



The GreenLab Research Facility: A Micro-Grid Integrating Production, Consumption and Storage of Clean Energy

*Bilal Mark McDowell Bomani
Glenn Research Center, Cleveland, Ohio*

*Malik Elbuluk
The University of Akron, Akron, Ohio*

*Henry Fain and Mark D. Kankam
Glenn Research Center, Cleveland, Ohio*

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National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

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Bilal Mark McDowell Bomani
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Malik Elbuluk
The University of Akron
Akron, Ohio 44325

Henry Fain and Mark D. Kankam
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Abstract

There is a large gap between the production and demand for energy from alternative fuel and alternative renewable energy sources. The NASA Glenn Research Center (GRC) has initiated a laboratory-pilot study that concentrates on using biofuels as viable alternative fuel resources for the field of aviation, as well as, utilizing wind and solar technologies as alternative renewable energy resources, and in addition, the use of pumped water for storage of energy that can be retrieved through hydroelectric generation. This paper describes the GreenLab Research Facility and its power and energy sources with recommendations for worldwide expansion and adoption of the concept of such a facility

1.0 Introduction

The GreenLab Research Facility focuses is on optimization of biomass feedstock that uses algae and halophytes as the next generation of renewable aviation fuels. The unique approach in this Facility is the achievement of optimal biomass feedstock through climatic adaptation of balanced ecosystems that do not use freshwater, do not compete with food crops or use arable land. In addition, the GreenLab Research Facility is powered, in part, by using alternative and renewable energy from photovoltaic and wind technologies which reduces the major environmental impact of current electricity sources. The excess energy from wind and solar is stored by pumping water to a reservoir which is connected to a hydroelectric power generation system. The ultimate goal is to have a 100 percent clean energy laboratory which, combined with biomass feedstock research, has the framework in place for a self-sustainable renewable energy ecosystem that can be duplicated anywhere in the world and can, potentially, be used to mitigate the shortage of food, fuel and water.

A solution to solving the world's food, fuel and water problems is needed today. While our research concentrates primarily on aviation fuel, there needs to be a concerted effort in the area of food and water as well, which lead us to come up with the Big 3 at GRC. To provide a green solution to the food, fuel and water crises; we do not use freshwater, do not compete with food crops and do not use arable land, which are the keys to what we think is an alternative, renewable and sustainable concept that can be implemented on any scale.

The projected growth of aviation depends on fueling where specific needs must be met. Safety is paramount and together with political, social, environmental and legacy transport systems requirements, alternate aviation fueling becomes an opportunity of enormous proportions, driven by conflicts between energy, food and freshwater demands, population growth, and climatic changes.

2.0 Alternative Fuels

By 2026, the world's liquid fuel (Refs. 1 and 2) demand is projected to grow by 20 to 25 percent, implying an increased U.S. demand from over 20 million bbl/day (2007) to 24 million bbl/day. In order to meet that demand with alternative fuels, even if one could grow algae on the open seas fed by continent-sized nutrient streams under the most opportune of conditions and convert it to oils, the equivalent volume demand would require nearly half the Gulf of Mexico or 0.8 million km. This assumes equivalency between refined barrels of plant oil and petroleum algae production.

By 2026, the world's jet fuel consumption is also projected to grow from 95 billion gal (2007) to around 221 billion gal (836 billion liters) per year (Ref. 3). Replacing 10 percent of aviation fuel with a renewable jet fuel would be similar in scale to current world-wide liquid biofuels (ethanol and biodiesel) production.

Achieving the (2026) goal for a 70 percent decrease in fuel burn in future aircraft (Ref. 2), would imply annual aviation fueling requirement of less than 66 billion gal (250 billion liter). Yet it would, also, require an additional decade or more to impact the aviation fleet and a biomass-fuel area equivalent of about 1/3 Gulf of Mexico.

The need for replacement fueling and the effects of biofuels on both legacy and future aircraft performance and design have been established in prior publications (Refs. 4 to 7). These publications clearly illustrate the conflicts between fuel types and the crops plus crop land necessary for alternate aircraft fueling. The aviation industry requires specific mobility fuels, and cannot replace jet fuel with current renewable fuels (ethanol, higher alcohols, pyro-oils, biodiesel, or hydrogen electricity). Industry is therefore pursuing new, large-scale, secure, sustainable biofuels within several “do no harm” restraints including (i) not competing with arable land or freshwater resources needed for food/feed production, (ii) low carbon footprints that do not lead to deforestation, and (iii) not engendering adverse environmental or social impacts.

