Project ECOAir

THE OHIO STATE UNIVERSITY

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Introduction

The timeliness and convenience of air transportation has led to billions of passengers utilizing air travel each year. Future advancements in aircraft technology will only increase industry appeal, causing a rise in air traffic and passenger rate. Although beneficial for airlines, this is a cause for environmental concern, as the aviation industry currently emits vast amounts of carbon dioxide (CO_2) between heavy flight traffic, nonrenewable fuel sources, and airport operations themselves. To prevent detrimental and irreversible environmental effects, changes must be implemented within the industry, including within airport operations.

Major airline companies and aviation contributors are working on plans for greener flight within aircraft design and fuel consumption, working toward the goal of net zero emissions by 2050. Alterations of these aircraft are projected to greatly decrease harmful emissions and promote flight efficiency. The success and viability of these developments is largely reliant on airports' ability to accommodate them with necessary infrastructure. To successfully fly with fuel-efficient engines, for example, commercial airlines first require access to adequate refueling facilities and timely turnaround processes that will ensure company profitability. If future aircraft changes do come to fruition, appropriate space and facilities must be ready to accommodate them.

Project ECOAir proposes a design that suits the estimated changes in aircraft while altering current ground processes. The concept aims to promote airport convenience and efficiency, aircraft accommodation, and sustainability. Accounting for the vast predicted increase in passenger rate by 2050, the bridged gate-pod design will disperse passenger activity to mitigate gate congestion and boarding complications. Subsequent open ground space will allow aircraft to taxi between gates and runways with ease, reducing ground traffic. The current complex and costly baggage transportation process will be optimized and transitioned underground, minimizing complications for both airlines and passengers. Several fuel options will be made available, and waste from processes such as deicing will be conserved. Ground support equipment will be mostly autonomous to improve safety and decrease turnaround time. Regarding the airport facility itself, clean energy and sustainable building materials will be utilized to decrease direct emissions.

By incorporating environmentally friendly technologies and reliable infrastructure, Project ECOAir's airport will sustain efficiency in air travel to promote a brighter future of aviation.

Preliminary Research and Assessment

2050 Commercial Aviation Outlook

To perform an analysis of the expected aviation outlook in 2050, the current state of the industry must be accounted for. This includes an assessment of commercial aviation consumers, vehicle structure, energy sources, and current environmental status.

Air Transportation Rate. Passenger traffic rate experienced a steady growth for decades until 2020, when the Coronavirus pandemic led to a substantial decrease in commercial air transportation. In 2019, the global airline industry served 4.558 billion passengers [19], declining to 1.8 billion during the pandemic [27]. Boeing predicts a near full recovery by 2024 [31], and by 2050, it is estimated that the global air industry will haul 16 billion passengers and 400 tons of cargo [56]. The projected increase in global population from 7.7 billion to 9.7 billion people [29] will lead to an inevitable increase in air transportation. This will require nearly double the number of today's operational aircraft, estimating 50,000 functional planes worldwide in 2050 [54].

Aircraft Shapes and Designs. Today, most commercial planes consist of a long, slender fuselage, a vertical and horizontal stabilizer within the empennage, and capacities of 100-200 passengers [20]. Within this layout, aircraft such as the Boeing 737 family and Airbus 320 have been ruling the industry for decades. On average, it takes 15 years for major aircraft companies to begin mass production and roll out of new plane designs. Furthermore, the considerable financial component involved in major alterations disincentivizes innovation within already working components. Therefore, it is expected that the primary aircraft flown commercially in 2050 will consist of similar physical layouts to current models, with some size variations and material changes.

Figure 1: Boeing ecoDemonstrator [11]

As one of the primary contributors to commercial aviation, Boeing will likely implement aircraft improvements over the next 30 years. Recent development has been seen on the 787-Dreamliner, making it one of the top commercial aircraft in use in terms of efficiency and sustainability. Improvements have shown a 30% decrease in its CO_2 emissions and a 60% decrease in its noise footprint compared to previous models [3]. The strong carbon fiber structure and 30% fuel reduction from hybrid laminar flow control [46] predict the 787 as a leading force in coming years. Developments have also been made on the Boeing ecoDemonstrator (Figure 1), which is predicted to serve a significant number of passengers by 2050. After testing in 2021, Boeing reported that the hybrid fueled aircraft is estimated to reduce CO_2 emissions by 75% throughout its lifecycle, powered by sustainable fuel and incorporating recycled materials like carbon-composite fiber. This model is currently undergoing testing between NASA and Boeing to research the effects of sustainable fuel use in its engines [10].

