Airports Supporting the Future of Aviation

A fact-based study of the changing aviation landscape depending on green fuel technology, safety, economics, and climate impact by 2050

The University of Texas at Austin - Women in Civil, Architectural, and Environmental Engineering

Lina Sela - Faculty Advisor

Safaa Arif - Civil Engineering, Undergraduate
Zoe Chen - Civil Engineering, Undergraduate
Talia Elkhatib - Environmental Engineering, Undergraduate
Tiffany Huang - Architectural Engineering, Undergraduate
Gaon Ok - Civil Engineering, Undergraduate
Alexandra Vaughn - Civil Engineering, Undergraduate

Table of Contents

Appendix

1) Windows across the airport equip photovoltaic cells. Water-stable haloplumbate used for interfacial modification forms on the perovskite surface by tetra-butylammonium iodide, and through the treatment of tetra-butylammonium iodide, passivation is present (Wang et all. 2021)

Wang, H., Zhang, Z., Milić, J., Tan, L., Wang, Z., Chen, R., . . . Luo, J. (2021). Interfacial Haloplumbate Modulation for Efficient and Stable Hybrid Perovskite Photovoltaics. ChemRxiv. doi:10.26434/chemrxiv.14331218.v1

Abstract

With the sustainable advancements of innovations in aviation, airports are challenged to environmentally improve particular design and infrastructure aspects to accommodate the changing aviation landscape. In the next 30 years, airports and airplanes are expected to sustain the growth of aviation connectivity while reducing harmful emissions. The projected traffic growth in 2050 is estimated to support around 10 billion passengers to fly yearly. If the current operational efficiency rate remains the same, over 2,800 million tonnes of CO2 will be expelled. (Waypoint 2050). As a harmful greenhouse gas, it is imperative to reduce such emissions. Fortunately, there are resourceful alternatives, such as battery-powered aircraft, which produce no emissions, and hydrogen combustion-powered aircraft, which reduce the climate impact by 50% to 75%. (Coykendall et all. 2021) To support these sustainable aircraft features, airports must be designed in flexible operation, especially regarding the transportation of people, fuel, and baggage to and from the plane. As such, newer terminal designs can be implemented and updated to allow mass, safe, and feasible transportation for commercially larger planes. Hence, newer modeling technologies also incorporate sustainable innovations, such as electricity generated from the airport to recharge internal operations and automated safety features to include zero waste and emissions throughout the layout. Additionally, recharging and refueling stations also require a design update to ensure planes of varying sizes and requirements receive the correct and exact fuel efficiently and safely. Essentially, more airports and modern technologies must be incorporated to sustain futuristic aviation and support the large influx of passengers over the next thirty years. Thus, engineers and analysts will explore and assess these potential and necessary alterations.

Fuel and Energy Transportation

Hydrogen fuel is a practical zero carbon emission alternative to kerosene fuel used in present-day planes. Liquid hydrogen has a high gravimetric density, making it the most efficient chemical energy; however, it has a larger volume compared to kerosene, about four times as big (Prewits, 2020). The volume size presents challenges with aircraft and storage tanks, but it can be solved using spherical and cylindrical-shaped tanks (Nicolay, 2021). In addition, planes can use batteries for extra refueling since hydrogen tanks are too large to accommodate extra fuel (Nicolay, 2021).

Hydrolysis or carbon capture can produce hydrogen, which must be compressed or liquified for transportation. It's projected that the total hydrogen required to support all airports will comprise only 10 to 25 percent of the global demand by 2050 (FCH 2 JU, 2020). Such market growth means that hydrogen production in the future will be advanced and large enough to support the aviation industry. Moreover, since most hydrogen produced is compressed instead of liquid, the airport will also need liquefaction and storage facilities (FCH 2 JU, 2020). Predictions for large airports using 500 tons of liquid hydrogen require 25,000 square meters of liquefaction storage space (FCH 2 JU, 2020). Today, this would be about 0.2 percent of Heathrow Airport's footprint (FCH 2 JU, 2020).