Two tons of jet fuel generates over 1.6 tons of carbon and over 2½ tons of water when burned. Globally, aviation fuel has been growing at about 4 percent per year, despite a 1 percent per year improvement in airplane fuel efficiency. The resulting high-altitude cloud formations and carbon footprint (CO₂ emissions) are of increasing concern to the commercial aviation industry which has set a goal that future growth in the industry should be carbon-neutral. Thus, renewable jet fuels are a critical need for this industry. The Commercial Aviation Alternative Fuels Initiative (CAAFI) and commercial aviation industry have set a goal of certifying a blended renewable jet fuel in the 2009 to 2012 time frame. To reach this ambitious goal, a program is underway to establish the technical feasibility, environmental sustainability, and eventual commercial viability of renewable biojet fuels. The basic technical feasibility of synthetic paraffinic kerosene (SPK) jet fuels produced from coal or natural gas, or of hydrogen-treated renewable jet fuels (HRJ) produced from vegetable oils or similar sources (now called hydrogenated esters free fatty acids HEFA-2011) having the same properties as conventional jet fuels has already been proven through several flight demonstrations by the U.S. Air Force, commercial airline partners, and four aircraft engine OEMs (original equipment manufacturers). The next stage is to develop secure scalable, sustainable, and economically viable feedstock for biojet fuels that satisfy the aircraft industry’s “do no harm” constraints, and reduce their reliance on petroleum-based fuels.

We are a society addicted to hydrocarbons. Our planet is gripped by our addiction to hydrocarbon energy generation sources. We need to rely on biomass fueling because it will do the following:

- Reduce hydrocarbon addiction

- Reduce CO₂, NO_x, etc., nano-particulate, altitude H₂O clouds, and emissions health and climate hazards
- Reduce foreign control of our future
- Require cooperative world-wide investments
- Require a paradigm shift in source and use of energy

Economic growth, testing, and projections of biomass production must address these fueling source changes in the face of worldwide issues:

1. Population is expected to grow 40 percent in 40 to 50 yr.
2. Aviation is expected to grow at 4 percent/yr.
3. 95 billion gal jet fuel were used in 2007 with 220 billion gal projected for 2026; replacement or even low-percentage blends require huge investments and huge biomass production.
4. Projected fuel burn reductions: air traffic management (ATM), 15 percent; future aircraft, 50 percent; future engines (intercool, recuperator), 25 percent (must respect laws of thermodynamics)
5. A combination of legacy aircraft, future ATM and future fleet implies a fleet (2026) with less than 40 percent fuel burn reduction
6. CO₂ goal of 80 percent reduction with no increase in other emissions
7. Aviation ground rules limit fueling options to “do no harm.”
8. Given above issues 1 to 5, goals for 6 and 7 cannot be met.
9. Aviation and fuel industries recognize 8; however, the space program does not.
10. Given issues 1 to 9, will aerospace grow, decline, or equilibrate?
11. Alternative fueling requires a paradigm shift in the conception, source, use of energy, *and* its funding. It will cost more with reduced dependence on oil/coal/gas/nuclear.
12. If *serious* consideration is given to issues 1 to 11, biomass fueling could provide a resolution to issue 10, using multiple sources, (even without projected 2026 aircraft fuel burn reduction goals or fuel economy improvements in power and transportation goals).
13. Our resources are 97 percent seawater, 43 percent arid land, and a solar source of energy
14. Our goals are to conserve freshwater and arable land and to protect our food supply, health, and climate through climatic adaptation of ecological cycles.

The challenge for us is to make our fuel resources secure, sustainable, economically viable and sufficiently available. The questions, issues and problems addressed lead to concluding that we must use Earth’s most abundant natural resources, which are biomass, solar energy, arid land (43 percent),

seawater (97 percent) with nutrients (80 percent), plus brackish waters and recovered nutrients to resolve the environmental triangle of conflicts between energy, food, and freshwater. Also, we must mitigate ultrafine particulate hazards. Such accomplishment requires a paradigm shift. We must develop and use solar for energy (in the form of virtually any renewable fossil fuel replacement resource: photovoltaic, thermal, wind, and drilled geothermal); biomass for aviation; and hybrid-electric-compressed air mobility fueling with transition to hydrogen and hybrid-electric in the long term.

3.0 Alternative Energy Sources

Presently, most of the world’s energy supply comes from coal, fossil fuels and nuclear sources. In spite of the increasing issues of resource limitations and environmental pollution, these sources continue to be important in providing energy for the next few generations. The increasing global demand for energy and for decrease of environmental pollution has prompted alternative or clean energy sources which do not

depend on fossil fuels. The high demand, also has a tolerable environmental impact.

Alternative or renewable energy sources such as solar photovoltaic (PV), wind, wave, tidal, geothermal and hydroelectric energies seem to meet the requirement for clean energy. Figure 1 shows a sample of some world generating cites of different renewable energy sources. Although the energy generated by these resources exceeds that by fossil fuels, renewable energy sources have not yet become a major part of the electrical power system grid. Figure 2 shows the alternative energy sources as contributing 7 percent of the total generation of electricity in the world. The projection is to double this contribution within the next decade. The following paragraphs describe solution and recommendations for integrating alternative fuels and alternative energy concepts into a self-sustainable renewable energy ecosystem that can be replicated throughout the world. The key benefit of the approach is that it is truly a Green solution, meaning that it is Alternative, Renewable and, most importantly, sustainable with little or no negative impact on the environment (Refs. 7 to 10).

