.

The directional antenna is the key comment to enable UAV-to-UAV communication. Wi-Fi routers of common use are not suitable for providing long-distance emergency communication, due to their short coverage range of around 100 meters. To address this issue, the direction antenna is used to extend the communication distance over kilometers by focusing the energy in one direction. The directional antennae used in this system is NanoStation 2 from UBIQUITI Networks.

The other important module to enable long distance UAV-to-UAV communication is the heading control module. It uses GPS information and a compass sensor to assure the alignment of directional antennae. The precision of heading control is crucial to maintain a robust UAV-to-UAV communication link over a long distance. Control algorithms are applied to reject the disturbances introduced by UAV motion and winds. The compass sensor used in the system is E-Compass LSM303 and heading control is imple-

The team completed an integration test in Austin, Texas with members of the Austin Fire Department, Worcester Polytechnic Institute and other Smart Energy Response System members. (Image courtesy of Shengli Fu and Yan Wan, University of North Texas/Released)

The researchers demonstrated their technology at the Global City Team Challenge in Washington, D.C. on June 1, 2015. (Image courtesy of Shengli Fu and Yan Wan, University of North Texas/ Released)

mented using Arduino UNO.

Finally, the Wi-Fi router provides a wireless link between the UAV and ground terminals, such as smartphones, laptops and tablets, and the heading control of directional antennas. Researchers chose the Tenda A6 wireless mini AP for its compact size and low weight.

To prove the feasibility of the system and evaluate system performance, researchers conducted various indoor and outdoor flight tests. Figure 2 shows one experimental setup with two hexacopters and two laptops on the ground. The end-to-end throughput is measured by iperf, a commonly used network testing tool, which runs on both laptops. The transmission power for directional is set as 20 dBm, the maximum achievable for the selected NanoStation. As shown in Figure 3, throughputs are recorded for three flight tests of two minutes each. The average throughput for the whole system is 7.8 Mbps. The lowest performance (blue line) is caused by the impact of heavy winds during the test, which not only affect the stability of the drone, but also make the directional antenna itself drift. Despite the room for improvement, the prototype and its experimental results show the appealing potential of drone-carried Wi-Fi communication.

Smart Emergency Response Application

The drone-carried, on-demand Wi-Fi system was developed as part of the Smart Emergency Response System to participate in the SmartAmerica Challenge initiated by White House and NIST in 2014. [13] The goal of SERS is to apply cyber-physical and human-in-the-loop technologies to rescue people, save life and attend to the critical need when disaster strikes. [14,15] The SERS project also participated in the Global City Team Challenge in 2015, with the emphasis on technology maturation, system integration and onsite deployment. [16] With the collaboration from Worcester Polytechnic Institute robotics team and Austin Fire Department as part of the SERS team, researchers successfully demonstrated the deployment of flexible, cost-effective and UAV-carried on-demand communication infrastructure, and its integration with existing emergency management systems to support the missions of first responders, rescue robots, mission command and control centers. In the demonstration scenario, victims were trapped in a chemical-leaky environment. UAVs were dispatched, which provided aerial views of the terrain to the operator of remotely controlled search and rescue robot to quickly locate victims, and more importantly established the communication link in the aerial layer through which control commands to the remotely controlled robot and video captured by the robots were transmitted. The demonstration suggested the capability of the drone-carried Wi-Fi system in improving the effectiveness of search and rescue missions.

Conclusions and Future Work

The drone-carried Wi-Fi communication system used directional communication and decentralized control to enable long-distance emergency communication. Flight tests and real-world demonstrations suggest its feasibility in practical use. In the future work, efforts will be devoted to improving the communication and control modules to achieve more robust long-distance communication links, and also to collaborating with emergency response personnel on testing and improving the technology to meet the needs of emergency response professionals.

The capabilities of a drone-carried Wi-Fi communication system could be critical for future military and emergency management operations, especially in remote areas without readily available communication infrastructure. With challenges with funding continuing to concern law enforcement and emergency personnel, finding technologies that are already built and tested by the Department of Defense (DoD) creates the ability for this technology to have a much more manageable cost. Advanced technologies created for military readiness, environmental safety and advancing the warfighter remains a top priority for the DoD. As a result, many of these technologies, including on-demand communications, have numerous crossover benefits utilized by the emergency management community, lessening the impact of disasters and saving lives.

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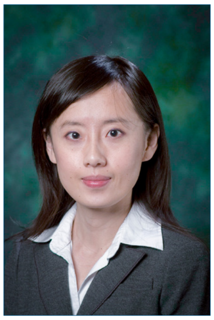