The airport can also have a nearby electrolysis unit to produce hydrogen on demand. These electrolysis units will be powered by on-site piezoelectric tiles, photovoltaic cells, and off-site renewable energy sources like solar or wind. Given the massive amount of foot traffic in airports, kinetic floor tiles are an excellent opportunity to harness that type of energy. Current research predicts advancements of piezoelectric tiles through device configuration and peptide selection, as a robust response in piezoelectric voltage will be safely and affordably manufactured without electrical poling (Petroff et al. 2021). Furthermore, windows across the airport equip photovoltaic cells. As a result, it is expected for there to be an increase in power transmission of 22.90%, along with superior functional resilience and resource waste reduction.[1] As for external generation, solar panels are expected to be more efficient and in-demand within the next thirty years. In 2030, the Solar PV generation share is expected to increase to 13%, and in 2050, to 25%. In 2030, prices are expected to decrease to 834 - 340 USD/kW and, in 2050, to 481-165 USD/kW. Hence technical refinements ensure that solar energy will produce more electricity and lower the cost required to implement panels (IRENA, 2019).

A hydrogen pipeline is the best long-term option for transporting hydrogen fuel (FCH 2 JU, 2020). Hydrogen pipes may be constructed on repurposed natural gas pipelines that are already in place or new dedicated hydrogen pipelines can be created. The former is the best option cost-wise as it is expected that gas pipelines are out-competed by renewable energy. However, further research and development are necessary to achieve a better cost-efficient method by 2050. Additionally, given hydrogen's chemical nature and properties, experts agree that new regulations will need to be developed to ensure adequate and safe handling of low-temperature liquid hydrogen when refueling planes (FCH 2 JU, 2020).

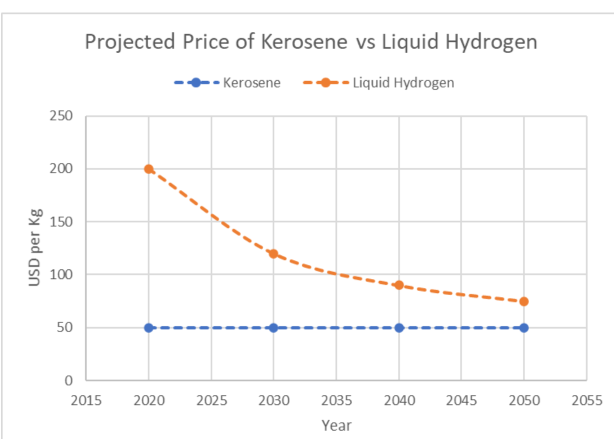


Figure 1. Liquid hydrogen prices take into consideration production, liquefaction, distribution, and dispensing costs (FCH 2 JU, 2020). Kerosene prices are modeled to remain unchanged in regards to hydrogen deflation for visual clarity.

In the early stages, liquid hydrogen is expected to be more expensive than kerosene. Hydrogen production is currently more costly than kerosene production. By 2040, liquid hydrogen production in Europe is likely to be between $2.60 to $3.50 per kg of liquid hydrogen compared to kerosene’s $1.90 per kilogram of liquid hydrogen in energy-equivalent costs (FCH 2 JU, 2020). However, liquid hydrogen fuel prices will approach those of kerosene by 2050 because of projected higher demands and production advancements (EU, 2020). Regardless of fuel type, costs will decrease as technology advances with time. It is anticipated that liquid hydrogen will fall from 4 times the price of kerosene today to about the same expense by 2050 (FCH 2 JU, 2020). There will be virtually no difference in cost between the two fuels. Furthermore, a recent case study determined that adequate hydrogen prices will range between 4 to 17 US dollars per kg of hydrogen (Apostolou, 2020). Therefore, current liquid hydrogen fuel costs shouldn’t deter options from examining its potential as a primary fuel source in aviation.

Airport Layout

The main objectives of the airport layout include creating an efficient and safe network of transportation while maintaining the capacity of the airport to accommodate the increased number of passengers and plane sizes that we are likely to see by 2050. Therefore, the airport layout will be centralized and follow an extensive spread-out design, like the SFO and Chicago O'hare airports' layout. In addition, the airport building will be structured in a circular arrangement with the roadways closely following the arc shape of the facilities and the main parking area occupying the center of the circle on the landside of the airport. This layout will maximize the flow of people entering and exiting the airport by utilizing a continuous loop system for incoming and outcoming automobiles.

Furthermore, the spread-out nature of the airport will increase the levels of safety both inside and outside the airport buildings. The outspread layout will help minimize the number of airport hotspots on the runways and taxiways by eliminating potential blindspots or compact areas for pilots to navigate around. By focusing on the geometry of the intersections between taxiways and runways, hotspots can be further minimized by avoiding angular transitions and intentionally designing taxiways to lead into runways following a standard right-hand turn instead. Like many present-day large airports, our airport will start with six runway lengths of about 12,000 ft. However, acreage will be set aside for two additional runways to be built out in the future should the airport’s demand call for it.