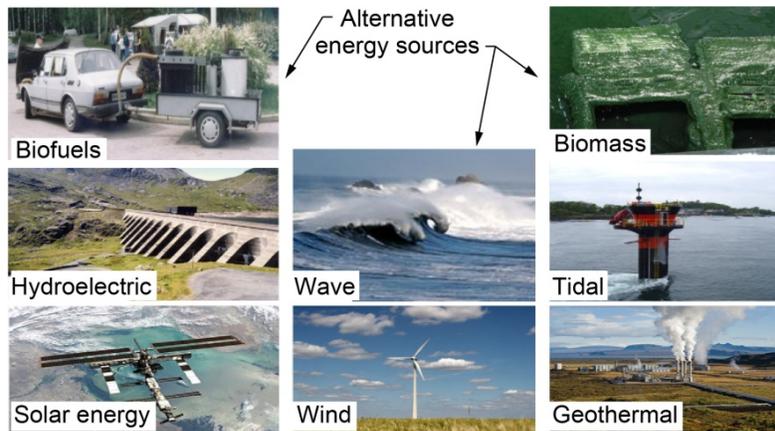


Figure 1.—Sample of renewable energy sources (Refs. 8 to 16).

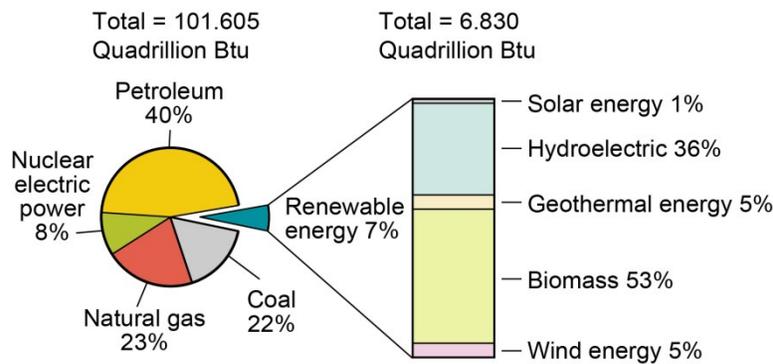


Figure 2.—Contribution of renewable energy sources to generation of electricity (Refs. 8 to 10).

4.0 The GreenLab Research Facility

As previously discussed, biofuels such as ethanol and biodiesel are renewable energy sources that are made from biomass materials. The use of biofuels has been gaining popularity over the past few years due to their ability to reduce the dependence on fossil fuels. They can be a viable option for sustaining long-term energy needs if they are managed efficiently. The GreenLab at GRC, shown in Figure 3, is a unique research facility that can be used to investigate possible future biofuel alternatives that are currently being researched and applied around the world. The main research objective is to develop biofuels for aviation. The program goals are to develop viable alternative choices for aviation biofuels production and refining processes, enable “well to wake and back” analysis, optimization, and performance testing of biofuels that meet Jet-A specifications, and provide unique bench scale laboratory for aviation-only biofuels feedstock research to provide independent assessments. The current research focus is on 3rd generation biofuel candidates: macro and microalgae, and selected halophyte species. The experimental techniques are coastline equivalent halophyte beds, open pond algae systems and photobioreactors. Figure 4 illustrates the NASA approach to producing aviation biofuels.

The GreenLab Research Facility is a facility that is patterned after the indoor biofuels laboratory. It serves as an example of a laboratory that is truly Green by having alternative, renewable and sustainable fuel, energy and technologies as its main focus. The GreenLab enables subjection of successful indoor plants and algae to real-world outdoor field trials. It poses several unique challenges that are discussed in this report. It also proved a benchmark for other GreenLabs around the world that desire to establish alternative

fuel and energy laboratories that do not use freshwater or arable land, and do not compete with food crops.

The primary research goal of the GreenLab Research Facility is the development of a climate adaptive biomass feedstock program that uses algae and halophytes for the next generation of renewable aviation fuels. More specifically, efficient iterative processes are being developed to use modeling, experimental verification and testing research to identify optimal algae/halophytes biomass candidates for aviation fuels. Additionally, processes and growth parameters are under study to improve feedstock properties and minimize complex and carbon positive refining steps to achieve greatest life cycle CO₂ reduction benefit and mitigate environmental risks.



Figure 3.—The GreenLab Research Facility at GRC.

Example: optimizing microalgae/cyanobacteria biofuel properties via transport processing and analysis.