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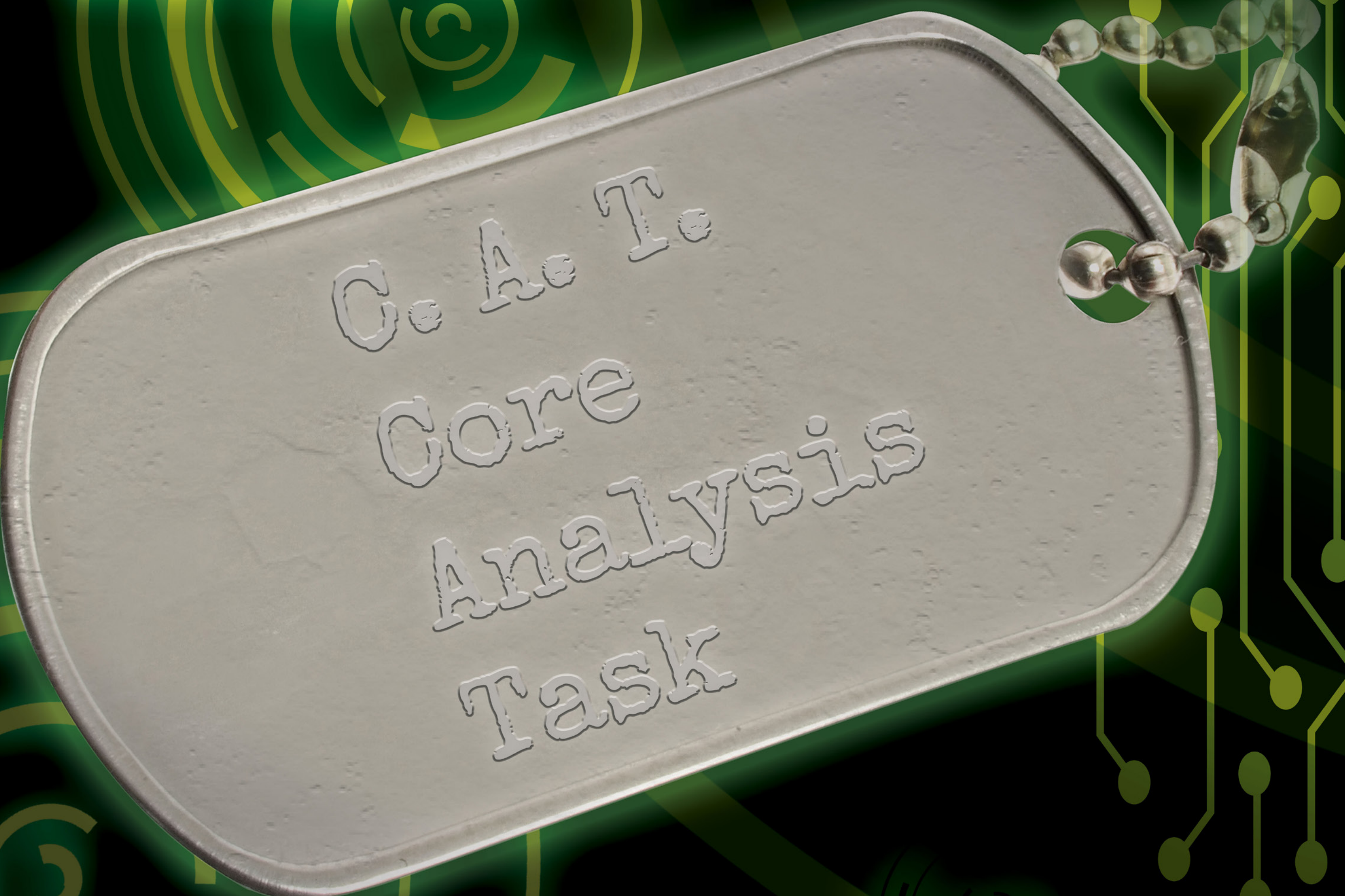
Maturing Opportunities for the Warfighter



The Core Analysis Task allows government agencies to quickly interface with industry and academia and gain access to the latest research and technologies with the potential to help the warfighter.

For more information, contact HDIAC at outreach@hdiac.org

Technical Inquiry Highlight: Pip

HDIAC received a request for technical information and analysis on cultural research addressing oil pipeline surveillance using unmanned aircraft vehicles in Nigeria.

Background Information

The U.S. Department of Defense spent more than $3 billion on UAV technology since 1990. [1] In addition to DoD's investment, UAVs are used by the U.S. government for firefighting, search and rescue, imagery and mapping, media, communication, intelligence gathering, border surveillance and infrastructure inspection. [2] As UAV technology gains popularity, commercial usage of this capability also increases. Businesses are using or considering using UAVs for deliveries, internet services, news reporting, photography, agriculture, population data and search and rescue missions. [3] Use of drones to survey infrastructure is cost effective and efficient. For example, in Alaska, it takes UAVs 30 minutes to survey a three kilometer section of pipeline versus five to seven days with a human survey crew. [4] Drone accuracy and efficiency is recognized and is therefore wanted in other parts of the world.

Nigeria is the 13th largest producer of oil in the world with 80 percent of its revenue coming from oil. [5,6] As a mono-economy, Nigeria relies on revenue from oil for economic stability and future growth. [7]

Protecting both infrastructure and oil assets is difficult with rampant theft and vandalism, especially in the Niger Delta. The Nigerian government and regional oil companies have a need for more effective oil surveillance; capable of monitoring vast areas of the nation's pipelines. Globally, UAVs [4] perform many industrial operations, including delivering supplies and surveying land and oil pipelines. [4,8]

Although a seemingly obvious choice, utilizing UAVs for oil security presents cultural concerns. Nigeria experiences culturally-based fear surrounding UAVs, as well as established corruption, where bank presidents, government officials, military officers and terrorist organizations benefit from oil theft. [5]

Resource Protection

Nigeria produces an estimated two million barrels of oil per day, with nearly 20 percent stolen daily. [5] Despite oil resources and a growing economy, Nigeria's Gross Domestic Product is more than $1 trillion, however the GDP per capita is only $6,000. [6] Protecting its oil production is therefore a priority for the Nigerian government.

As a result of increased corruption, vandalism and theft, the Nigerian National Petroleum Corporation opted for a "phase-rehabilitation of all the state-owned refineries." [10] The reconfigured strategy includes the Nigerian Army Engineering Corps securing and protecting pipelines while also providing survey capabilities. [11] This effort also includes distinct divisions among pipelines, storage and products marketing. [10]

UAVs for Surveillance

Of the 16,083 total Nigerian pipeline breaks in the last 10 years, only 2.4 percent were accidental ruptures, while vandals were responsible for the other 97.5 percent. [6] By taking the role of surveillance cameras, UAVs may prove an effective deterrent against oil theft. The United Nations uses drones in Africa to supply assistance and to remind terrorists groups and militants that they are being watched. [12] This preventative measure could be employed and be effective to deter oil thieves.