In addition to reducing hotspots, the large spread design will allow for safe ambient air levels and reduce the spread of diseases. This issue has become increasingly significant with the coronavirus pandemic, and it is safe to assume that this trend will continue to be a notable factor of sustainability in the future. According to Dr. Fauci, “new terminals need to allow more space for people to spread out” to maintain enough area to make social distancing easily possible (Fauci, 2020). The open layout of the airport will make this possible since it will decrease the likelihood of infectious air particles mixing in the air and spreading among airport customers.

The immense and spread-out nature of the airport will also create more possibilities to implement sustainable energy infrastructure. For instance, one of the goals of our airport will be to generate as much solar energy as possible to cover the energy needs for lighting purposes in the airport. Therefore, the main parking area in the middle of the landside of the airport will be a covered garage that will implement solar panels on the roof to generate solar energy for airport use. Similarly, photovoltaic cells will be implemented on the tops of the airport terminal buildings. For aesthetic reasons, parts of the roofs can even be converted into watch platforms or garden lounging areas to promote greenery, aesthetic pleasure, and incorporate the solar panels on the roof in a pleasing manner. Combining the solar panel area on the garage and the terminals would produce an area of about 2 million square feet.

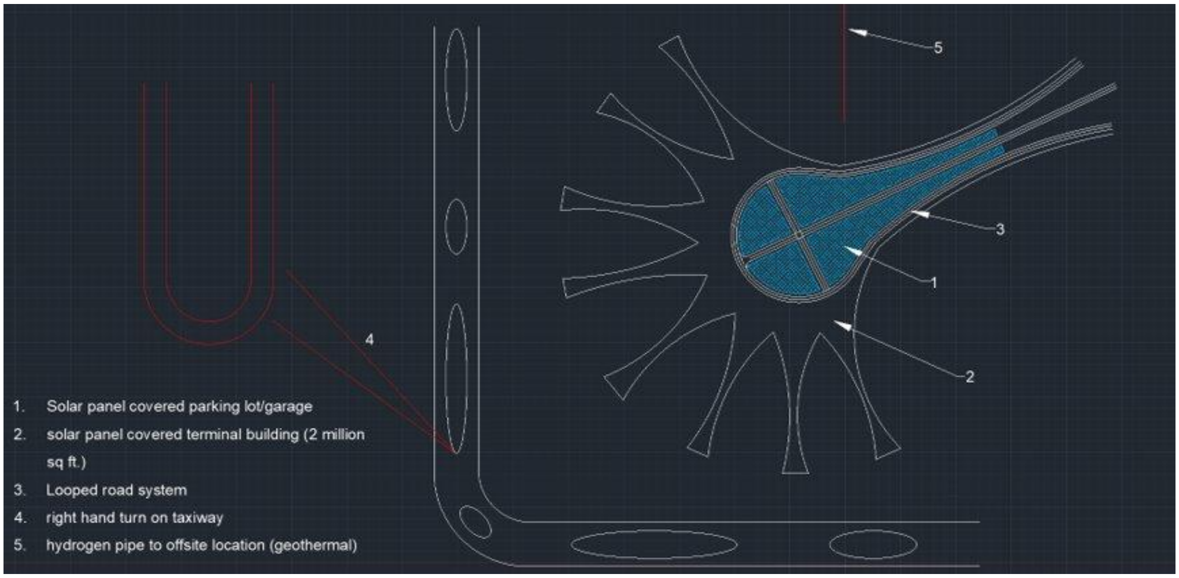


Figure 2. Modeled original layout of proposed airport design.

Assuming that approximately 20 kWh of energy is used annually for an average airport per square foot, we can calculate the average annual energy use of our airport to total up to about 40 million kWh. However, assuming that only 40% of this is used for lighting purposes, we can say that approximately 16 million kWh would be necessary to generate solar power for airport lighting. Studies done on solar farms, such as those conducted by SAS, and recent innovation in solar powered airports, such as the Cochin International Airport in India, indicate that generating this amount of energy would require about 45-55 acres of space to be dedicated to solar panels, which equates to about 2 - 2.5 million square feet. Therefore, it is safe to assume that implementing solar panel roofs on the terminal and garage buildings of the airport will generate enough energy to cover the energy demand for lighting from the airport. As the ambition of the airport grows, more than 100 free acres will be set aside as an energy farm to make further use of solar and wind energy. Hence, it is possible to use this free land to generate further energy for ambient heating and cooling.

