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ASSISTING DEVELOPMENT ACROSS THE AFRICAN CONTINENT USING SPACE APPLICATIONS

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This paper will present the conclusions of International Space University's 2012 Masters program Team Project on Space and Africa. Remote sensing applications, spin-off technologies, and even self-sustaining commercial industries can bring benefits to many countries. In addition to those countries with an already well-established space industry, there exists a need to demonstrate how space can be used in assisting in the sustained socio-economic development of underdeveloped or developing nations, and answering the question of how these applications or technologies can assist countries with little or no space development. The Identifying and Developing Effective Applications of Space for Africa (IDEAS for Africa) team from the 2011-2012 Masters program at the International Space University in Strasbourg, France, has assessed how space can contribute to improve the sustained social and economic development in Africa. Using three dissimilar African countries as examples, the IDEAS team proposes space spin-off technologies, satellite applications, and space business potentials applicable in fostering development. Each area: spin-off technologies, satellite applications, and space business potentials - was analyzed for each of the three example African nations. South Africa, Morocco, and Liberia were selected not only based on their respective levels of space development, but also because they differ geographically, socially, economically, and politically. Consequently, a broad comparative analysis can be performed by investigating the effects of space activities for these three selected countries. Additionally, due to the dissimilarity of the three countries, parallels can be drawn to other nations which are at comparable levels of development, to show how space can be used to drive development across the African continent.

I. INTERNATIONAL SPACE UNIVERSITY

The International Space University (ISU) is the world's foremost educational institution devoted to fostering the development of tomorrow's global space industry workforce. It was founded in 1983 by Bob Richards, Peter Diamandis, and Todd Hawley, and has a principal campus in Strasbourg, France. ISU conducts both a one year Masters Program in Strasbourg and an intensive Space Studies Program held in different locations around the globe each year.

This year's Masters Program included over 40 students from around the world. As part of their curriculum, they were divided into two separate year-long team projects. The authors of the present paper were members of the Space and Africa project, which imagined the myriad ways that the global space industry and the technological innovations it has developed over the past half century can improve the lives of the over 1 billion peoples of Africa, and aid Africa's development in the coming century.

II. INTRODUCTION

With its breathtaking landscapes, pristine environments, and unique flora and fauna, the continent of Africa is beauty defined. But the forests being destroyed by logging and remade into agricultural lands, or the industrial pollution spilling into rivers and streams tell a different story. And while Africa is known for its incredible wilderness and rich biological diversity, irresponsible management and poaching threatens this magnificent and irreplaceable heritage. The continent's rich natural environment also means that catastrophic floods bring havoc to homes while droughts threaten animal populations and even jeopardize human communities.

Africa is a celebration of world-renowned colors and tremendous festivals. But no African celebrates when regional, national, and international conflicts tear families and countries apart. Africa is a land of ancient tribal customs, and cutting edge research - it is a land of democracies, monarchies, and dictatorships. Above all else, Africa is a land comprised of many lands - a continent of contrasts. No single viewpoint describes it. Africa escapes easy generalizations and defeats broad categorization.

As the team spent time investigating Africa, our understanding and appreciation grew and grew. We wondered how "space" fits into this already rich and deeply human story, filled with human stories and bursting with tragedy and wonder and promise and hope. The IDEAS for Africa team faced quandaries and uncertainties very early on in our process. Was our project *Africa for space*, or *space for Africa*? In other words, should the aim of our project be investigating and understanding the ways that Africa can contribute to the global efforts of space exploration, to take a place at the table with other continents and states with existing and emerging space capabilities? A project along these lines envisioned African launch sites for European and Asian rockets, and using Africa's vast mineral resources to cheaply fund and assemble space systems.

We firmly rejected this approach.

After learning about the political, economic, health, and environmental concerns in Africa, the focus of our investigations and the aim of our efforts is to promote space for Africa — space first and foremost for the needs, and in the interests, of Africans.

In contemplation of the daunting tasks and ethical implications behind this report's proposals, Jacques Arnould, the philosopher in residence at CNES, advised the IDEAS for Africa team that:

"space is not a solution... space is a way to make real the policy that you introduce."

In light of this, the policy of our group is that research and applications from the space sector should be used to improve lives and strengthen communities.

We hope that this paper and the final report on which it is based reflect with clarity and fidelity our beliefs, findings, and proposals. The possibilities contained herein are as aspirational as they are practical, and Space for Africa can be as achievable as it is inspiring. We look forward to working with partners from Africa and from around the world in making these changes real, and bringing our ideas to the people of Africa.

The following paper is a summary of the work done during the ISU's Masters Team Project. For a full description of the project visit our team website*.

III. STUDY FRAMEWORK

Proposing space-related solutions with the potential to ease Africa's problems is not a clear task, and first warrants a better understanding of problems afflicting life in Africa, their root causes, and the obstacles to alleviating them. An investigation was undertaken into the different sociopolitical aspects of Africa, which hereinafter will be referred to as "focus areas". Following this, three African countries to serve as representations of the whole continent were selected to illustrate how the proposals put forward can be applicable across the continent. These representative countries will hereinafter be referred to as "target countries".

III. I Focus Areas

Our literature review revealed that the focus areas most impacting life on the African continent are agriculture, education, energy, environment, health, and STEM (Science, Technology, Engineering, and Mathematics). While our analysis is grouped into these specific focus areas that affect life in Africa, understanding life in Africa includes the realization that these topics are in fact interlinked. The following provides a basic overview of these various situations throughout the continent.

Agriculture is the most important sector in Africa's economy, employing approximately 60 percent of its labor force. When compared to a three percent world average, African labor provides almost a quarter of the continent's Gross Domestic Product

* For the Final Report visit *http://africa.isunet.edu* and click on *Final Report*.

(GDP)[1]. However, agricultural development suffers from unpredictable environmental conditions and the challenge of a rapidly increasing population. Despite recent improvements, African food security remains a major issue.

Access to quality education still remains a challenge in Africa. Unfortunately, schools across the continent often lack basic facilities. Universities suffer from overcrowding, regional conflict, and staff being lured abroad by higher pay and improved living conditions. For primary education, the situation is improving with more children being enrolled in schools, especially in Burkina Faso, Madagascar, Niger, and Zambia[2]. There are disparities in education for different races, and women typically have lower education levels than men.