Cultural Implications

For decades, Nigeria has suffered from a societal and stigma-related culture of corruption. Government officials, military officers, security forces and militia groups stole oil not only for profit, but for power. [13] This culture of complicit theft is one reason Nigeria is implementing new methods to attempt to reduce corruption and illegal bunkering.

With the emergence of commercial utilization of UAVs to monitor pipelines and storage tanks, Nigeria stands to gain more control of oil security and profits. Unfortunately, the introduction of UAVs brings culturally-established fears forward. In 2014, Boko Haram, a terrorist organization, abducted 276 schoolgirls. The outcry for the girls' safe return resonated globally, and the United States sent support to Nigeria to help recover the girls. The United States also deployed UAVs from a base in neighboring Chad [14] and has plans to expand drone bases in Africa. [15] The use of UAVs in this instance raised awareness of drone surveillance capabilities and also increased fears of being watched. "Without touching anything, going anywhere near them, we're sending a clear message: we know where you are, surrender." [16]

Conclusion and Recommendations

UAVs will be a necessary step in securing Nigeria's pipelines. UAVs have the technological capabilities of visualizing, identifying and inspecting Nigeria's extensive oil infrastructure. The ability to detect and observe oil leaks and spills as well as record illegal activity will be paramount in moving forward to better the nation's economy. UAV surveillance will greatly benefit these efforts by providing a birds-eye-view of the process from beginning to end.

Nigeria's policy changes will begin to inhibit the established culture of corruption. By outsourcing security details and removing former militants from the process, Nigeria is making it clear that the future of its oil is directly tied to the future of the country. These efforts will continue to suppress institutional corruption.

From a cultural viewpoint, education is key to not only change societal expectations but also to reduce fear. As drone usage becomes more commonplace for commercial, military and humanitarian missions, a deeper understanding of the technological advancements will emerge.

UAV technology is readily available and viable for extensive applications. Increases in commercial use of UAVs will force addressing new regulations, policies, certifications and risk evaluations.

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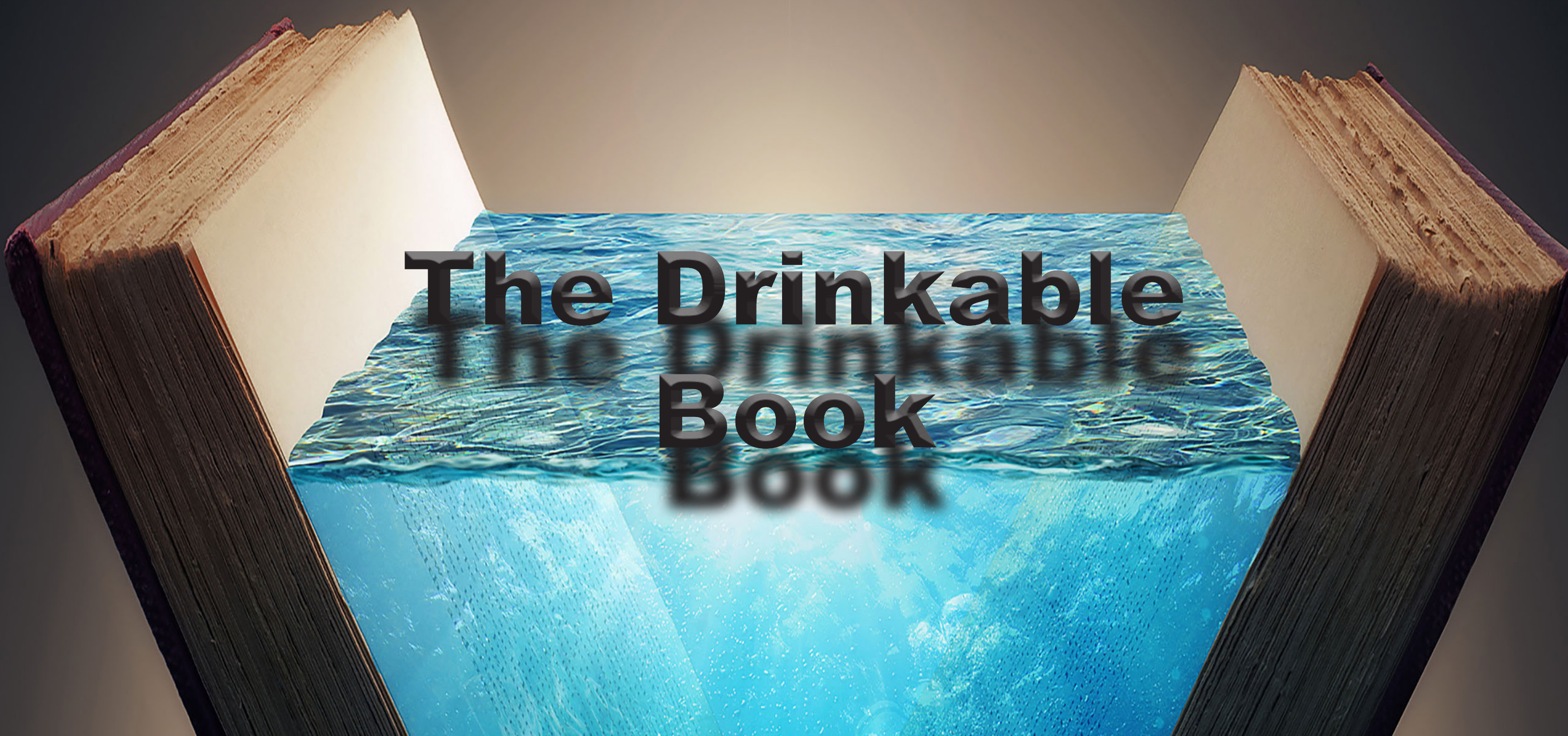