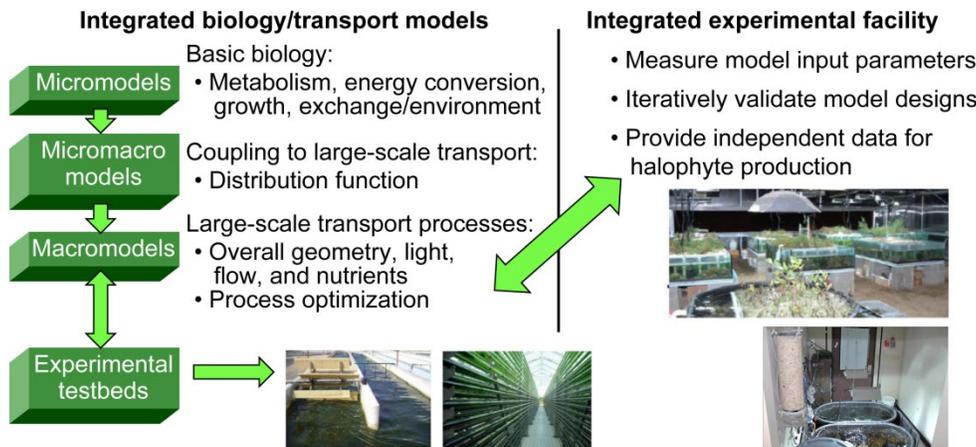


Figure 4.—NASA-Unique Approach to Aviation Biofuels.

5.0 Alternative Energy Conversion

Renewable or alternative energy sources such as photovoltaic (PV) and wind are clean technologies that can reduce the major environmental impact of current electricity sources. The electricity obtained from these energy sources is normally unregulated, and is not in a suitable form to be directly connected to the power system grids or to non grid-connected loads. Therefore, regardless of the power ratings of the renewable energy generation unit, it must be converted to a suitable form by utilizing power electronic converters and other controllers (Ref. 8). When connected to the grid, the role of power electronic converters and controllers is not only to convert electricity to a suitable form, but also, ensuring that the distributed generation unit connected to the grid will not create problems that can impair the quality of the power supply and the safety of all other equipment connected to the point of common coupling (PCC). Examples of these systems are discussed for solar and wind energy systems. Figure 5 shows typical power electronic converters arrangement for

solar systems. The unidirectional and bidirectional power converter are required to ensure that the energy storage devices (ESD) and loads can be supplied by the grid or by alternate energy formats such as the PVs.

For wind systems, several possible power electronic topologies used can be classified into two groups: direct-in-line wind turbines and doubly-fed generator wind turbines. An example of the first group that uses a squirrel cage induction generator is shown in Figure 6. The generator can be mechanically coupled to the wind turbine directly or via a mechanical gearbox. The variable frequency voltage of the generator is rectified and fed to the inverter to produce a constant frequency voltage that can be connected to the grid. It is important to note that at the present time, unsubsidized alternate energy solutions are cost prohibitive to implement on large scale. However, as petroleum prices rise, implementation options may change. This requires any proposed alternative energy system to be grid ready as well as power ready and that may also costs lots of money

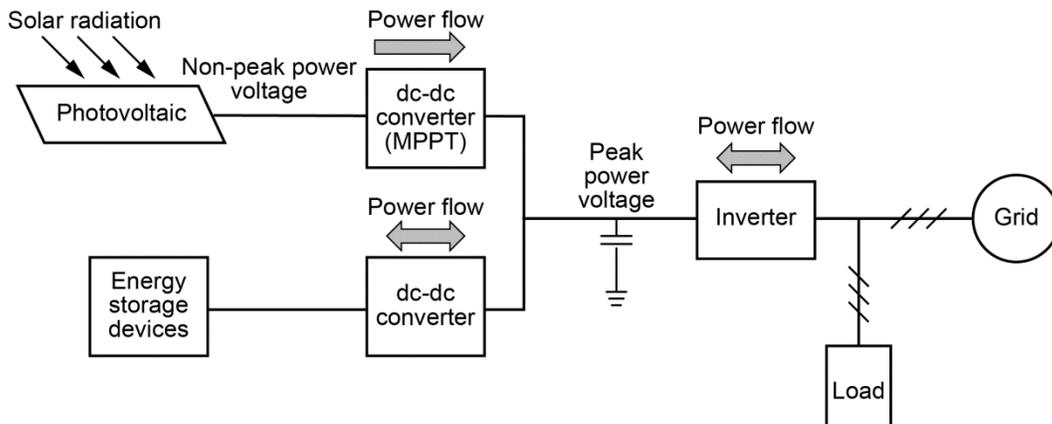


Figure 5.—Power electronic converters for PV systems.