Figure 3: Airbus ZEROe series [8]

Aside from Boeing, Airbus has announced promising expectations for 2050 with their ZEROe aircraft (Figure 2). The ZEROe series consists of three liquid hydrogen powered design concepts, including the Turbofan, Turboprop, and Blended-Wing Body [6]. These aircraft include a hybrid-electric propulsion system, using fuel cells to complement the gas turbine [7]. By 2035, this aircraft series will be able to carry ranges of 100-200 passengers over 1,000 to 2,000NM distances, progressing to commercial use in the next 30 years.

Figure 2: Pipistrel electric aircraft fleet [45]

Green technologies are also being developed for use in general aviation that will have strong capabilities by 2050. Small aerospace companies are creating sustainable flying methods involving all-electric models that produce little noise and zero carbon emissions. The Pipistrel Group has revolutionized pilot training with the Electro plane models (Figure 3), which require short takeoff and landing distances and significantly decrease training costs by 70% [44]. Lilium is developing the first general aviation vertical take-off and landing jet; an all-electric plane with a 6-passenger capacity that will be launched into commercial operations by 2024 [35]. Dozens of additional aerospace companies are developing electric solutions to decrease carbon emissions and provide private pilots with better flying experiences.

Overall, research shows that the most prominent large passenger flights will occur with Boeing 767, 777, and 787s, while handfuls of 737's and 747's will still be in operation. The ecoDemonstrator and Dreamliner models will provide large contributions to efficient long-duration travel. Airbus's main contributions will continue to be the 320-350 models, with an emphasis on the functional operational development of the ZEROe series. It is probable that the industry will see several successful passenger flights with the ZEROe planes, as well as fully electric powered general aviation aircraft.

Renewable Fuels and Energy Sources. Prior to the COVID-19 pandemic, the global aviation industry contributed 2.1% of the world's CO_2 emissions, producing 915 million tons of CO_2 in 2019 [5]. Representatives of air transportation have recently declared the urgent goal to reduce this number to net zero emissions within the next 30 years. The largest current contributor to aviation emissions is aircraft fuel, and therefore drastic alterations to the fuel types used must occur.

The most promising fuel outlook for 2050 is sustainable aviation fuel (SAF), made of resources such as feedstocks and waste oils [12]. By implementing SAF, the industry aims for an 80% CO_2 emission reduction compared to conventional kerosene [50]. A major benefit of SAF is the simplicity of implementation, as combustion does not require installing a new propulsion system within current aircraft. It is currently being integrated into traditional aircraft fuel, with some airlines incorporating SAF at ratios of 10-15% [33]. To reach a complete use of SAF in 2050, up to 445 million tons will be needed annually at that time [3]. The future of this fuel type looks promising according to Boeing, who recently committed to a supply agreement of 2 million gallons of SAF, with plans for 100% SAF implementation by 2030 [40]. Due to manufacturing companies' increased interest in sustainable fuel, there is an expected decrease in price in the near future. Therefore, it is assumed for this report that the use of SAF will be widely available in 2050.

Alternatively, Airbus is confident in plans for the ZEROe aircraft series, which will be primarily powered by liquid hydrogen. Although not currently developed to the point of SAF, testing of H_2 is currently underway to fulfill the requirements for incorporation into industry by 2035. In the year 2050, H_2 will be a sustainable method of propulsion for new Airbus models and will produce zero carbon emissions [6].

Within general aviation, fully electric propulsion systems will likely be integrated by 2050. Although they will not be optimized for large scale commercial aviation, it is projected that most functional private planes will be made with electric capabilities. This system will cut CO_2 emissions and decrease the cost of private flying drastically. In sum, it is likely that SAF, liquid hydrogen, and minor electric power will make up most aircraft propulsion techniques used in 2050. As such, it is crucial that these options be readily available to various airlines within future airport designs.

Landscape. Future rising sea levels predict that multiple U.S. airports will be submerged by the year 2150. When designing an airport for 2050, it is important to consider continual changes in landscape factors past this timeline to analyze the type of renovations and maintenance this design will require. There is an estimated 5m sea level rise by 2150; problematic for several airports including JFK, MIA, and SFO [14]. As these major U.S. airports become inoperable due to environmental factors, any new airport design should be placed in a location where sea level rises do not have a direct impact.