The Drinkable Book

Access to clean, safe and reliable drinking water is often taken for granted in industrialized countries but is still an obstacle to soldiers deployed in remote, underdeveloped areas and a challenge to basic survival throughout the developing world. Diseases such as cholera and typhoid, long since eradicated in areas served by modern water purification systems, continue to claim thousands of lives every year in emerging nations, like Kenya and Sierra Leone. Dr. Theresa Dankovich, a research scientist at Carnegie Mellon University, in concert with advertising agency DDB North America, devised a revolutionary concept dubbed The Drinkable Book. The project is designed to provide immediate relief in the form of emergency drinking water and offer educational safety information to allow its users to better utilize available water resources in the future. [1] It also has the potential to become a revolutionary tool for the Department of Defense.

The United States Army issues purification tablets containing iodine, halazone and chlorine to deployed soldiers to treat individual canteens of water. These tablets are relatively bulky, slow acting and less effective in low temperature water (sometimes creating the need to heat the water being treated) and in water with extremely high or low pH ratings. Under these conditions soldiers are recommended to double the number of purification tablets used per liter of water, increasing the purification time to as much as 35 minutes per canteen and adversely affecting the taste and odor of the resulting purified water. [2] The Drinkable Book offers a potential solution to these drawbacks by saving weight, acting relatively quickly, and creating no adverse effects in regard to taste or smell of the treated water.

The human health impact of contaminated and disease carrying water is shocking. Worldwide, waterborne diseases are the number one killer of children under five, and more people die from the consumption of unsafe drinking water than from all forms of violent behavior combined, including war. Unsafe or inadequate water, sanitation and hygiene methods cause approximately 3.1 percent of all deaths worldwide. [3]

From the outside, The Drinkable Book is indistinguishable from a normal book. It is approximately one and a half inches thick with 20 pages. But, each millimeter thick page is embedded with sliver nanoparticles, which are deadly to the waterborne pathogens and parasites that cause the deaths of about

3.4 million people each year but have no negative health effects on humans. [4] To use the filter the reader simply tears out the page, slips it into the filter holder, and pours contaminated water into filter. As the water passes through the page, microbes are killed by the silver nanoparticles. The paper kills more than 99.9999 percent of harmful microscopic organisms, which puts the resulting water on par with U.S. tap water for purity. Examples of bacteria destroyed by silver nanoparticles include cholera, E. coli, and typhoid. [1]

"Essentially," says Dr. Theresa Dankovich, the Carnegie Mellon Postdoctoral researcher who developed the filter paper, "the microbes come in contact with the silver in the paper and as a result they are killed by the interaction and the water is clean for us to drink." Dankovich invented the bactericidal silver nanoparticle paper concept at the heart of The Drinkable Book while completing her Ph.D. in Chemistry at McGill University in Montreal. In 2014, she co-founded the non-profit pAge Drinking Paper to complete the product development for this filter paper and to study the health effects of using such a water filter. [5]

Brian Gartside, a designer at DDB North America, took the paper filter concept and designed an easy to use system around it. Along with WATERisLIFE, a charitable organization helping to test the new technology in Africa, he also added the tips and directions for safe water usage and sanitation procedures on the pages, giving the book an educational component designed to prevent future perils, as well as to address short term water needs. By educating those in need of clean water on how to make the most of available resources and how to avoid waterborne illnesses, the Drinkable Book not only satisfies the immediate needs of the people it is designed to help but arms them with the knowledge of how to live more healthy lives on their own. [6]

Matt Eastwood of DDB said that the scientific principles behind The Drinkable Book will revolutionize water purification techniques around the world. "The product costs only pennies to produce, making it by far the most cost efficient purification method currently on the market. Each filter or individual page is capable of giving one person up to 30 days of clean water…which makes a single book capable of providing someone with clean water for up to one year." [7]

WATERisLIFE, a charitable organization, believes access to clean water is a human right and hopes the invention will change the world and help to provide clean water for everyone. The organization works closely with local governments and community organizations to focus on an integrated approach that ensures households, schools, orphanages and medical facilities have access to safe water, proper sanitation and hygiene programs, and continuing education in these areas. [8]

Each page contains two filters, and each filter can be used to treat around 100 liters of water. Field tests were conducted in Africa and Asia from 2013 to 2015 along with controlled laboratory tests and a full commercial release is expected within a couple of years, pending approval from the Food and Drug Administration.

The concept of water sterilization through nanoparticles appears to have tremendous commercial potential, as well as being a lifesaving humanitarian aid, due to the cost advantages over traditional water filtering products and the simplicity of use it offers. "It should be something that is widely used because it doesn't require electrical power and is very intuitive," Dankovich said. [7]

As the potential for water purification through nanoparticles continues to evolve the military applications will continue to grow as well. The potential of this technology to improve the health and wellbeing of soldiers' deployed to inhospitable climates where fresh water is not readily available should not be under estimated. By freeing them of the need to carry large amounts of purified water or harsh chemical purification tablets with them on patrols, they will be able to carry more equipment or to travel lighter to prevent fatigue. This system will also work more quickly than the traditional purification tablets and have no negative taste side effects on the treated water, which could prevent full consumption of the amounts of water needed to maintain hydration.

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Alternative Energy: Increased Options for Biofuel Production Using Yeast

By: Jamie H. D. Cate, Ph.D.