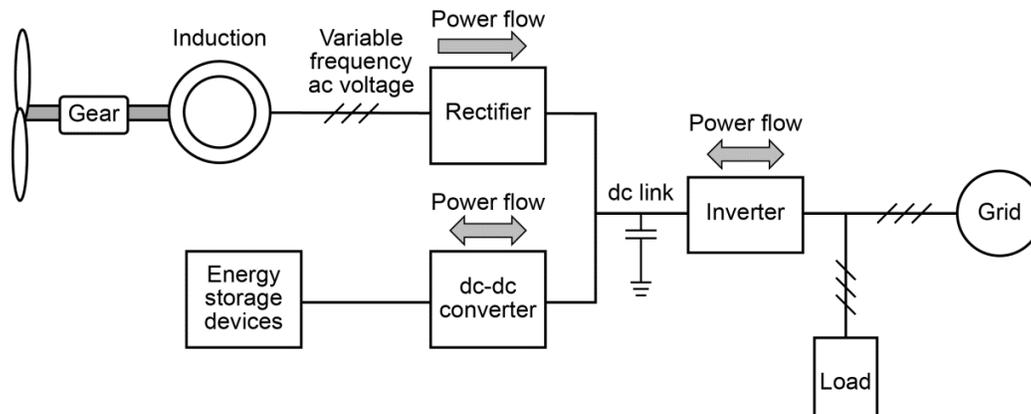


Figure 6.—Power electronic converters for wind turbine.

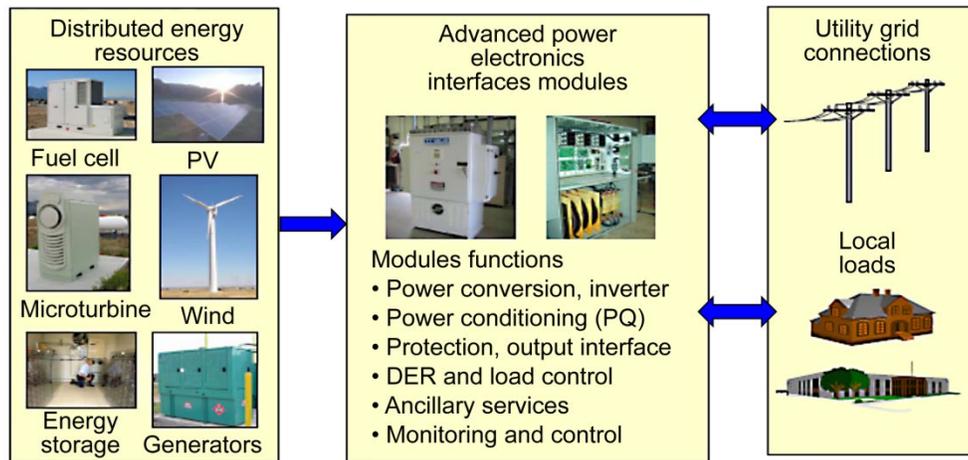


Figure 7.—Distributed Energy Resources and Interface with the Utility Grid (Refs. 9 and 10)

5.1 DERs and Micro-Grids

Integration of renewable generating sources into the existing power system grid, known as distributed energy resources (DER), can provide a more reliable and better quality power to consumers. Implementing DERs can be as simple as setting up backup electricity generators not connected to the grid, or it can be a sophisticated power generation station with energy storage, control and management systems, which can receive or supply energy to the grid. The power ratings of the distributed generation units (ranging from few kilowatts to tens of megawatts), the types of converters and topologies used for interfacing depend on the available resources and on consumer loads and grid demands. Issues related to the interconnections of DERs with the utility grid are currently being conducted worldwide. Problems related to the transition between modes of operations of DERs are discussed, and algorithms during transitions are developed and implemented. Figure 7 shows the infrastructure of a distributed energy system, which includes, the energy sources, the storage devices, the power electronics interface, the grid and the customer loads (Refs. 9 to 11).

There are a few possible sources of energy from which the load can obtain the power; it can be from the alternative energy sources, from the energy storage devices (ESD), or from the grid or from the combinations of these sources. The choice of source or combination of sources used to supply the loads has to be made carefully to ensure maximum and efficient energy utilization. This depends on several factors, such as the instantaneous power available from the sources, energy on the ESD, load characteristics, price of energy from the grid at that instant and the desired power-factor. Integrating these factors with a decision tree in the power electronic interface modules for optimum energy utilization and cost constitutes the energy conversion conditioning system (ECCS). During power outage on the grid, the energy

sources and the ESD supply power to the loads and fulfill instantaneous peak power demand. The ESD can be charged-up either by the grid or energy sources depending on the instantaneous power available and the load demand. The sizing of the ESD has to be determined, based on the anticipated loads, outage times and energy sources characteristics. The ESD are used to compensate the high transient load power demand that cannot be delivered by the energy sources due to their slow response.