ECOAir Design Rationale

Location. The proposed location of this airport is Fairfax County**,** Virginia. The nearby existing airport, Dulles International Airport (IAD), is considered the primary airport for Virginia and Washington D.C., with 103 nonstop domestic and 52 international destinations [1]. In 2019, IAD served 24.06 million passengers, making it one of the busiest and largest airports in the U.S. [39]. Despite its heavy traffic rate, IAD has few plans to become sustainable and eco-friendly. According to U.S. News, IAD produced 3.97 million metric tons of CO2 emissions, with a carbon intensity of 95 [37]. These emissions could decrease with the implementation of a new, nearby design.

Fairfax County was chosen due to its proximity to major cities, projected population increase, elevation, and potential for carbon emission decrease. At an elevation of 312 feet [23], this location provides optimal atmospheric conditions for takeoff and landing and is located outside of the range of problematic sea level increase. The county population is projected to grow by nearly 200,000, reaching 1,308,224 by 2040 [57], deeming it a suitable location for industry and employment opportunities. The average annual temperature is predicted to rise from 56.5˚F currently to 60.7˚F in 2050, providing optimal conditions for functional renewable energy sources such as wind turbines and solar panels [41]. This airport, in replacement of Dulles, will become a central destination for the Northeastern United States. The current Dulles airport will primarily function as a cargo and non-passenger transportation hub. Consequently, passenger emissions will be largely reduced, while still utilizing the space occupied by Dulles' current facility.

Figure 4: ECOAir airport concept

Physical Airport Structure. The new airport will centralize all passenger activities within the main building. There will be an underground facility that hosts all preflight activities prior to leading passengers up escalators to the main floor, where they will begin the boarding procedure. Passengers will be directed through one of the four bridges that span across the taxiways, each leading to several gate pods. These pods separate what would be considered a main terminal into smaller sections to decrease passenger congestion and provide convenient gate access. Extending above each terminal is a rounded bridge that allows easy transport between gates for passengers with connecting flights. This simplification allows these passengers to bypass the main building and incoming bridge traffic during layovers. Planes can easily arrive and depart from gates more independently from surrounding aircraft and will have plenty of space to move between pods to reach the runways. The back wing-like walls provide storage for ground operation equipment on one side and small electric charging stations on the other. See Figure 4 for the final design.

Infrastructure. The airport building infrastructure is sustainable, made from materials such as mass timber and reused steel. Mass timber is fire-resistant and strong, weighing 1/5 that of a concrete alternative and demonstrating a high strength-to-weight ratio [53]. Construction is cost efficient, as mass timber buildings are roughly 25% faster to construct than concrete buildings and require 90% less construction traffic. Replacing steel with mass timber reduces building carbon emissions by roughly 20%. The use of mass timber can also sequester CO_2, ultimately inverting emissions [53]. Additionally, the airport incorporates electrochromic glass windows as a means of energy conservation. As the U.S. Department of Energy reports, conventional windows experience energy loss accounting for 30% of heating and cooling energy. Using electrochromic "smart" glass that adapts to external conditions will minimize energy use by reducing heat energy in the winter and air conditioning in the summer, as well as electrical lighting year-round [48]. Electrochromic windows have been evaluated to provide significant heating, ventilation, and air conditioning (HVAC) and lighting savings, specifically in commercial buildings. They are especially efficient when windows are unobstructed by neighboring buildings, making it a beneficial component of this airport that is surrounded by flat land. Finally, the exterior roofing and general exterior of the airport will be colored white. A light exterior will reduce greenhouse effects by a small margin and will keep the airport cooler in the summers, reducing energy consumption via the HVAC system [43].

Apron and Taxiways. The ground space will be comprised of graphene-enhanced materials using the recently developed Gipave technology: a polymeric asphalt super modifier made of nanotechnology and recycled plastic [30]. Not only is this material proven to resist long term deformation on busy runways, but it will produce 70% less CO_2 emissions compared to standard asphalt [58]. Results from testing the low-maintenance, environmentally friendly material project it to be a cost effective, sensible option for a 2050 airport.