Geothermal pumps are a great way to reduce fossil fuel consumption from an airport by using the water deep within the ground to heat and cool the airport's terminal buildings. Ground loops filled with fluids will work underground to cool the buildings during the summer and heat them at colder temperatures depending on where the airport is located and the climate patterns of that location. Although excavating approximately 500 ft into the ground and inserting geothermal pumps seems impractical, this system can be a long-term sustainable solution. The pumps will be easy to maintain and reduce the toxic emissions currently released into the atmosphere from current traditional HVAC systems. In the future, solar panels can be built on the land over these ground loops so that the energy generated from the solar panels can provide renewable energy for the geothermal pumps to continue working, thus creating a positive feedback loop.

Space will also be set aside in the airport for waste collection. First, waste generated from the airport will be consolidated and transported to an onsite waste collection establishment. Then, electric vehicles will transport the waste to a nearby waste processing plant that will ideally convert this waste into energy such as fuel, gas, and electricity. Theoretically, the airport could use this energy, and the waste produced from this consumption could again be used as input to regenerate energy sources for the airport.

Gate Design

The gate design of an airport is crucial in ensuring the efficiency; while terminal design used to occupy approximately one-fourth of airport budgeting before 1965, the expanded size of aircrafts and increasing limitations placed on runway lengths have placed increased stress on designing an effective terminal. The physical layout of our terminals will aim to create less congestion during peak hours, while an updated wireless infrastructure will supplant communication across the airport and improve the quality of service.

Airport layouts typically are modeled after three styles: centralized, linear, and gate-arrival terminals. Hybrid layouts like New York's LaGuardia Airport have integrated the advantages of varying layouts to best serve its varying audience, from directing commuters efficiently to gate-arrival terminals via shuttles, while other terminals use the finger pier layout. Our airport combines the efficiency of gate-arrival terminals with the more engaged, directive layout of a centralized system. According to Braniff and Trans World Airlines, an average of 15% more staff are needed to operate gate-arrival terminals in Kansas City compared to the traditional centralized terminals. The use of two centralized terminals will encourage commuters to interact with restaurants, shops, and entertainment centers, stimulating the airport environment and its services.

The designed terminals allow for shared use between airlines, especially between airlines that typically have different traffic patterns. This minimizes the cost of funding separate operators for shuttles and transporters while decreasing congestion between commuters.
Because of competition, airlines occupying independent gates tend to operate under an implied rate of marginal utility. This behavior means that one can achieve considerable savings by combining several small operations into one common service shared by all (de Neufville, n.d.).

The implementation of the IEEE 802.16 standard will allow future airports to be interconnected on a smoother scale. 802.16-2017 allows for scalability and later modifications by combining wireless cells into the existing, wired network used by most airports. The mainstream use of 4G standards, for example the 802.16e standard, would allow for future airports to be streamlined while sharing the same gate during different peak periods.

	802.16/c	802.16a/REVd/2004	802.16e
Spectrum	11-66 GHz	2-11 GHz	2-6 GHz
Channel Conditions	LOS	LOS, NLOS	NLOS
Bit Rate	32-124 Mbps	1-70 Mbps	Up to 50 Mbps
Modulation	QPSK, 16QAM and 64QAM	OFDM 256 sub-carriers, QPSK, 16QAM and 64QAM	OFDMA, QPSK, 16QAM and 64QAM
Mobility	Fixed	Fixed, Portable	Mobile (upto 120Km/h)
Channel Bandwidths	20, 25 and 28 MHz	Selectable channel bandwidths between 1.5 and 20 MHz	Selectable channel bandwidths between 1.25 and 20 MHz
Typical Cell Radius	1-3 miles	3-5 miles Maximum range 30 miles based on the tower height	1-3 miles

Figure 3. Table of different IEEE Standards that our airport would operate on, allowing different networks to connect and relay information without hindrance (Kerczewski et al., 2009).