5.2 The Role of Energy Storage Devices

DERs respond relatively slowly to sudden increase in load demand. It is reported that for micro-turbine and fuel cell systems, the time constant for the power output can range from 5 ms to 50 s. If the DER system is not connected to the utility grid and no energy storage devices (ESD) are installed, due to this slow response, a sudden increase in load power demand will result in a voltage reduction to achieve energy balance. There are a few types of ESD that are being used and researched in power system applications: batteries, flywheels, ultra-capacitors (or super-capacitors), superconducting magnetic energy storage systems (SMES), pumped-hydro, and mixed-salts (Refs. 11 and 15). Battery technologies, particularly the lead– acid batteries, are widely used in power system applications due to their low cost, high energy density and capability, and their established and mature technology. A fuel cell has energy storage similar to a battery in that an electro-chemical reaction is used to create electric current. Fuel cells are suited for distributed generation (DS) due to their low emission and high efficiency. Power rating of a fuel cells system can be from 100 kW to few MW. Heat produced from the electrochemical reaction for electricity production can be used for combined heat and power (CHP) application. The dc voltage generated from the fuel cells may be too low for an inverter to operate efficiently; therefore a dc-dc

converter is normally used to step up the voltage to a higher level. Other energy storage devices such flywheel technologies are gaining popularity and have been applied in wind turbine technologies. Mixed salts are considered in solar-thermal systems. Pumped-hydro is reliable and more commonplace in electric power systems. At present, ultra-capacitors or super-capacitors are mainly used for low-energy, high peak power applications. They have been used in drive systems to improve ride-through capability during voltage sags; their applications in DER have yet to be found. SMES systems are known for their fast response and high efficiency, however compared to other energy storage systems they are presently too expensive to be competitive with hydrocarbons. and require cryogenic support systems. In power system applications, SMES have been used for voltage sag compensation and to improve stability performance

5.3 Interconnections of DERs

As stated earlier, distributed energy resources (DERs) are typically small-scale power generation technologies in the range of few kilowatts to tens of kilowatts used to provide an alternative to or an enhancement to the traditional electric power systems. A micro grid is a small power distribution system that includes a variety of these sources in combination with energy storage devices (ESD) and loads. When included with distributed generation (DG) and distributed storage (DS), a micro grid is also referred to as distributed energy resources (DER). Recently there has been considerable research and development on implementation of DERs, their

interconnections and the security requirements of future electric power systems, in which DERs are likely to be an essential component (Ref. 17). DERs generate electricity from many small energy sources such as solar and wind sources. The electricity obtained from the energy sources is normally unregulated and is not in a suitable form to be directly connected to loads, as common commercial products or to the grid. Therefore, regardless of the power ratings of a distributed generation unit, it has to be converted to a suitable form by utilizing *power electronics converters* (part of the ECCS). Figure 8 shows different interconnection of DERs operating in grid-connected mode with the loads connected directly or in parallel with the grid. The interconnections can be with power only drawn from the grid or with power drawn and supplied back to the grid. The interconnection is a concern to the utility provider, especially with regard to the power quality and safety of personnel or connected equipment. The grid-connected mode may or may not include ESD, with several factors that determine this choice. If the grid is intended as a backup supply to the load, ESD may not be required. Power is obtained from the grid when power from the energy sources is unavailable. With no ESD, power required for a sudden load change or during peak power demand is obtained from the grid and the alternative energy sources. However, power outage on the grid will result in the power supplied to the load being totally dependent on the energy sources. Thus, due to slow response of the energy sources to react to an instantaneous sudden load demand, the quality of the power supplied to the load will be impaired. In the worst case, when the energy sources are not generating power, power outage on