Ground Operations. The majority of ground support equipment, including crew transport and taxiing devices, will be fully electric and mostly autonomous. These devices will be stored in the back wings of the facility with access to several charging stations powered by solar panels.

Figure 5: Taxibot in use [51]

To conserve fuel, Taxibots will assist pilots in gate pushback and guide the plane across the apron (Figure 5) [51]. A Taxibot is a semi-autonomous device controllable by the pilot, capable of towing large class aircraft. CO_2 emissions and noise levels will be significantly reduced because of its use, as aircraft engines will not have to be powered on upon initial departure. No aircraft modifications will be required for this device to be used, and 85% of the normal taxiing fuel consumption will be cut compared to current gate pushback processes [28]. Fuel can be conserved so that the pilot must only power on the engines directly before takeoff, at which point the Taxibot will continue directing the plane to the runway, streamlining traffic on the apron. The Taxibot and other autonomous devices will increase the safety of ground operations. Incorporating artificial intelligence will decrease ground accidents caused by human error, while still allowing options for pilots to take full control of the plane's path if necessary.

Deicing. Today, aircraft deicing procedures result in the excess drainage of harmful chemicals into local water supplies. Solutions to this issue have been attempted by collecting the runoff water, yet this does not completely negate the thousands of gallons of wasteful fluid currently used in a single process.

To combat the issue of wasted deicing fluid, two alternative methods will be implemented at this airport. First, an open hangar will be built with infrared lighting to mostly replace use of fluid. This hangar will reduce glycol use by as much as 90% and will complete the deicing process in 75% less time than current methods. As a second option to infrared, controlled atmosphere separation technology (CAST) will be available, should standard glycol mixtures be needed in severe weather conditions. CAST will distill the mixture of deicing fluid and water collected on the ground to separate the fluid from runoff water. With CAST, up to 57% of all the deicing fluid used on aircraft can be treated for further re-use or resale [16]. By recovering the deicing fluid using this process, airports currently can save nearly $3.50 per gallon recycled. This economic benefit will allow CAST to maintain a profit over time and will be a greener alternative to allowing deicing fluid to drain into the Fairfax County water supplies. Overall, pairing infrared technology with as-needed fluid separation procedures will drastically decrease wasted material, and infrared heating will especially improve turnaround time between flights.

Figure 6: Visual of underground baggage conveyor belt

Baggage. Baggage systems in current airports include a variety of conveyor belts and scanners, tracking luggage from main baggage check to the aircraft. It requires substantial labor to move bags off the belts, onto trucks, and into the plane. A large portion of traffic on the ground space is a result of time-consuming luggage loading. To mitigate mistakes and time delays, this system will be optimized and redesigned. Bags will be transported via conveyor belts from baggage check to an underground sorting location, centralized underneath the main structure of the airport. Here, bags will be autonomously sorted into grouped luggage pod units using pre-existing scanning technology and machine learning. These pods will move on radial conveyor belts directly up to the gate to which they will be captured and loaded into the aircraft.

Fuel. Fuel sources will be available for refueling at gates through an underground piping system. SAF and liquid hydrogen fuel lines will be separated, each leading to different gates. Refueling will continue to take place simultaneously with passenger turnover. Automated fuel trucks will be available as a secondhand fueling option, should there be maintenance occurring on the underground piping system. A liquid hydrogen hub, primarily used by ZEROe planes, will be placed on the airport grounds, using electrolysis to provide fuel to the fuel lines.

Sustainable Energy. Project ECOAir has incorporated several forms of sustainable energy sources projected to be easily accessible 30 years from now: the main features being solar panels and wind turbines. Considering the expected upcoming surge in use of solar energy, solar panels are a lucrative option to power airport components. This is due to their low cost and the anticipated high demand for rechargeable hybrid aircraft. Panels will be located on the roof of the main building as well as edges of the airspace. Strategically placed mirrors will redirect deflected light to surrounding panels, increasing each panel's efficiency, while adhering to FAA regulations regarding glare [32]. Sun tracking technology will also be used to align the panels so that maximum efficiency can be achieved throughout each day. Most of the solar power output will contribute to the electric charging stations in place for both aircraft and ground support equipment.