Infrastructure for Recharging and Refueling Aircraft

The airport will have the capacity to fuel both hydrogen and battery fueled airplanes. Both of these options require charged batteries to operate and transport. Since charging such a large battery could take upwards of eight hours and the time between flights is not as long, the airport will implement battery swaps. Battery swapping is more time-efficient than charging the battery inside the plane. So, the airport will need to have a place to charge batteries that are not in use. We propose a level in each terminal that has the capacity to charge plane batteries and hydrogen fuel cells. Specifically, these recharging and refueling stations are located on the bottom floor within each terminal, and provide a way for electric vehicles to transport operations. Cumulative operations are demonstrated on the figure below.

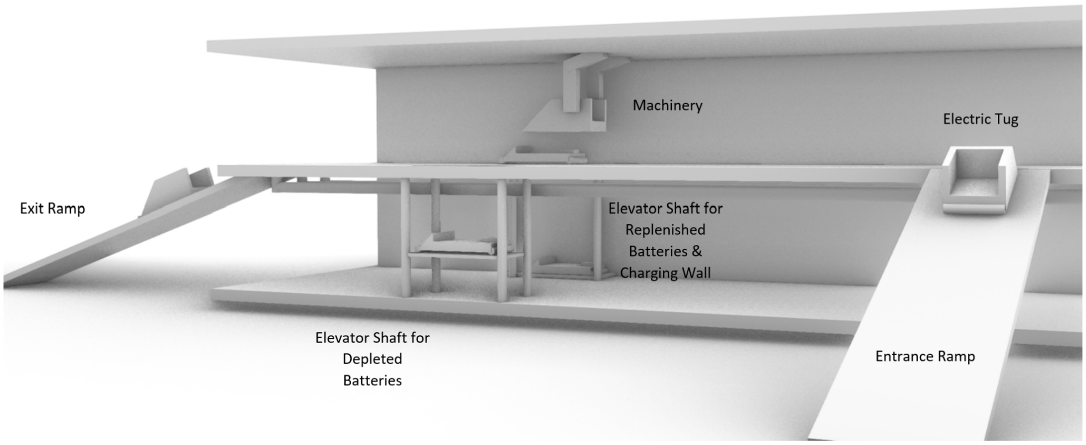
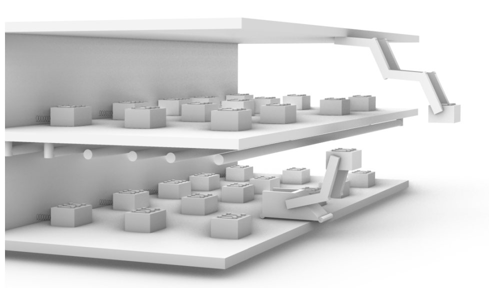


Figure 4. First two floors of the airport are represented. These Floors are solely dedicated to recharge and refuel operations. only show 2 of the elevator shafts in the facility, however there will be space for up to 10 elevator shafts, meaning space for 10 electric tugs at one time.

Additionally, such levels will be at the ground floor of each terminal and house backup batteries and charging stations for the planes that are able to load and unload passengers at a specific terminal. Electric tugs will have replaceable batteries. Tugs that need a battery swap will enter through a ramp on the side of the facility. Once inside, the top of the tug will be lifted up off the battery by machinery and the batteries will be swapped (the battery of the tug includes the base of the tug and wheels). The uncharged battery will be pushed leftwards onto an elevator shaft that will lower it into the first floor for recharging. It will then be recharged and placed on an elevator shaft on the right side of the facility and installed in another tug.

Plane batteries will also be swapped and will be located at the other side of the building. There will be a mechanic arm on the second level that will extend out towards the plane to replace the batteries in the wing most adjacent to the facility. For the other airplane wing, an electric tug will cart the battery to the other side of the plane and will also have a mechanic arm to reach up to the airplane and swap the battery. The concept can be seen in the following figure.



Using battery-powered planes and hydrogen-fueled cells poses some safety hazards including electrocution and fire. For example, when performing a battery swap, one must be careful since the battery can reach high temperatures. Larger planes will need larger, and in turn heavier batteries with more fuel cells. A common problem with such a large battery is heat control. For example, a fire could break out from the battery overheating, similar to the Boeing 787 fire in 2013 (Thomson, 2014). In the future, it is presumed that lithium-ion batteries will have improved both in energy storage and heat control.