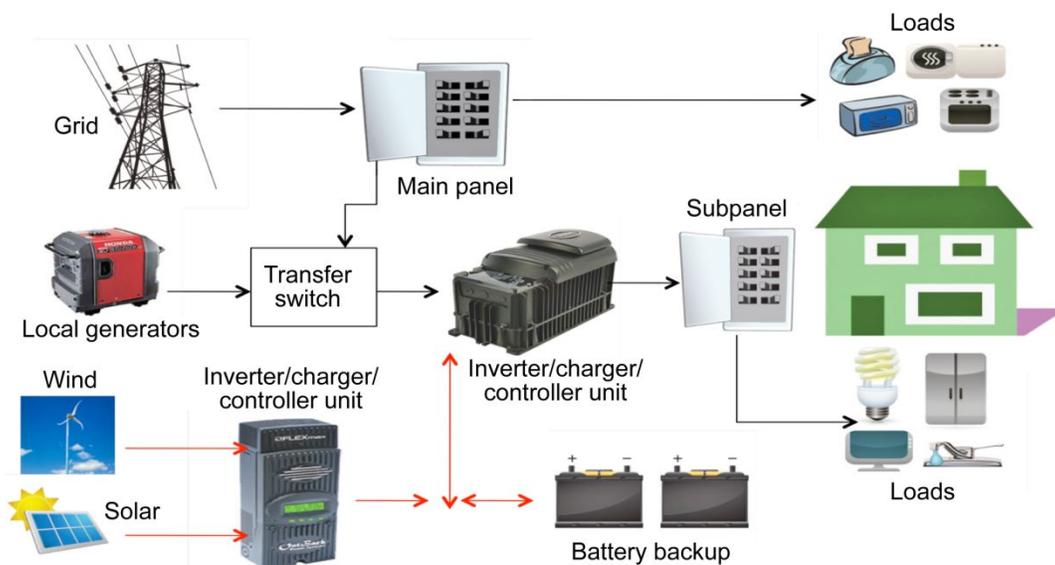


Figure 8.—Example of interconnection of DERs with the utility (Refs. 14 and 15).

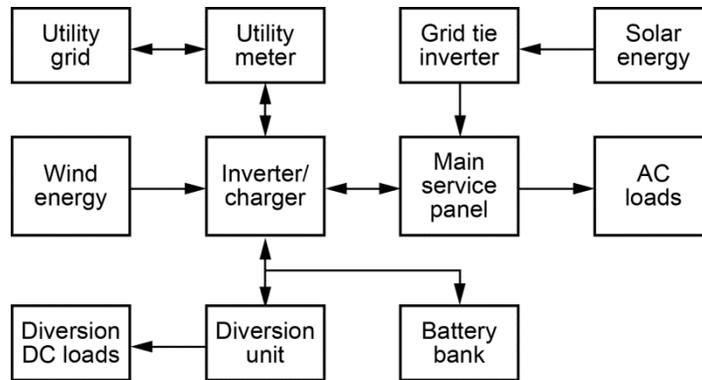


Figure 9.—Tentative power system architecture for the GreenLab.

the grid will result in no power available at the load. If the energy sources are sized to supply the load only during average power usage, then during a power outage on the grid, peak power will not be fulfilled. Excess energy generated by the energy sources can be fed back only to the grid or stored for critical demand loads.

6.0 Green Laboratory Power Systems

The current power consumption of the green lab is approximately 20 kW. This is used by the many pumps, lights, fans and filters as shown in Table I. There is an on-going task of work currently being done to develop a structure and implement a power system architecture that will feed the electricity needs of the GreenLab from the commercially available renewable energy resources. Emphasis is put into energy from windmills and photovoltaic and on back-up power devices. Figure 9 shows the proposed grid-connected DER system architecture to supply energy from windmills and photovoltaic with battery back-up systems. DC loads are connected to the dc link via a dc-dc converter.

Renewable energy systems are commercially available for both residential and industrial applications. Advances in power electronics and energy storage devices are helping in reducing the weight, size and increasing reliability. Commercial wind power development, in which large wind turbines are connected to the electric grid and produce electricity for widespread distribution is, however, a relatively recent phenomenon. During the early 1980s, hundreds of commercial wind turbines were installed in three areas in California. There are several single-phase wind and solar energy systems with all of the required power electronics and battery back-up energy system. Some systems are a fully integrated, utility-connected wind generator designed specifically for homes and small businesses. Several wind

systems have been installed world-wide and at different power levels. For example, 30 percent of Denmark's electricity comes from wind energy systems (Refs. 12 to 16). Figure 10 shows two examples of these systems. Figure 10(a) shows both solar and wind applications in powering a childcare center at NASA Johnson Space Center (JSC) and in Figure 10(b) a windmill is used to supply power to the GreenLab Research Facility at GRC. Currently there are two wind turbine systems that are partially supplying wind energy to the GreenLab Research Facility.

TABLE I.—GREEN LABORATORY POWER REQUIREMENTS

Item	No.	Rating (W)	Total power
Tunze 6205 Pumps	19	55	1045
Tunze 6305 pumps	6	64	384
Tunze 6105 pumps	2	45	90
Aquaclear 500 Filter	16	14	224
Dual voltage Homer Head pump	2	246	492
Reeflo snapper (universal motor)	4	104	416
Wave Generator Tunze 6261 Pumps	6	50	300
Blue Line Aqua pump	1	390	390
Tunze Protein Skimmers pump	2	22	44
Delta Star Chiller	4	1104	4416
Ad Smith Fans	2	373	746
MAG24 Pump	1	237	237
Motors for moving the lights	7	5.5	38.5
Galaxy Lights	26	400	10400
*Evaporative Cooling	1	93	93
Total	99		19315.5



(a) Childcare Center, JSC



(b) GRC GreenLab Research

Figure 10.—Demonstration of commercially available wind and solar energy sources

7.0 Summary

A description of the GreenLab Research Facility at NASA GRC is provided in this paper. The Facility comprises two complementary components: (i) the indoor or incubator facility and the (ii) outdoor growth facility. Each of the two facilities possesses a variety of climatic adaptive ecosystems, power and energy sources and requirements. The goal is to promote worldwide expansion and adoption of the research and development facility to enable the commercialization of biomass production for energy, fuel, food, feed and freshwater recovery.