Quiet Revolution vertical axis wind turbines (Figure 7) will be placed in pairs along the edges of the airport green space, each pair spanning 9.3m to prevent wind interference. Variations of 6m tall masts support the turbines, using a hydraulic system to position the turbine horizontally for maintenance. Energy conversion results from a 3.13m diameter of rotation, requiring significantly less space than traditional wind turbines [45]. These turbines will be used for their sustainable, carbon-fiber composition and impact on noise reduction. They will operate under 20m/s wind speeds, making them a useful option for Fairfax, County, as the highest expected wind speed ranges from 4-10m/s [13]. These devices are predicted to remain operational for the airport past the year 2080, prior to needing replacement.

Figure 7: QR6 turbines [45]

Geothermal technology will be utilized in the form of an underground piping system, taking advantage of the natural difference between subsurface soil temperatures and above-ground air. The main building will be heated through a series of buried pipes circulating fluid. A heat exchanger will then transfer heat into the building's existing air handling, distribution, and ventilation systems. Fluid will be recirculated back into the ground and heated again. For cooling, the geothermal heat pump will use the ground as its heat sink, releasing heat through the pipeline loop configuration [21]. This geothermal method is especially efficient because it is not dependent on consistent temperatures and weather conditions. This technology will reduce the airport greenhouse gas emissions by 40% compared to standard heating processes. It will also reduce water consumption, eliminating the costliest components of the airport's HVAC system [53].

Technology Readiness Levels (TRLs)

Integral components of this proposal involve technology that has mainly been successfully tested, while minor additions require further improvement to be put into use. Assessing TRLs can provide an estimate of the improvements necessary to integrate this airport design in the coming years. See Table 1 and 2 below for a breakdown of these assessments [55].

Table 1. TRLs – Aircraft Components

Component	Current TRL	Projected 2050 TRL	Critical Rank*	Justification
Electric vertical takeoff jet	6	8/9	2	- Beginning stages of development and testing - Not absolute necessity for airport concept success; low critical rank
Airbus ZEROe aircraft	6	8	4	- Plans underway for testing and implementation - Expected market output by 2035 - Only component requiring hydrogen hub use in airport concept; high critical rank
SAF	9	9	5	- Small amounts currently implemented into Jet A fuel - Essential component of efficient fuel plans; high critical rank

*Critical Rank: Refers to the necessity of component in the airport design. 1-Low Importance, 5-Design critical