Although biofuel production has intensified in the last decade, liquid fuels derived from oil remain the largest contributor to transportation. [1] Thus, biofuels have yet to make a significant dent in mitigating climate change, which is due in large part to greenhouse gas emissions from fossil fuels. [2] And substitutes such as electric cars, compressed natural gas and hydrogen fuel cell vehicles remain niche contributors.

The U.S. Department of Defense is the largest government consumer of energy in the United States, with petroleum-based liquid fuels composing approximately two-thirds of the DoD's consumption. [3] The military is shifting toward renewable energy use as an operational imperative. Utilizing alternative energy sources, such as solar, wind and biomass energy, can increase warfighter efficiency, enhance energy security and cut installation and operational energy costs. Several military bases use renewable energy sources, like solar and wind farms, to offset energy costs and the DoD directs by 2025 at least 25 percent of any DoD facility consumption to come from renewable energy sources. [4]

Biological sources for liquid fuels have a long history. Alexander Graham Bell advocated for producing ethanol from plant biomass nearly 100 years ago. [5] His vision, however, is only partially realized due to technological, economic and policy challenges. Two large-scale sources of ethanol are now well developed: the use of sugarcane juice and corn starch. Sugarcane ethanol is widely adopted in Brazil, and presently provides a large proportion of the liquid fuel needs for the country. [6] Corn ethanol produced in the United States expanded rapidly in the past decade, having reached over 15 billion gallons per year. [7] The Army is exploring the use of a fuel cell that runs off of corn ethanol. [8]

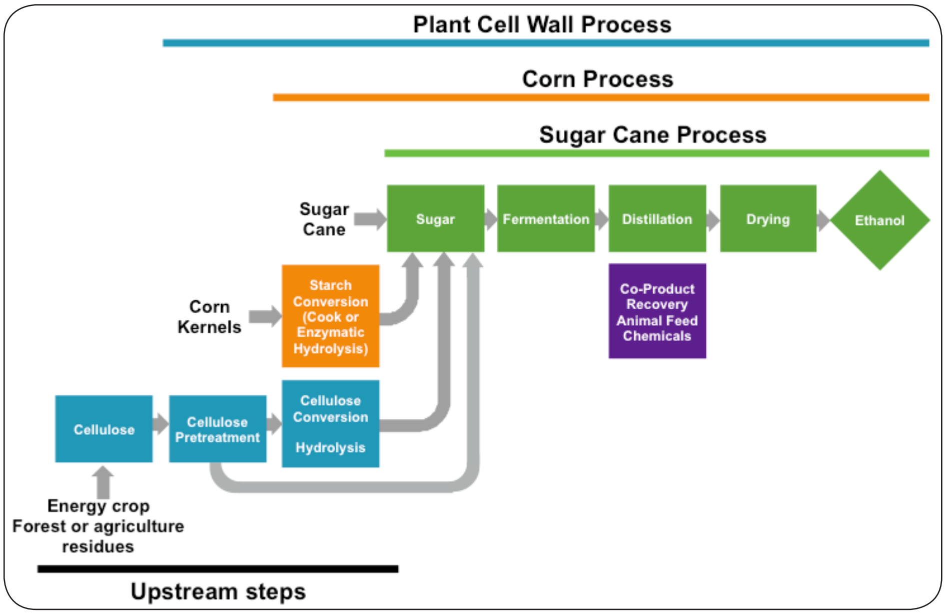

Figure 1. Comparison of bioethanol production processes. Ethanol production from sugarcane, corn starch, and plant cell walls shares similar downstream steps, but different upstream steps add cost to the use of corn starch and plant cell wall material. (Figure adapted from schematic by Dr. Bruce Dale, Michigan State University/Released)

Sugarcane and corn ethanol production, however, are highly sensitive to economic conditions, and have been impacted by fluctuations in the price of oil and the value of the dollar. Further, the American car fleet limits the amount of ethanol that can be blended into the fuel mix, the so-called "blend wall" of approximately 10-15 percent ethanol (E10 and E15 gasoline). [9] This limit is driving the search for biofuels that more closely mimic present hydrocarbons derived from oil.

A far more abundant source of liquid biofuels, termed "lignocellulosic biofuels," could come from perennial plants, such as grasses or fast-growing trees, in the form of carbon fixed in the architectural component of plants–plant cell walls. In 2011, the Department of Energy extensively modeled how much plant biomass could, in principle, be used in the United States. [10] The DOE estimates that energy crops and food crop residues could provide more than 1 to 2 billion barrels of biofuel per year, or up to about 30 percent of the liquid fuel presently used in the United States. There are many economic, environmental and policy challenges, however, to scaling up lignocellulosic biofuels. [2,10]

The technological challenges for making biofuels from plant biomass is illustrated in Figure 1. Sugarcane juice requires the least pre-processing before it is fermented by yeast to make ethanol. A step up in technological difficulty and cost, ethanol production from corn requires the additional process of