The main energy sources in Africa are coal, oil, and hydroelectric power. Coal consumption takes the lead, whereas hydroelectric potential remains vastly under-exploited. This homogeneous generation profile, constrained by minimal financial investments and lacking regional links to facilitate power trade, has resulted in a severe energy crisis in many countries across the continent[3]. Growth in capacity has stagnated across the African continent over the past several years. As a comparison, the total energy generation across the continent remains less than that of Spain. Given current trends, the electrification of most African countries will not be achieved by 2050[4].

The diverse and complex nature of Africa's territory poses great challenges. Desertification and droughts are two of the major environmental challenges Africa faces. Every year, the continent loses four million hectares of forests due to desertification[5]. The main cause of desertification is deforestation, with trees being cut to meet energy needs and expand agricultural land[6]. Northern Africa is one of the driest areas of the world, receiving only seven percent of Africa's total precipitation. Eastern Africa has been a frequent sufferer of the most severe recent droughts[7].

Due to the lack of trained medical professionals and improper practices, the African healthcare system is incapable of meeting the basic needs of its people. In addition to the human lives lost, the poor healthcare system slows economic development. Resources which could otherwise have been committed to economic growth are instead put towards combating infectious disease, maternal death, and malnutrition. African countries have yet to benefit from the many advances made in medical research, and often rely on traditional medical practices. Every year, several thousands of Africans die of diseases that can be inexpensively prevented and treated. A recurring theme among reports on the continent's progress is that for it to develop economically, it needs to implement public health policies and practices with a proven efficacy[8].

Technological advancements are going to play a key role in providing sustained development in Africa. This technological progress will require skilled professionals in the fields of science and engineering. Due to the current socioeconomic situation in Africa, highly qualified professionals often leave their home country to seek employment in the developed world. Approximately a third of all African scientists and engineers live and work abroad. Scientific and educational development across the continent is crucial to prevent Africa's "brain drain"[9].

III. II Target Countries

From the project onset it was evident that it would be impossible to prescribe one space application for the whole of Africa. Different countries and regions have different needs and capabilities. In order to manage this, three target countries were selected to act as representations of the whole continent. The three target countries (South Africa, Morocco, and Liberia) met our requirements for their disparate characteristics. With their geographical locations (northern, southern, and central Africa), their climate and environment (desert, semi-arid, and tropical rainforest), their governance (republics and a constitutional monarchy), and in their levels of development and challenges, they reflect the diversity across Africa. As a result, the IDEAS for Africa team believes that South Africa, Morocco, and Liberia emerge as very good representatives of common African realities, and are excellent discussion points for this project.

South Africa

The Republic of South Africa is arguably one of the most developed countries in Africa. The climate varies across the country, with the eastern region being sub-tropical and the west being semi-arid, making for difficult farming conditions[10].

The economy of South Africa is the largest in Africa. It relies on natural resources, agriculture, and advanced manufacturing. This is especially true for the aerospace and defense industry which are well established in South Africa. Apartheid-era sanctions resulted in South Africa developing its own autonomous defense industry. Education in South Africa is very well established, as it constitutes the single largest federal budget expense (5.4 percent). However, South Africa is also the country with the highest number of crimes per capita in the world, with approximately 16,000 murders, 15,000 attempted murders, 66,000 sexual assaults, and 200,000 assaults in 2010 - 2011 for a population of slightly less than

50 million. Although the country has developed tremendously in recent years, there are areas for improvement[10].

South Africa has a renewed interest in space and in 2010 reestablished its space agency to coordinate the country's space efforts and implement its National Space Strategy. The South African National Space Agency (SANSA) has three major functions:

1. Implement the national space program
2. Advise the Minister for Science and Technology on space issues
3. Acquire, assimilate, and distribute space-derived data[11]

The 1993 Space Affairs Act established the South African Council for Space Affairs (SACSA). SACSA administers all legal aspects of South African space activities. It maintains a registry of all current objects launched into space by South Africa[12]. However, the establishment of space activities in South Africa did not originate from the development of SACSA. It was a combination of the work completed by academics in constructing satellites, and the necessity to develop autonomous launching capabilities as a direct result of Apartheid-era sanctions against South Africa. The National Party's government developed a series of launchers (RSA-series) as well as the Overberg Test Range (in Afrikaans *Overberg Toetsbaan* or OTB) to handle South Africa's defense needs when the international community was restricting trade with South Africa[13].

Morocco

The Kingdom of Morocco gained its independence from France in 1956, and is an active member of the Arab and international community. With its largely Muslim and Arabic-speaking populace, Morocco is regionally considered more a part of the Middle East than of Africa. To this end, Morocco is the only African country that remains not a member of the African Union, although Morocco is still deeply involved with African diplomacy. While a member of the United Nations, it is not subject to the International Court of Justice. Morocco’s legal system derives from French roots and Islamic law[14].

Morocco is an emerging country with a supply and demand based economy, although specific sectors still remain under strict government control. Morocco's economy is the fifth largest in Africa after South Africa, Algeria, Nigeria, and Egypt. The main constituents of the economy are agriculture, industry, and the services. It must be remarked that the Moroccan tourism sector is becoming increasingly prominent[15].

Due to its relative proximity to Europe, and its position between the U.S. and Asia, Morocco is a country that attracts a great deal of foreign investments, including the aerospace industry. There are currently over 100 European and U.S. companies working in Morocco, including European Aeronautic Defense and Space Company (EADS), Boeing, The Safran Group, Daher, Souriau, and Zodiac Aerospace. These companies create more than 7,000 jobs in Morocco[16], with GIMAS (*Groupement des Industries Marocains Aéronautiques et Spatiales*) playing the role of managing and organizing the aerospace sector[17]. In 2001, Morocco launched its first remote sensing microsatellite. Dubbed the Maroc-Tubsat, it was built by the Technical University of Berlin[18].