However, the benefits of using battery-powered or hydrogen-fueled planes outweigh the potential risks. Battery-powered and hydrogen-fueled planes will eliminate carbon emissions that are associated with today's airplanes. Kerosene fueled planes also produce non-carbon emissions from water vapor and nitrogen oxides, for example. These non-carbon emissions also contribute to the growing climate change problem.With a combination of battery-powered and hydrogen-fueled planes, our airport will have near 0 carbon emissions.

Additionally, the combustion of fossil powered airplanes creates noise pollution, and drastically more so when incorporated into larger flight engines. In order to sustain the comfort of flying in significantly larger aircrafts, a new efficient source must be incorporated to reduce noise combustion. Fortunately, both electric and hydrogen fueled planes produce little to no sound, further ensuring that passengers are not disrupted during their flight (Berton et all. 2009).

Ground Support Equipment

Accumulative processes of ground support systems within current airports may often lead to traffic congestion. The rise of flight demand is optimized against decreased wait times; thus, to ensure that flight take-offs and boarding are available immediately, a flexible system must be incorporated into the ground support equipment for the entire aircraft turnaround process. Fortunately, solutions to this issue may be solved through specific updates and technology advancements explored in the upcoming years.

Primarily, by using artificial intelligence programmed into each aspect of the turnaround process, delayed flights would substantially be non-existent, hence improving the overall flow of the future sustainable airport. Here, data would be wirelessly extracted from sensors, and immediately incorporated to assess optimized scenarios to reduce impedance-based difficulties. Delay-tolerance applications would then automatically deliver the needed piece to and from the aircraft immediately, while recording and applying the performance of each mechanized network. (Bulusu, 2021).

Through these automated systems, back-up manual operations are also feasible, and the entire system is reliantly subject to future changes if needed. Specifically, when related to the multimodal transfer of cargo, luggage would be delivered from the airport to the loading dock of the aircraft through a similar system in which people were transferred as stated in the airport layout. Below-level speed tubes that connect the ground floor of the airport would transport carts of luggage that are already pre-laid to optimize space. Moreover, baggage will be automatically transferred into the airplane by means of a retractable tube that is connected to the speed rail. Once the cart of luggage arrives near the airplane, it is left in a side part extension of the tube to not block other traffic, until it is then lifted off from a dock through a conveyor belt like baggage loader, which either immediately drops off the baggage into the airplane, or is transported into a baggage cart tractor depending on the terminal where the aircraft is docked at. These baggage cart tractors will have tracking systems implemented on them, in order to find baggage more quickly and reduce the risk of lost baggage claims. Additionally, both the baggage loaders and baggage cart tractors are located on the ground floor of the airport, and each gate terminal for each aircraft is also equipped with a base dock to ensure all packages are transported onto the aircraft in a safe, flexible and timely manner. This system will allow for the passenger to have a more convenient flight, as it will lessen their time spent on transporting their luggage as well as the possibility of having their baggage off-track . Updates to this system may easily be incorporated into adding or removing transportation services located on the ground floor.

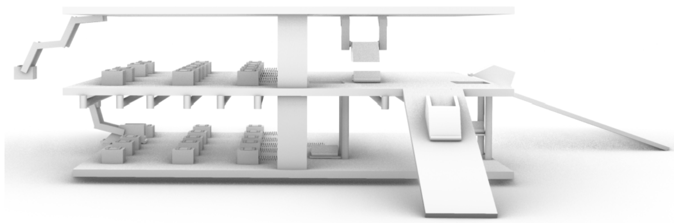


Figure 5. Automated electric tugs pulling into the two bottom floors of the airport located in every terminal. These vehicles are transporting allocated carts for aircraft systems.

As for the exact electronics and towing vehicles in operation, self-driving vehicle technology with mechanized manual controllers allow for ground support operations to run smoothly, even if an unexpected delayed event occurs. Humans will control these operations through a virtual apparatus as to not be physically present in the machinery (Gupta et all. 2012). Guaranteeing this outlook ensures that efficiency and human safety is increased. Furthermore, such applications will be either run on batteries, hydrogen or other biological net-zero sustainable source of fuel. Any green fuel source may be incorporated into the ground floor design, as electrical recharging could be done by energy collected by the airport either through piezoelectric or photovoltaic cells. Hydrogen and other refuel applications will also be smoothly incorporated into the process as needed. Likewise, backup systems will be put in place in a justified ratio to certify that even if half of the airport is malfunctioning, the entire airport will still continue to operate smoothly.