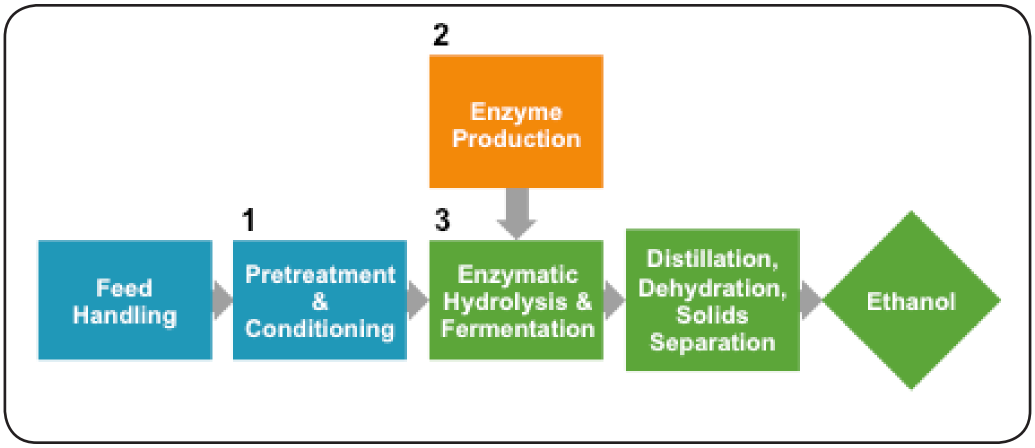

Figure 2. Simplified diagram of reference process of bioethanol production from corn stover. Separate reactor vessels unique to the use of plant cell wall material that require optimization are numbered 1-3. Reference scenario prepared by the National Renewable Energy Laboratory. [13] Other steps not shown include wastewater treatment, burner/boiler for power generation from waste biomass, and ethanol storage. (Released)

breaking down starch to soluble sugars before yeast fermentation. In the United States, corn ethanol production is highly optimized, but is still being improved, by consolidating starch breakdown with fermentation, for example. [11]

Making biofuels from plant biomass is far more complex than making corn or sugarcane ethanol (see figure 1). First, the plant biomass must be transported to a central processing plant, possibly requiring more than 1,000 square miles of agricultural output. [10] Once collected, the plant biomass must be "deconstructed" or broken down to release soluble sugars from the plant cell wall. Breaking down the plant cell wall requires thermochemical treatments, followed by the use of catalysts. Finally, the released sugars must be converted into a usable biofuel. Thus, although some companies have begun to roll out lignocellulosic ethanol production plants, the Energy Information Administration reports that only about 1.3 million gallons (or about 30,000 barrels) of ethanol were produced between January and July of 2015. [12]

How can lignocellulosic biofuels eventually be produced economically? Many unknowns must be addressed, ranging from how best to break down the plant cell wall to soluble sugars, to the question of which biofuels to make. Should the process be entirely chemical, for example as modeled by the National Renewable Energy Laboratory? [13,14] The main advantage of using an entirely chemical route is the prospect of leveraging scale-up knowledge from the chemical industry. Or would a process that combines biological and chemical steps work more economically, such as the recent rethinking of "acetone-butanol-ethanol" fermentation, followed by chemical upgrading? [15] The NREL devised a reference case for a biological process to convert plant biomass to ethanol (see figure 2). [16] The process uses a thermochemical pretreatment step to increase the exposed surface area of plant cell wall polymers and release the abundant 5-carbon sugar xylose. Pretreatment is followed by enzymatic breakdown of cellulose in the plant cell wall to release the 6-carbon sugar glucose. The enzymes, known as cellulases, are produced in large quantities in a separate reactor beforehand. Finally the xylose and glucose streams are combined in one reactor for co-fermentation by an engineered bacterium, Zymomonas mobilis. The reference case therefore requires three separate reactors, one for the pretreatment step, a second for cellulase enzyme production and a third for enzymatic breakdown of cellulose, followed by xylose and glucose co-fermentation (See Figure 2).

The NREL reference case presupposes the optimal way to convert plant biomass to ethanol should go through glucose and xylose, the most abundant sugars derived from the plant cell wall. But perhaps researchers should learn from nature how microbes consume plants. This is already true for the "cocktails" of cellulase enzymes that are used to break apart cellulose. [16] Many fungi, including those that make the cellulases, figured out how to degrade the plant cell wall and consume both the glucose and xylose components, but do not make biofuels themselves. For example, the fungus Neurospora crassa in nature normally degrades burnt grasslands. The parallel biochemical pathways N. crassa uses to degrade the plant cell wall and consume the resulting sugars have been identified (see figure 3). [17] N. crassa and many other fungi prefer to consume plant cell wall sugars as short polymers of glucose or xylose, called cellodextrins or xylodextrins, respectively. This natural preference could open up new options for how to produce biofuels from plant material.

Using synthetic biology approaches, the plant cell wall dedicated pathways were moved from N. crassa and related fungi to the yeast S. cerevisiae, to make ethanol by co-fermentation of the 6-carbon and 5-carbon sugars. All of these co-fermentations require more optimization, but they represent a number of new scenarios that hold promise. These include co-fermentation of 1) cellodextrins plus xylose [18], 2) cellodextrins plus xylodextrins, 3) glucose plus xylodextrins, or 4) sucrose plus xylodextrins [17] (see figure 4). In other words, there are now many more options to choose from compared to the NREL reference case. [16] All of these combinations require rethinking the upstream steps, and could significantly reduce the capital costs of a lignocellulosic biofuel facility. For example, they could lead to less intensive pretreatment and cellulase enzyme requirements. In the longer term, these could be combined with fermentation of other sugars present in the plant cell wall in lower quantities [19], and to produce biofuels other than ethanol that are more hydrocarbon-like. [13-15]

On the immediate horizon, there is substantial interest in Brazil to combine sugarcane ethanol production with lignocellulosic ethanol production. [20] This would increase the ethanol yield per hectare, and exploit the fact that leftover sugarcane stalks are already concentrated into large bagasse piles as part of the standard sugarcane ethanol production process. It is possible that xylodextrins could be extracted from bagasse with hot-water pretreatment and co-fermented with sucrose, with a minimal capital investment.