Liberia

The Republic of Liberia is located in West Africa and was established in 1847, 25 years after the first group of freed African-American slaves arrived on the west coast of Africa. The country has been devastated by two lengthy civil wars which began in 1989 and finally ended in 2003. In 2005 President Ellen Johnson Sirleaf was democratically elected, in a period when the unemployment rate had reached a record high of 85 percent. A relative stability has been achieved under the new government, but the country’s severe and ongoing socioeconomic and security problems remain unresolved. The presence of the UN is evident throughout the country, with a force of more than 18,000 peacekeepers. Liberia has a population of approximately four million people (July 2011 estimate), with a growth rate of around three percent per annum. Approximately 44 percent of the population is under the age of 14, and the total life expectancy is around 57 years, among the lowest worldwide[19].

IV. IDEAS FOR AFRICA

The IDEAS team will assist Africa in improving its socio-economic development by evaluating the impact, distribution, and utilization of:

1. Spin-off technologies
2. Satellite applications, and
3. Space business potentials

which address the following focus areas:

1. Agriculture
2. Education
3. Energy
4. Environment
5. Health
6. STEM

Our proposals are designed to deal with major problems in the whole continent, but they are more suitable for application in certain countries rather than in others. The following will describe the proposals to address each focus area and a recommendation for a target country of recommendation is then made. It is important to note that the intent is that these target countries can act as representations of other countries in African with similar challenges, and thus the reader can draw parallels to multiple African countries.

IV. I Agriculture

As such a vital component of the economy of many African nations, agriculture cannot be overlooked when investigating how space can benefit the continent. The following proposals are designed to address the focus area of agriculture by incorporating satellite applications and space spin-off technologies, and will be shown to be applicable in all three target countries.

FarmaBooths

FarmaBooths are small information centers in strategic locations so that local farmers from four or five villages can easily access their information. Based on the Village Resource Centers (VRC) concept in India, the centers will provide up-to-date information from satellite imagery about crop distribution, irrigation management, and soil nutrient variation tailored for African farmers. The connectivity gap between the satellites and the FarmaBooths will be filled in by the Pan-African e-Network. This network provides satellite internet connectivity to rural areas across Africa, including the target country of Liberia.

Within Liberia rice and cassava are the main staple crops and rubber, palm oil, and cocoa are the dominant export crops. Despite high proportions of the Liberian population involved in agriculture, there is only enough self-produced food to feed half of the population[20]. Fig. 1 shows the percentage of Liberians involved in food production relative to the percentage of Liberians self-reliant on their own food production.

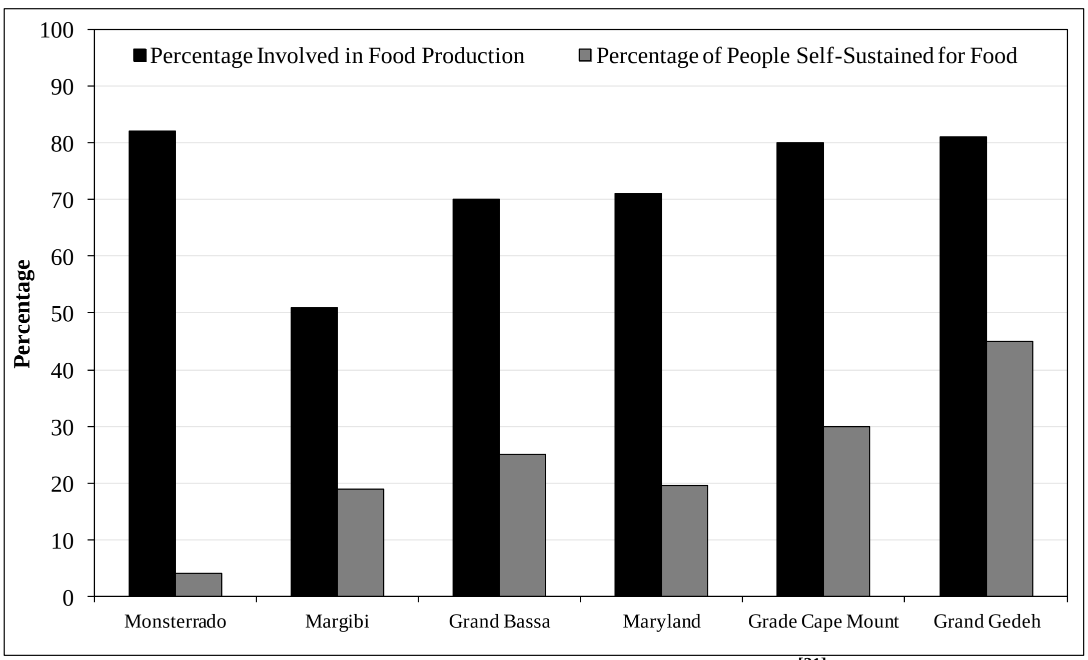

Fig. 1: Liberia food production in various counties[21]

FarmaBooth information centers can be tuned depending on geographic location, variety of crops, and environmental characteristics of the surrounding area. For example, information provided to croplands in more arid regions would provide advanced details about water reservoirs, whereas crowded agricultural zones would have access to mapping information to ensure farmers were respecting property rights.

The FarmaBooth system has four major components: the space-segment providing both remote sensing and communication capabilities, the data interpretation centers, a centralized FarmaBooth facility, and the individual FarmaBooths themselves as data accessing facilities. In terms of the space segment, there is already adequate space-based infrastructure to provide both the remote sensing needs and related communication requirements. The already existing infrastructure includes, for example, AVHRR (Advanced Very High Resolution Radiometer) on the NOAA satellite, HRG (High Resolution Geometrical) on SPOT5, LISS (Linear Imaging Self Scanner) on IRS, MODIS (Moderate Resolution Imaging Spectroradiometer) on the Aqua and Terra satellites, or the TM (Thematic Mapper) instrument on Landsat. The data interpretation centers convert raw satellite data into easily understandable information for farmers and this component will be provided in collaboration with the VRC data interpretation centers in India. The centralized FarmaBooth facility is to be located in a major city center for training sessions and teleconferences. Finally, the individual FarmaBooths are to be located in rural locations and are where the information is disseminated to the farmers.