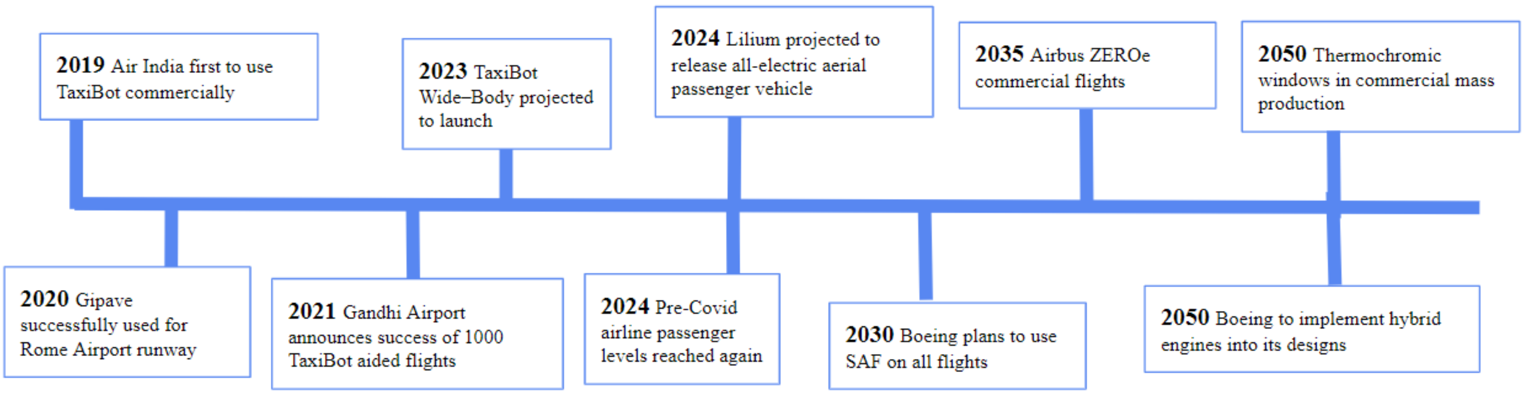
Table 2. TRLs – Airport Components

Component	Current TRL	Projected 2050 TRL	Critical Rank*	Justification
Electrochromic glass windows	7	8/9	3	- Commercially available, undergoing continual testing - Will improve energy efficiency, but not integral to design success; mid critical rank
Gipave	7	9	5	- Initial testing recently proven successful on European runways - Integral to runway composition; high critical rank
Taxibot	9	9	4	- Proven success at major airports - Efficient ground maneuvers dependent on component; high critical rank
CAST Deicing	9	9	2	- Approved in U.S. - Secondary role to infrared deicing; low critical rank
Infrared Deicing	8	9	5	- Used at major airports like JFK - Primary method of deicing and waste conservation; high critical rank
Sun Tracking	7	9	3	- Currently operational - Airport has high power demand and space must be conserved; mid critical rank

*Critical Rank: Refers to the necessity of component in the airport design. 1-Low Importance, 5-Design critical

Implementation Timeline

Below is a timeline representing major technology milestones relating to the airport technology. These advancements are necessary for the complete success of this 2050's design concept.



Citations: Row 1 - [28, 28, 36, 6, 34]
Row 2 - [49, 28, 31, 40, 9]

Conclusion

ECOAir's design concept features will greatly increase airport efficiency and contribute to the industry-wide goal of reaching net-zero emissions. Passenger convenience is achieved through streamlined paths to terminals, while ground operation efficiency is optimized through use of automated devices and underground baggage transportation. This airport concept can accommodate the predicted variability in aircraft, offering a variety of fuel options and adequate ground space. Finally, sustainability will be achieved through use of eco-friendly runway materials, renewable energy, and waste conservation. Future developments within this proposal will focus mainly on the baggage system and deicing process. Regarding baggage, current AI developments suggest that passengers could be offered additional options regarding their luggage claim, such as allowing the airport to deliver luggage within a defined radius. Additionally, innovative uses for the conserved deicing fluid should be explored, such as storing the leftover glycol from CAST for deicing wind turbines in cold weather. Further developing these unique elements will elevate the success and capability of the facility.

In the next 30 years, air travel will undergo exciting developments to curate a more sustainable industry. While monitoring innovation of commercial aircraft, engineers must think creatively to construct facilities that will adapt to the anticipated changes, ensuring adequate aircraft resources and positive passenger experience. The TRL levels listed indicate that this airport concept is implementable, as much of the technology is available. Therefore, airports do currently have the potential to transition to greener flight. However, the cost and construction implications of tearing down and remodeling an existing airport present an array of limitations. It is for this reason that this project proposes an entirely new design with alternative plans for existing locations.

Aviation in its past, present, and future states is centered around innovation. From the first successful flights of early aircraft models to now, where thousands of commercial aircraft operate each day, the industry has made significant advancements that have gained substantial societal interest. Looking toward the future, engineering initiatives such as Project ECOAir are pushing the boundaries of conventional air transportation, promoting monumental strides toward greener flights and bluer skies.

Appendices

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Appendix B: Calculations

1. Construction Emission Savings:

$$0.7x + 0.2y = z \qquad (1)$$

$x =$ asphalt paving emissions (kg or tons), $y =$ concrete mixing emissions in (kg or tons), $z =$ total reduced construcxtion emissions in (kg or tons)

2. General Reduce Emissions:

Assumptions:

a. All ground vehicles are powered by renewable sources.
b. Planes utilize TaxiBot whenever possible.
c. 10% of fuel used in each flight is during takeoff and landing.

$$E = C - (G + 0.085F * N) \qquad (2)$$

$E =$ Airport emissions after green practices (tons/year), $C =$ Baseline emissions before green practices (tons/year), $G =$Emissions due to ground vehicles (tons/year), $F =$Emissions due to jet fuel for one flight (tons/flight), $N =$ Number of flights per year (flights/year)

3. Deicing Savings:

Given: 90% of glycol reduced to IR Deicing, $125 dollars per IR deicing, 4000 gal./plane without IR deicing, 57% of glycol is re-used using CAST, $3.50 saved per gal. using CAST,

$$(4000 * 20) - [(172 * 16.5) + 125] = \$51495 \text{ saved per deicing} \qquad (3)$$

$$100 * \frac{(0.1)*(4000)*(1-0.57)}{4000} = 4.3\% \text{ of original glycol to be replaced compared to traditional methods}$$