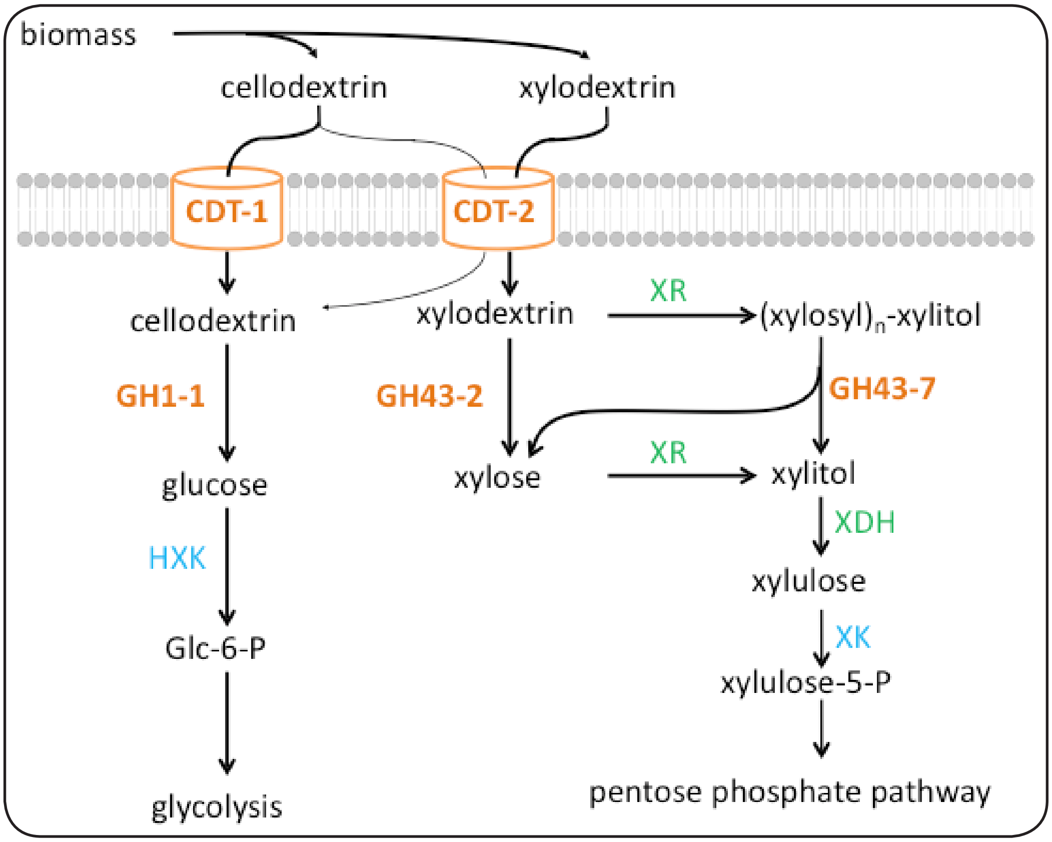

Figure 3. Parallel pathways for oligosaccharide consumption in the fungus Neurospora crassa. The sugars derived from the plant cell wall are cellodextrins from cellulose, and xylodextrins from hemicellulose. Intracellular cellodextrin utilization requires the transporters CDT-1 or CDT-2 along with ß-glucosidase GH1-1 and enters glycolysis after phosphorylation by hexokinases (HXK) to form glucose-6-phosphate (Glc-6-P). Intracellular xylodextrin utilization also uses CDT-2, and requires the intracellular ß-xylosidases GH43-2 and GH43-7. The resulting xylose is then assimilated through the pentose phosphate pathway via xylose/xylodextrin reductase (XR), xylitol dehydrogenase (XDH), and xylulokinase (XK). (Figure adapted from Ref. 14/Released)

[17] Although further development of yeast strains capable of co-fermenting different combinations of 6-carbon and 5-carbon sugar streams will be required, the new combinations with cellodextrins and xylodextrins open up many pathways to explore to realize a fully economical lignocellulosic biofuels process.

Often times the most elegant solutions for technical problems come from nature. The newly proposed methods to produce biofuels produced from perennial plants may allow DoD the opportunity to utilize renewable energy and meet mandated goals. The military shift towards renewable energy is both a political and operational imperatives. DoD's move toward more efficient alternative energy can increase efficiency, enhance security and lower installation and operational energy costs.

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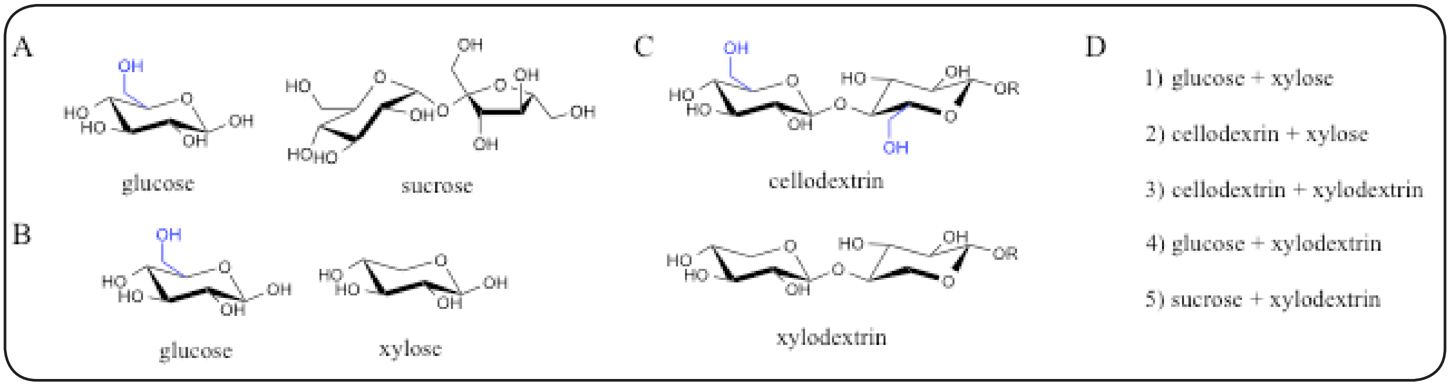