The flow of information for the FarmaBooths involves seven steps:

1. An Earth observation satellite acquires the image
2. Images are sent to ground stations
3. Data is sent to processing and interpretation centers
4. Interpreted data is returned to ground stations
5. Interpreted data is uplinked to a communication satellite
6. Recommendations and map data is sent to the FarmaBooths
7. Occasional feedback from farmers is sent to interpretations centers

The target country of Liberia was selected for implementation of the FarmaBooth proposal largely because of its insufficient food production capabilities as well as its involvement with the Pan African e-Network[†].

Organically Derived Colloidals

A spin-off from NASA's Space Shuttle Program, Organically Derived Colloidals (ODCs) are molecules extracted from the shell of marine animals that reduce fungal infections and provide nutrients to crops. Combined with Aeroponic growing techniques, this spin-off allows for higher yield of crops with less water usage.

ODC is an organic disease control product that helps to reduce plant losses by mitigating the effect of invasive species. It simulates a plant's natural defense system in the presence of pathogens, and then switches off when the disease is eliminated. The main element of the ODC is Chitosan, produced from the exoskeleton of crustaceans (like lobster, crab, and shrimp). The ODC molecules will first cling to cells in the tree roots. Once these molecules have attached to the plant cell receptors, a chemical response is activated throughout the plant that stimulates photosynthesis and helps to overcome environment stresses, like invasive species[22].

ODCs can be applied at any time of the plant life cycle - to seedlings before planting when the seeds begin to sprout, or during the entire planting season. ODC are a biologically safe plant supplement that strengthens the plant structure to prevent fungal infections. They contain no enzymes, hormones, petrochemicals, acids, manure sources, and do not harm plant mineral uptake. ODCs have been applied to various crops including yams, potatoes, coffee, corn, carrots, cauliflower, soybeans, spinach, peas, papaya, melon, cucumbers, rice, tomatoes, and apples[23]. The effects of ODC on tomatoes are shown in Fig. 2.

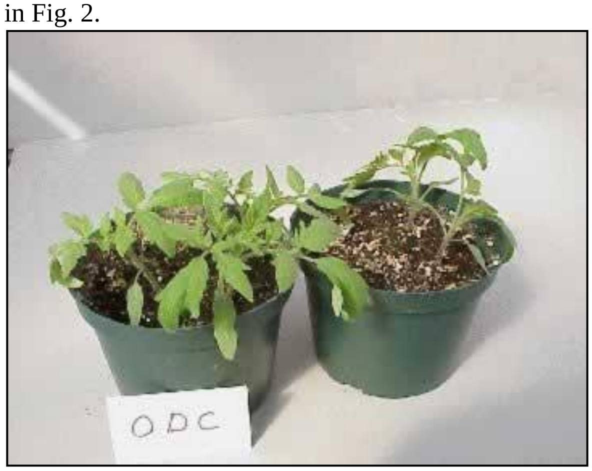

Fig. 2: Tomatoes under same growing conditions (ODC treated on left)**[23]**

The degree of implementation will depend on the particular needs and conditions that exist in any African country. One of the main advantages of ODCs is the inexpensive nature of the product and the almost immediate effects on plant growth. The cost per acre of ODCs is around 25 USD and can reduce the sprouting time by over 50 percent (from 28 to 10 days for tomato plants)[22].

Moreover, countries that have difficult growing conditions because of desert environments (*e.g*. countries within the Sahara desert) can use ODC in conjunction with an Aeroponics growing system as this drastically reduces water usage. Aeroponics systems use up to 95 percent less water than traditional growing methods[23]. However, Aeroponics

[†] *See Also* IAC-12-B1.5.8x13132 – *Desert Movement Predictor And Farmabooths: Two Earth Observation-Based Applications For Pan-African Development*, which discusses FarmaBooths and the Desert Movement Prediction Center in greater detail.

can be prohibitively expensive for developing nations as the cost can be upwards of 5,000 USD/m^2 or 25 USD/plant.

Within the three target countries, Liberia would not be applicable for such an application both because of the large initial investment and because growing conditions in Liberia are currently underutilized. This means that there is not yet the need for a means of improving crop output. In both Morocco and South Africa, desert conditions mean that water conservation and effective use of space is of paramount importance.

Implementation in Morocco may however be faced with challenges. Although a major portion of the Moroccan economy relies on agriculture, the population uses many archaic techniques and may be reluctant to embrace new systems. The high initial investment required for Aeroponics may be prohibitive for the emerging country. The most efficient approach is likely an ODC system that is slowly introduced, with a population gradually adapting from their traditional practices to the Aeroponics system. While implementing ODCs and Aeroponics may not be initially feasible, Morocco will ultimately need to apply sustainable agricultural methods that work with their desert conditions.

Finally, in South Africa, the conditions exist for the implementation of both ODCs and Aeroponics. South Africa has very poor conditions for crop growth, with only approximately 11 percent of the land being arable[10]. Furthermore, the higher GDP in South Africa over other African countries means that the high initial investment for the Aeroponics system is not prohibitively expensive. As such, the implementation of both ODCs and Aeroponics in South Africa is recommended.

IV. II Education

A self-made space infrastructure is almost non-existent in Africa. An African space workforce is in short supply and almost all the countries lack dedicated educational institutions for space. As a result, most countries do not train their own engineers and those with the potential often pursue education abroad, reinforcing brain drain. This section will highlight proposals to address the focus area of Education and will have application in Morocco.

African Space Education Center

In October 2011, the International Astronautical Congress was held for the first time on the African continent. More than 5,000 people from widely different educational and professional backgrounds (including space agency officials, senior executives, space industry professionals, and academics) gathered in Cape Town, South Africa. Conference papers were presented on space for Africa, and the participants were hopeful towards the improvement of space capabilities across the African continent. To capitalize on this excitement and the topic of space and Africa, it is crucial to recognize the potential and importance of building a domestic African workforce that will benefit from space education.

An African Space Education Center (ASEC) has the potential to be developed in one or multiple African countries. In order to be effective however, the host nation will need to have a strategic location, current space capabilities, established aerospace industry, and economic and political stability. For these reasons the target country of Morocco is believed to be a suitable host nation for an ASEC. Morocco is strategically located between mainland Africa and Europe, and between the America's and Asia. There are currently more than 100 American and European space and aerospace companies with a presence in the country. These companies use Morocco as a base for their international logistics[16]. Additionally, Morocco has a remote sensing education center offering courses to domestic and regional users. The center offers short GIS (Geographic Information Systems) and remote sensing courses throughout the year. The courses cover all aspects of remote sensing and its various applications[24].