Moreover, research presented through applying aspects from an APU to a GPU can further ensure that the ground systems are also upgradeable with the advancements of varying aircraft (Prawitz et all. 2021). Whether an airplane is powered on hydrogen or batteries, the automated GPU will transfer the needed product from the ground floor to the aircraft via a tenable biological based diesel engine which can also be refueled in the ground floor at each terminal and sent information, similar to how current space GPUs are used, as needed.

Conclusion

In order to accommodate the future aviation landscape, it is crucial to incorporate sustainable modern technologies as well as resourceful alternatives to reduce harmful gasses. Our project implements an airport design that supports the emerging aviation technology and aims for a climate-friendly future for the next 30 years. Battery-powered aircrafts and hydrogen fueled aircrafts in our airport design can help reduce carbon emissions that are associated in airplanes today, and are time efficient in recharging the aircraft due to the swapping of the batteries. Additionally, the gate design of the airport is highly beneficial for commuters as it reduces congestion and allows them to communicate with a variety of airport services through an updated wireless infrastructure. With the airport layout being spread out, the flow of people will be maximized and safety levels will increase inside and outside the airport structures by eliminating blind spots that can lead to potential accidents, and allowing for ambient air levels that will reduce the rate of contagious viruses. Flexible systems with programmed artificial intelligence and new automated technology will eliminate delayed flights and allow for convenience in baggage transportation with the use of baggage loaders and baggage cart tractors. The design nature of the airport is flexible to accommodate improvements in evolutionary architecture, and more technology should be incorporated to have a future aviation landscape that is safer, faster, cleaner, and quieter for the next 30 years.

References

Apostolou, Dimitrios. (2020). Optimisation of a hydrogen production – storage – re-powering system participating in electricity and transportation markets. A case study for Denmark. Applied Energy, Volume 265, ISSN 0306-2619. https://doi.org/10.1016/j.apenergy.2020.114800.

Baral, N., Yang, M., Harvey, B., Simmons, B., Mukhopadhyay, A., Lee, T., & Scown, C. (2021). Production Cost and Carbon Footprint of Biomass-Derived Dimethylcyclooctane as a High Performance Jet Fuel Blendstock. ChemRxiv. doi:10.26434/chemrxiv.14761002.v1

Berton, J., Envia, E. and Burley, C.,(2009) "An Analytical Assessment of NASA's N+1 Subsonic Fixed Wing Project Noise Goal," AIAA Paper 2009-3144.

Bickert, S., Caballero Alarcon, M., Damar, C., Dickson, N., Gavalli, L., Laukia, J., Tanaka, T., & Thrasher, T. (2016). (rep.). *ICAO Environmental Report* (Vol. 4, Ser. Cochin International Airport - World's first solar powered airport, p. 177). ICAO.

Christiaan van Manen. , W. (2021, May 12). *Europe's aviation landscape in 2040*. Deloitte United States. Retrieved February 20, 2022, from https://www2.deloitte.com/nl/nl/pages/consumer/articles/europe-aviation-landscape-in-2040.html

Coykendall, J., Shepley, S., & Hussain, A. (2021, October 21). *Decarbonizing Aerospace*. Deloitte Insights. Retrieved March 1, 2022, from https://www2.deloitte.com/xe/en/insights/industry/aerospace-defense/decarbonizing-aerospace.html

De Neufville, R. (n.d.). *DESIGNING THE AIRPORT TERMINAL*. Transportation Research Board. Retrieved February 20, 2022, from https://onlinepubs.trb.org/Onlinepubs/sr/sr159/159-022.pdf

Duane, McCormick, Jordan, Snyder, Wookyung, Kim, Jeffrey, & Mendoza. (2020, December 31). *Acoustics of Future Low-Emissions Combustor Technology, Volume I – Final Report*. NASA Technical Reports Server. Retrieved February 20, 2022, from https://ntrs.nasa.gov/citations/20205011099

Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU), Hydrogen-powered aviation : a fact-based study of hydrogen technology, economics, and climate impact by 2050, Publications Office, 2020, https://data.europa.eu/doi/10.2843/766989

Gupta, G., Malik , W. A., & Jung, Y. C. (n.d.). *An integrated collaborative decision making ... - researchgate*. Retrieved March 1, 2022, from https://www.researchgate.net/publication/268571930_An_Integrated_Collaborative_Decision_Making_and_Tactical_Advisory_Concept_for_Airport_Surface_Operations_Management

IRENA (2019), Future of Solar Photovoltaic: Deployment, investment, technology, grid integration and socio-economic aspects (A Global Energy Transformation: paper), International Renewable Energy Agency, Abu Dhabi.