Figure 4. New options for co-fermentation of plant cell wall-derived sugars. A) Glucose and sucrose used in first-generation bioethanol production from corn and sugarcane, respectively. B) Glucose and xylose derived from cellulose and hemicellulose proposed for use in co-fermentation of plant cell wall material (ref NREL). C) Oligosaccharides released and consumed by fungi in nature. D) Expanded options for co-fermentation of C6 and C5 sugars. In A) – C), the extra hydroxymethyl in glucose units (C6 sugar) compared to xylose units (C5 sugar) is shown in blue. R=H for cellobiose, xylobiose; R=additional glucose or xylose units for longer cellodextrins and xylodextrins, respectively. (Released)

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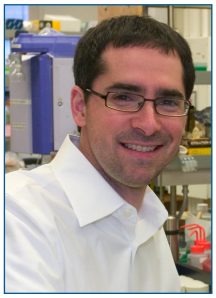

Jamie H. D. Cate is professor of biochemistry and molecular biology and of chemistry at the University of California, Berkeley. He is also a Faculty Scientist at Lawrence Berkeley National Laboratory. His research focuses on the production of biofuels, as well as protein synthesis. He is interested in understanding how microbes extract carbon from plant biomass, an abundant resource for a sustainable chemical industry. Dr. Cate's lab is using synthetic biology and systems approaches to retool baker's yeast for biorefinery applications. The lab also probes the molecular basis for protein synthesis, and the structural basis for antibiotic action on the ribosome. Dr. Cate received his Ph.D. in molecular biophysics and biochemistry from Yale University, and has been on the UC Berkeley faculty since 2001. He received a Searle Scholars award in 2000 and was honored with the 2008 Irving Sigal Young Investigator Award of The Protein Society.

Calendar of Events

January/February 2016

CBRN First Response 2016
CBRN
Bristol, UK
1/26/2016-1/27/2016

Solar Summit Mexico
AE
Mexico City, Mexico
1/27/2016-1/28/2016

Florida Emergency Preparedness Association Annual Meeting
CIP/HD
Daytona Beach, FL
2/1/2016

9th Annual EMAT Leadership Symposium
HD
San Marcos, TX
2/7/2016-2/10/2016

ASM Biodefense and Emerging Diseases Research Meeting
M/CBRN
Arlington, VA
2/8/2016-2/10/2016

Annual MN Governor's Homeland Security and Emergency Management Conference
HD
Minneapolis, MN
2/9/2016-2/11/2016

Biometrics for Border Control: Impact of Immigration and the Mobile Society
B
Rome, Italy
2/16/2016

Smart Energy Summit
AE
Austin, TX
2/22/2106-2/24/206

Identity Management and Biometris Summit
B
Miami, FL
2/23/2016-2/25/2016

NY State Mergency Management Association Annual Winter Conference
HD
Syracuse, NY
2/23/2016-2/25/2016

NCT CBRNe Europe
CBRN
Amsterdam
2/23/2016-2/25/2016

March/April 2016

Res/Con New Orleans
CIP/HD
New Orleans, LA
3/1/2016-3/3/2016

CBRNe Summit Europe
CBRN
Paris
3/2/2016-3/4/2016

ConnectID 2016: Physical and Digital Identity in the 21st Century
B
Washington, D.C.
3/14/2016-3/16/2016

Power Grid Resilience Summit
CIP/HD
Philidelphia, PA
3/21/2016-3/23/2016

BioPharma Asia Convention
M
Singapore, Korea
3/22/2016-3/24/2016

2016 Virginia Emergency Management Symposium
HD
Newport News, VA
3/29/2016-4/1/2016

Southwest Border Security Week
HD
South Padre Island, TX
3/30/2016-4/1/2016

International Biomass Conference
AE
Charlotte, NC
4/11/2016-4/14/2016

SPIE Defense + Commerical Sensing 2016
HD/CBRN
Baltimore, MD
4/17/2016-4/21/2016

2016 Partners in Emergency Preparedness Conference
HD
Tacoma, WA
4/19/2016-4/21/2016

28th Annual Missouri Emergency Management Conference
HD
Branson, MO
4/19/2016-4/22/2016

Hannover Messe
HD
Hannover, Germany
4/25/2016-4/29/2016

Homeland Defense & Security Information Analysis Center
104 Union Valley Road
Oak Ridge, TN 37830

HDIAC Call for Papers

The HDIAC Journal is a quarterly publication, focusing on novel developments and technology in the alternative energy, biometrics, CBRN, critical infrastructure protection, cultural studies, homeland defense and security, medical and weapons of mass destruction fields.

- Articles must be relevant to one of the eight focus areas and relate to Department of Defense applications.
- Articles should be submitted electronically as a Microsoft Word document.
- We require a maximum of 3,000 words.
- All submissions must include graphics or images (300 DPI or higher in JPG or PNG format) to accompany the article. Photo or image credit should be included in the caption.

HDIAC is now accepting abstracts and articles for consideration for the 2016 publications. For more information, contact the Managing Editor at publications@ hdiac.org

2016 Publication Schedule

Volume 3; Issue 2
(Publish June 2016)
Abstract deadline: 1/4/16
Article deadline: 2/1/16

Volume 3; Issue 3
(Publish Sept. 2016)
Abstract deadline: 4/15/16
Article deadline: 5/16/16

Volume 3; Issue 4
(Publish Dec. 2016)
Abstract deadline: 7/15/16
Article deadline: 8/15/16