This center could open the door to greater space education in Africa, and serve as a beacon of learning to Africans interested and inspired by space. It would allow Morocco and its neighbors to create the space infrastructure and workforce for more advanced space endeavors. As a business case, it could be duplicated in many other countries and showcase the demand for space education, and drive international cooperation with space agencies and centers from around the world. The success of any business is tied to many external factors. Monitoring and understanding political effects is crucial when establishing any business. It must also have a sustainable competitive advantage for the customers[25]. Morocco has a stable monarchist government and its laws actually attract investment from abroad[26]. King Mohammed VI has ruled since King Hassan's death in 1990. He is seen as a modernizer for the country as he introduced many economic and social reforms[27]. Morocco spends 5.6 percent of its total annual GDP on education[15]. Education until age fifteen is both compulsory and free in Morocco[14], and there are fourteen higher education universities in Morocco. Consequently, Morocco is well situated to host a space education center.

The ASEC will provide education on engineering, sciences, management, policy, economics, law, and satellite applications. This will allow the students to be able to gain a complete background in space to ensure they are fully capable of participating in the space profession. To provide this, the ASEC will promote a "hands-on" approach to education. Hands-on training is a crucial aspect that enables space professionals to be industrially competent. The vision and mission of the ASEC will be:

Vision:

- To become a premier space education center focused on value creation through "hands-on" learning and international collaboration

Mission:

- To provide high quality space education, learning, and research to African regions' global partners
- To serve as a hub for international dialogue and collaboration
- To drive synergy between educational institutes and its shareholders (i.e. industry needing qualified professionals) towards value creation

IV. III Energy

The high cost of electricity generation due to the small scale of demand restricts development in many African countries. High efficiency electrical power plants require significant upfront investments and are expensive to upkeep. This forces nations to rely on less efficient but less expensive coal-fired plants. The following will describe a proposal to address the small-scale demand of energy in African and will have an application in the target country of Liberia.

Solid Oxide Fuel Cells

A fuel cell is a device which converts potential energy in a fuel source into electrical energy through an electrochemical reaction. Fuel cells have been used in spaceflight as a source of electrical power for the spacecraft and also as a source of water, as the by-product of the most common fuel cell types is water[28].

There are various types of fuel cells which differ in their fuel type, operating temperature, and materials used. The spin-off proposed is a Solid Oxide Fuel Cell (SOFC) which uses natural gas as an input fuel (although SOFCs can be modified to be fuel flexible), operates at a very high temperature (typically in the range of 800^{o}C), use a solid oxide or ceramic electrolyte (for conducting oxygen ions from the cathode to anode), and do not require an expensive platinum catalyst to initiate the electrochemical reaction as do fuel cells that operate at lower temperatures. However, it is difficult for SOFCs to change their electrical output. Therefore, SOFCs are best suited to provide baseload power, which is a power generation source that provides a continuous level of power to meet the minimum electricity demands[28].

The basic structure of an SOFC is shown in Fig. 3. There are two basic reactions that occur in a fuel cell; a reduction reaction and an oxidation reaction. A reduction reaction is when free electrons combine with an oxidizer (which is molecule, atom, or material that easily accepts free electrons) to produce a product. Conversely, an oxidation reaction is when a reductant is split into a product and free electron. The combination of these two reactions is called a Redox Reaction.

The reduction reaction for an SOFC occurs on the cathode layer, whereas the oxidation reaction occurs on the anode layer. The electrolyte layer allows for the flow of the reduction reaction product, while not allowing for the passage of electrons. This means that the electrons generated in the oxidation reaction at the cathode size have to pass through a circuit, creating electricity[28].

The main advantage of using a SOFC in developing African nations is that they are highly efficiency on low scales, meaning that infrastructure can be built near their locations of consumption.

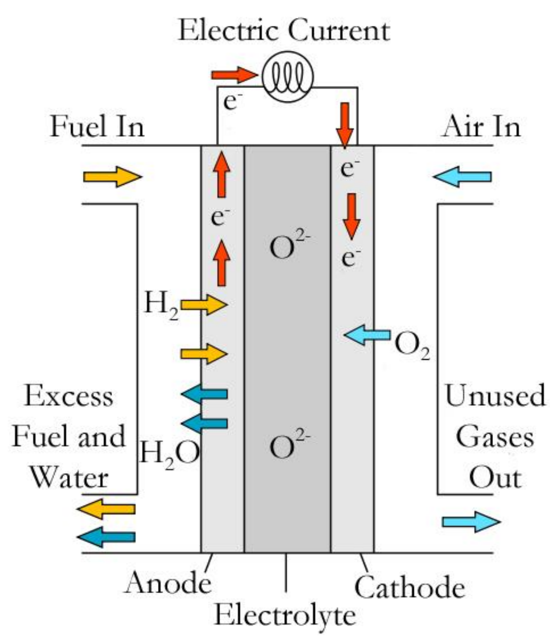

Fig. 3: Operating principle of an SOFC**[29]**.

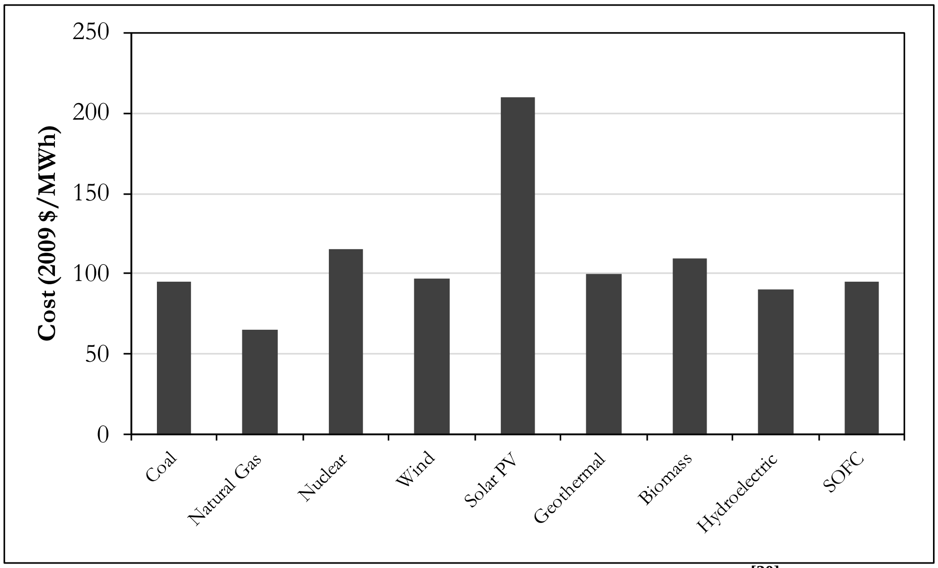

Fig. 4: Cost of energy generation by various sources[30]