Kerczewski, R. J., Budinger, J. M., Brooks, D. E., Diamond, R. P., DeHart, S., & Borden, M. (2009, March 7). *Progress on the Development of Future Airport Surface Wireless Communications Network*. NASA Technical Reports Server. Retrieved February 20, 2022, from https://ntrs.nasa.gov/citations/20120012841

Kölbach, M., Rehfeld, K., & May, M. (2021). Efficiency Gains for Thermally Coupled Solar Hydrogen Production in Extreme Cold. ChemRxiv. doi:10.26434/chemrxiv.14377049.v1 This content is a preprint and has not been peer-reviewed.

Prawitz, M., Tschauder, A., Weiske, S., Pasel, J., & Peters, R. (2021). A compact, self-sustaining fuel cell auxiliary power unit operated on diesel fuel. Energies, 14(18), 5909. doi:http://dx.doi.org/10.3390/en14185909

NASA. (n.d.). *A ground-delay-based approach to reduce impedance-based airspace complexity - NASA technical reports server (NTRS)*. NASA. Retrieved March 1, 2022, from https://ntrs.nasa.gov/citations/20210017634

Nicolay, Karpuk, S., Liu, Y., & Elham, A. (2021). Conceptual design and optimization of a general aviation aircraft with fuel cells and hydrogen. International Journal of Hydrogen Energy, 46(64), 32676–32694. https://doi.org/10.1016/j.ijhydene.2021.07.127

OUC. (n.d.). *Airports*. Business energy advisor. Retrieved February 20, 2022, from https://ouc.bizenergyadvisor.com/article/airports#:~:text=An%20average%20airport%20(a%20subset,energy%20use%20(figure%201)

Petroff, C., Cassone, G., Šponer, J., & Hutchison, G. (2021). Intrinsically Polar Piezoelectric Self-Assembled Oligopeptide Monolayers. ChemRxiv. doi:10.26434/chemrxiv.13151069.v1 This content is a preprint and has not been peer-reviewed.

Prewitz, Bardenhagen, A., & Beck, R. (2020). Hydrogen as the fuel of the future in aircrafts – Challenges and opportunities. International Journal of Hydrogen Energy, 45(46), 25378–25385. https://doi.org/10.1016/j.ijhydene.2020.06.238

Reuters Staff. (2014, December 2). *Design flaws led to 2013 Lithium-Ion Battery Fire in Boeing 787: U.S. NTSB*. Reuters. Retrieved February 20, 2022, from https://www.reuters.com/article/us-boeing-787-battery/design-flaws-led-to-2013-lithium-ion-battery-fire-in-boeing-787-u-s-ntsb-idUSKCN0JF35G20141202

Rosenkrans, W. (2017, August 9). *Hot spot intelligence*. Flight Safety Foundation. Retrieved February 20, 2022, from https://flightsafety.org/asw-article/hot-spot-intelligence/

SAS. (2010). Solar Farm II Fact Sheet. Cary; North Carolina.

Thomson Reuters. (2014, December 2). *Design flaws led to 2013 Lithium-Ion Battery Fire in Boeing 787: U.S. NTSB*. Reuters. Retrieved March 1, 2022, from https://www.reuters.com/article/us-boeing-787-battery/design-flaws-led-to-2013-lithium-ion-battery-fire-in-boeing-787-u-s-ntsb-idUSKCN0JF35G20141202

U.S. Energy Information Administration. (2019). International Energy Outlook 2019. Retrieved from https://www.eia.gov/outlooks/ieo/pdf/ieo2019.pdf

Wang, H., Zhang, Z., Milić, J., Tan, L., Wang, Z., Chen, R., . . . Luo, J. (2021). Interfacial Haloplumbate Modulation for Efficient and Stable Hybrid Perovskite Photovoltaics. ChemRxiv. doi:10.26434/chemrxiv.14331218.v1 This content is a preprint and has not been peer-reviewed.

Waypoint 2020. Aviation. (n.d.). Retrieved March 1, 2022, from https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050/

Williams, K. (2020, August 18). *As amenities sit unused, airports reconsider their design*. The New York Times. Retrieved February 20, 2022, from https://www.nytimes.com/2020/08/18/business/airport-remodeling-coronavirus-safety.html