The primary motivation for the reported work derives from the large gap between the production and demand for energy from alternative fuel and alternative renewable energy sources. The basic issues center on sustainability of humanity. Such sustainability depends directly on the ability to secure affordable energy, food, feed, fuel with conservation of arable

land and freshwater. These issues are addressed directly in the GreenLab Research Facility where focus is directed to optimization of biomass feedstock utilizing primarily, but not exclusively, algae and halophytes as the next generation of renewable aviation fuels.

The unique approach is directed at the achievement of optimal biomass feedstock through climatic adaptation of balanced ecosystems that do not use freshwater or arable land and do not compete with food crops. The incubator laboratory screens seeds, seedlings, waste treatment, and ecosystems with a variety of controlled saline, lighting and nutrient conditions preliminary to transitioning to the outdoor laboratory. Successful biomass treatments are then transported and implemented on a larger scale more realistic of actual soil and water conditions in six parts of the world in the outdoor facility. The climatic adaptive approach enables saline-tolerant plants to thrive in freshwater environments, as well as, adapt freshwater species to grow in saline environments. The adaptation is extended to fish which in turn supply rapid growth, reproduction and nutrients. Aquatic life, primarily fish, becomes the health monitoring system for the GreenLab. Reclamation of contaminated waters becomes a necessity. Algae from the incubator laboratory are both tested for reclamation and sources of fueling biomass.

To offset the GreenLab Research Facility power consumption, alternative and renewable energy from wind and photovoltaic (proposed micro-grid) technologies reduce the major environmental impact of commercial electricity. The ultimate goal is to have a 100 percent clean energy laboratory dedicated to biomass research within the framework of a self-sustainable ecosystem that can be duplicated anywhere in the world, and can, potentially, be used to mitigate the shortage of food, fuel and water.

Biomass-derived biofuels represent viable alternative fuel resources for aviation, with byproducts for feed or direct use as food and residuals as energy sources. Utilizing wind and solar technology as alternative renewable energy resources supplements the GreenLab energy and power demands.

References

1. Reilley, J., Paltsev, S., and Choumert, F., 2007, "Heavier Crude, Changing Demand for Petroleum Fuels, Regional Climate Policy, and the Location of Upgrading Capacity: A Preliminary Look," MIT Joint Program on the Science and Policy of Global Change, Report No. 144, Massachusetts Institute of Technology, Cambridge, MA.
2. <http://web.mit.edu/globalchange/www/MITJSPGCRpt144.pdf>
3. Energy Information Administration, 2009a, "Chapter 1—World Energy Demand and Economic Outlook," International Energy Outlook 2009, Report Number.: DOE/EIA-0484(2009).
4. <http://www.eia.doe.gov/oiaf/ieo/world.html>

5. Daggett, D. L., Ben-Amotz, A., and Benemann, J., 2009, "Feasibility of Algal Oil for Renewable Jet Fuel," submitted to Journal of Applied Phycology.
6. Daggett, D., Hadaller, O., Hendricks, R., and Walther, R., 2006, "Alternative Fuels and Their Potential Impact on Aviation," ICAS 2006–5.8.2, 25th International Congress of the Aeronautical Sciences, Hamburg, Germany.
7. Daggett, D. L., Hendricks, R. C., Walther, R., and Corporan, E., 2007, "Alternate Fuels for Use in Commercial Aircraft," ISABE–2007–1196, Beijing, China.
8. Hendricks, R. C., 2007, "Sustainable Secure Alternate Aviation Fueling," 2007 NASA Seal/Secondary Air System Workshop, NASA/CP—2008-215263/VOL1, Cleveland, OH, pp. 75–99.
9. Elbuluk, M., Idris, N. R. N. Idris, "The role power electronics in future energy systems and green industrialization," IEEE2nd International Power and Energy Conference, 2008, (PECon'08), pp. 1–6.
10. <http://www.netl.doe.gov/>
11. <http://www.nrel.gov>
12. http://www.energy.ca.gov/distgen/equipment/energy_storage/energy_storage.html
13. <http://windenergy.com/products/skystream>
14. <http://www.xantrex.com/power-products/overview.aspx>
15. <http://www.outbackpower.com/>
16. http://www.cse.anl.gov/electrochem_energy_storage/index.html
17. <http://www.power-thru.com/>
18. http://grouper.ieee.org/groups/scc21/1547.6/1547.6_index.html

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