The cost of generation is however slightly more expensive than hydroelectric or advanced natural gas plants, as shown in Fig. 4. This is true though only when these facilities are built on large-scales with a high efficiency, which is not the current situation in many African countries. For example in the target country of Liberia, electricity generation costs can be in excess of USD 400 per MWh[31]. The degree to which SOFCs can be implemented in the three target countries, and across the rest of Africa, will vary according to a variety of factors, including availability of financing, local electricity demand, local electricity tariffs, fuel availability, and existing infrastructure.

As a consequence of the recent development in South Africa, the country faces an energy supply crisis which has resulted in rolling blackouts, and cuts of electricity to neighboring countries[32]. In response to this, the state-owned electricity company Eskom has called for investments of USD 45 billion for new plants and distribution networks to reach the goal of universal electricity access by the end of 2012[33]. Most electricity generation in South Africa is from coal-fired power plants. As such, marketing SOFCs as an alternative to existing coal plants is not recommended, as it fails to benefit from existing infrastructure and expertise, is more costly, less profitable, and ultimately fails to take advantage of the small scale generation capabilities of SOFCs. To meet the large scale of the demand, South Africa is transitioning from its almost entirely coal-powered energy sector to pursuing conventional nuclear power generation[33]. Due to the lack of any proven natural gas resources and the lack of natural gas distribution infrastructure[34], the introduction of SOFCs into South Africa for public electrical generation would likely be met with limited success. There have been proposals to artificially convert some of the South Africa's coal resources into natural gas, which could be used to generate electricity in a more environmentally-friendly way. However, the added cost of converting coal to natural gas would make SOFC-generated electricity even less competitive against coal and nuclear power.

In Morocco, SOFCs would also likely not achieve significant market penetration, due to the lack of domestic natural gas supplies and infrastructure. Furthermore, the country is almost completely dependent on its neighbors for its energy supply, with approximately 96 percent of its electricity needs coming from direct low-cost electricity imports[35]. The low cost and easy access to foreign electrical generation would make SOFCs for public grid generation unfeasible. Current electrical infrastructure investment in Morocco is focused on renewable sources of energy such as solar and wind generation[36]. As such, unless the current trend in funding changes to promote SOFCs, it is unlikely that this technology could be implemented economically in Morocco.

In Liberia, SOFCs would be well suited to meet the demand for inexpensive electric power generation at a small scale as most electricity is currently generated on a local scale[31]. The most significant barrier to such a system is the availability of SOFC fuels and the lack of infrastructure to affordably distribute it to the geographically disparate locations. As Liberia also lacks access to natural gas, an alternate fuel such as octane or diesel could be used, but this would require modifying the SOFCs to tolerate such fuels.

In general, SOFCs will provide the greatest benefit to nations that have access to natural gas, have sufficient demand for small-scale power generation, and have access to sufficient funding, either from domestic public finances or from alternative means. While these requirements may seem sufficiently restrictive to prevent SOFCs from succeeding at all in Africa, there are certain niche locations in which they could be very advantageous. One such application is in supplying reliable baseload power to the commercial enterprises in Nigeria in place of less efficient conventional backup generators. Although Nigeria has made great strides in improving access to electrical power, it suffers from chronic power shortages, due to under spending on maintenance and growth in demand[37]. Consequently, surveyed Nigerian enterprises have reported power losses 320 days per year, forcing over 60 percent of them to rely on backup power generators.

IV. IV Environment

Africa's diverse and unique natural environment must be cherished and preserved for future generations. Its careful stewardship is also crucial to any sustainable social and economic development. To preserve and protect Africa's priceless natural animals and natural environment, two space-related solutions are offered to combat poaching and the encroachment of deserts, with application in the target countries of South Africa and Morocco.

Anti-Poaching

Poaching is the hunting or catching of game or fish that is either on another's property or is subject to environmental protection. Illegal poaching is a major environmental problem in Africa.

Several species are currently under significant pressure from poaching in Africa. For example in South Africa, the rhinoceros is hunted for its horns and the perlemoen (a large sea snail) is harvested as a delicacy. Many African countries have anti-poaching programs in which national park and law enforcement officers participate. However, sparse geographical distributions of animals and their low population densities makes enforcement difficult. To stem the tide of poaching, methods are required to patrol vast areas or survey large populations for signs of poaching activity.

Satellite systems are well-suited for poaching control due to their potentially wide coverage capabilities. For example, Iridium and GPS cover the entire globe, allowing animal tracking all over the planet. To reduce the number of poaching incidents, a system needs to be established in which those who hire poachers, and those who buy poached products, are found. To stop these poaching syndicates, a real-time system of tracking poaching events needs to be implemented.

The IDEAS team proposes a system for real-time monitoring and response to poaching by using Global Navigation Satellite System (GNSS) and satellite communication technology. Macro species like the rhinoceros would be equipped with satellite tracking collars, provided with heartbeat sensors, accelerometers, and microphones. Information from these sensors would be relayed to law enforcement agents to inform them if the animal is running or has been killed, indicating a poaching incident, as well as an alert for tell-tale gunfire sounds. For micro species like the perlemoen, the use of hydrophones anchored to a rock near a known colony location is a more effective way to detect poachers. The hydrophones would provide alerts for the sound of small boats and rifles, once again indicating a poaching event. The overall benefit of the proposed collar and hydrophone buoy designs are the provision of real-time poaching activity information to law enforcement officials. This will allow personnel to respond immediately by proceeding to the location of the poaching event and confronting the poachers, setting up roadblocks and ambushes near the location, or by deploying aircrafts to track the poachers. These responses will greatly increase the chances of poachers being caught, which in turn increase the chances that the syndicates behind the poaching can be identified and dismantled.

One of the main benefits of the anti-poaching system will be to prevent further damage to the African environment. Aside from the obvious moral obligations, Africa has a significant economic necessity to protect the environment, as its degradation will lead to reduced income from activities such as tourism.

The prevalence of poaching in South Africa is quite high and it is well known that this act is extremely detrimental to the country. However, that is not to say that this problem does not exist in either Morocco or Liberia. In Morocco, illegal fishing is a major issue with swordfish commonly being poached for food[38]. Within Liberia, the issue of illegal poaching of elephants is a major problem. Since the 1980s, approximately 95 percent of elephants have been poached, with only approximately 1,000 currently remaining[39].

Desert Movement Predictor

In the arid regions of Africa, water resources are scarce and access to them is often unpredictable. This constraint and uncertainty in accessing the resource can increase human pressure on the environment, resulting in further water depletion. Desertification is a process by which fertile land becomes desert. Population growth, increased food consumption, and short-term economic interests all contribute to desertification. Other contributing factors include over-grazing, excessive firewood gathering, wasteland cultivation, inefficient use of water resources, excessive agricultural harvesting, and lack of environmental protections related to factories, mines, and transportation infrastructure. Human activities are not the only source of desertification, as natural climate effects from wind, water, salination, and freeze-thawing erosion also contribute[40]. Rehabilitation measures are often difficult and expensive, while prevention measures are cheaper but require management and policy approaches that promote the sustainable use of arid regions. If no countermeasures are taken, desertification will threaten future improvements in human well-being[6].

In the last 35 years several studies have attempted to understand wind dynamics (which pertain to the activity of winds to reshape Earth's surface) in the Sahara desert. Since the early 1970s, Landsat satellite images have facilitated the observation of inaccessible landforms in arid regions. These images have been used to recognize sand accumulations, identify different types of dunes, and observe sand dune movement. The near-infrared band best discriminates sand dunes from other surface landforms. These Landsat studies however were focused on specific locations in the desert and were always complemented by ground-truthing[41]. Landsat images have also been used to analyze large sand dunes. By using images taken in 1973, 1991, and 2000, Chinese scientists measured the rates of dune migration in the Gobi desert, and the evolution of dune areas and volumes[42].

Fig. 5: Landsat image of dunes approaching Noukchott, Mauritania.[43]

The IDEAS team believes that desertification across Africa can be combated and alleviated with an international Desert Movement Prediction Center, whose activities would include data acquisition from satellite operators, remote sensing data-processing and analysis, research on the physics of dune movement, as well as desert movement prediction and recommendations. There are a large number of satellites available to provide the required imagery and data products (*e.g.* Landsat, Aqua/Terra, SMOS, Meteosat, etc.). To assess and predict dune movements, both wind patterns and InSAR optical images are necessary.

Moreover, the Desert Movement Prediction Center is an application for the target countries of Morocco and South Africa as they are the ones affected by desertification of the three target countries and have the means to afford the USD 64 million project cost‡.

IV. V Health

Life and health are endangered in many African countries, and ingenious solutions from the space industry can be implemented to save and improve lives. Aside from the obvious moral imperative to improve the health of Africans, the poor conditions put unnecessary strain on the social and economic development across the continent. A space spinoff and an ingenious application of space-based technology can help Africans lead healthier and longer lives, and these can be applied to the target countries of Liberia and South Africa.

DHA Supplement

DHA (Docosahexaenoic Acid) is a dietary fatty acid that acts as a major structural fat in the brain and retina. DHA accounts for up to 97 percent of the Omega-3 fatty acids in the brain, and up to 93 percent of the Omega-3 fatty acids in the retina[44].

DHA acts to change specific cells properties, including cell membrane viscosity, elastic compressibility, permeability, and interaction with regulatory proteins. The combination of these promotes electrical signaling to the Central Nervous System (CNS). The result of this is increased signaling to the brain and an increase in learning ability and memory. High levels of DHA are deposited into the CNS during the early stages of life - notably the last trimester of pregnancy, first two months of infancy, and throughout the first few years of life[45]. Within the retina, DHA is found within the photoreceptive outer segments. Enhanced levels of DHA in this photoreceptive layer facilitate a faster response to stimuli, and therefore enhanced vision[46]. Without proper supply of DHA during the early stages of development, it can lead to impaired learning abilities and visual acuity[47]. The purpose of the DHA spin-off is to promote neurological and retinal development for various stages of life, including infancy, childhood, adulthood, pregnancy, lactation, and aging.

The DHA supplement is a spin-off technology that has the capabilities to be implemented in any one of the three target countries because of their common need to promote nutrition. However, the main application will be for the target country of Liberia. This is because of its large challenges in terms of food security and malnutrition in combination with the inexpensive nature of the DHA supplement at USD 25 for a two months supply.

‡ *See Also* IAC-12-B1.5.8x13132 – *Desert Movement Predictor And Farmabooths: Two Earth Observation-Based Applications For Pan-African Development*, which discusses FarmaBooths and the Desert Movement Prediction Center in greater detail.

It must however be stressed here that the DHA supplement was subject to a major controversy in the United States in 2008. During this time DHA was added to infant food formula, and at this time it was able to bypass US Food and Drug Administration screening processes. Following its release, there were reported cases of nausea, vomiting, diarrhea, increase liver size, and even sudden infant death syndrome. In total, there were 98 reports of such incidents. Therefore, prior to any introduction to African populations the effects of the DHA tablet need to be thoroughly scrutinized to ensure that it is safe for consumption[44].

Telemedicine Van

Telemedicine is a satellite application which provides healthcare services, and helps distribute medical information to remote areas. On the other hand a telemedicine van is a mobile telemedicine service which can perform diagnosis, apply therapies, aid disease preventative measures, and improve individual health education. The Telemedicine Van will comprise the ability for remote consultation, diagnosis, treatment, radiology, dermatology, and ophthalmology.

Fig. 6: Example of a Telemedicine Van[48].

By combining satellite communications, information technology, and modern medical sciences, it will enable rural African populations to have access to a higher quality of healthcare services than presently possible. Telemedicine vans are not a new concept, they have been previously implemented in Bosnia, Italy, and India. A program is currently underway to implement telemedicine vans in Zambia[49]. The Telemedicine Van will enable patients in remote areas access to national and international medical specialists in medical centers located in urban areas and abroad, while also providing the capabilities for storing and management of clinical data.

This proposal is relevant for all three target countries, but would most likely see the highest degree of implementation in South Africa because of its relatively high costs of upwards of USD 400,000 per van. The proposed Telemedicine Van would be equally applicable to many other African countries that face problems of insufficient medical healthcare for remote and rural areas. Modifications to the van could be made to better support incidences of HIV infection (*e.g.* equipping the vans with HIV medication or the ability to perform HIV testing) depending on the region of implementation.

IV. VI Science, Technology, Engineering, & Mathematics

STEM industry and education within African will help reduce the number of highly-skilled workers from leaving the continent to seek opportunities in other countries. The following proposal will address the focus area of STEM with application in the target country of South Africa.

Overberg Test Range

During apartheid-era sanctions in the mid-1980s, South Africa developed its own autonomous launching facilities at the Overberg Test Range (OTB). The facility was built to handle up to ten Low Earth Orbit launches per year, but was cancelled in 1994 along with the entire Republic of South Africa space program[50]. Without significant governmental assistance, no commercial entity could re-establish the OTB into a full launching facility. As such, it is recommended that the OTB is initially developed into a sounding rocket research facility, dubbed the Overberg Sounding Rocket Research Facility (OSRRF).

Developing the OSRRF will provide a boost to the prestige of the South African space industry, laying the foundation for the nation to become a full space fairing nation. It will establish the country as a hub of science and technology advancements in Africa, and will help to further reinforce South Africa as a leader in space development on the continent. The establishment of a commercial sounding rocket research facility will allow engineers, scientists, and technicians to gain experience in rocket design, testing, and construction. These skills will be necessary in the future to fully use the OTB without incurring the large risks associated with the full development. It will also enable skilled workers to remain in South Africa and reduce the detrimental economic effects of the national brain drain. There are many positive political effects that will result from such a project within the African continent. By allowing individuals from other countries to participate on a project of this magnitude, stronger international relations between South Africa and the rest of the participating African countries can be established. South Africa has established itself as a strong leader in Africa and is committed to ensuring African cooperation. However, in the refurbishment of the OTB, local industries and professionals should be given priority. Finally, the OSRRF could also create educational and outreach links with the local community, for example by organizing field trips and open days for students from the aforementioned ASEC.

Because this proposal is by necessity located in the target country of South Africa, the most immediate impacts of it will be within South Africa. This also comes with the added benefit that the project can receive sufficient funding as it is expected that the project would cost upwards of USD 16 million over five years in order to launch sounding rockets with similar performance to NASA's Terrier-Malemute (see Fig. **7**).

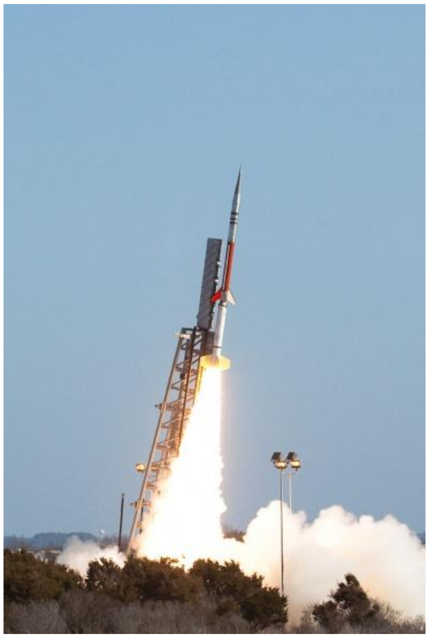

Fig. 7: NASA's Terrier-Malemute sounding rocket.

Having said this, there are also indirect benefits to the rest of the continent. The educational nature of the OSRRF will have profound impacts across the continent in terms of promoting youth involvement in the space industry. Furthermore, establishing the OSRRF as a location where researchers from across the continent can come and use the resources will promote cooperation between South Africa and the rest of the continent.

V. CONCLUSIONS

The twenty-first century can be the century of African development, driven by space technologies, and driving further space innovation. The ideas we propose for Africa are ripe to become realities.

Realizing the complexity and diversity of life in Africa, the IDEAS for Africa team first grouped our concerns in six focus areas of research – agriculture, education, energy, environment, health, and the STEM fields. We then chose three African countries to represent the wide range of African nations and their individual characteristics - South Africa, Morocco, and Liberia. We divided our research into three categories: space-based spin-off technologies; applications of satellite technology; and space business potentials.

Spin-off technologies hold great potential to improve the quality of life in developing countries. In particular, they are advantageous in countries that cannot afford to directly invest in developing their own domestic space assets. Organically Derived Colloidals and Aeroponics have been shown to increase crop yields and reduce water requirements. DHA tablets have been demonstrated to increase brain functionality. Finally the Solid Oxide Fuel Cells offer low-cost and efficient small-scale electricity generation.

Satellite applications have the ability to increase quality of life in the countries that can afford to deploy them. For example, a multipurpose facility for gathering and distributing space-based agricultural information (named FarmaBooths) would allow localized communities to take advantage of modern farming practices and optimize land use. The proposed Telemedicine Van allows isolated communities to access advanced medical care. A Desert Movement Prediction Center could enable governments to make informed decisions in response to desert movement. Satellite-based anti-poaching systems could provide real-time information to local law enforcement agencies and animal rights groups, and help protect endangered species such as elephants, rhinoceros, and perlemoen.

We found that Africa has significant potentials in reviving and commercializing the Overberg Test Range for sounding rocket launches. Lastly an African Space Education Center could provide education services and hands-on learning, raising African capacity in high-tech fields.

Our recommendations all have three critical elements in common. They address problems in Africa that hinder growth and development, they use space technologies that have a significant advantage over existing terrestrial technology, and they are practically implementable. It is our hope that these recommendations will stimulate both African leaders and space professionals to fully exploit the promise that space holds for Africa.

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