# SCA New Technology R+D
# Application of Biofuel in NYC Schools

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## 1. Executive Summary

**NYC Goals to Reduce Carbon Emissions**

NYC has created policies, laws, and initiatives to massively reduce the City's carbon footprint. In 2014, NYC committed itself to the 80x50 plan, to reduce greenhouse gas emissions 80% from 2005 levels by 2050 with an interim target of 40% by 2030. In 2017, NYC went further by issuing Executive Order 26, committing itself to the Paris Climate Agreement which targets carbon neutrality and 100% clean electricity by 2050.

**Why Biofuel?**

Biofuels are a plant and/or animal based renewable alternative to fossil fuels. They burn cleaner and with lower emissions compared to the No. 2 and No. 4 heating oils used in NYCDOE schools. Biofuels can be used as an interim carbon reduction strategy while NYC moves to achieve full electrification of the DOE portfolio.

**Benefits of Biofuel**

Biofuels can be potentially used with existing boiler plants after retrofitting certain equipment. This lowers the project costs of a biofuel retrofit program compared to an electrification program due to the reduced scope and ability to work with existing equipment [1].

There are 175 schools that use No. 4 oil and 640 schools that use No. 2 oil [2]. These schools have emitted a total of 201,168 $tCO_2e$ in FY2021. The NYCSCA plans to convert all schools away from No. 2 and No. 4 oil to B99.9/B100. Consultations with fuel suppliers, burner manufacturers, and researchers from Brookhaven National Laboratory (BNL) and the National Oilheat Research Alliance (NORA) have informed the process in which biofuel can be used in existing schools. Data from the 2016 NYC GHG Inventory as well as different research studies by BNL and NORA were used to estimate the potential emission reductions when switching from fuel oils to B99.9/B100.

Compared to FY2021 emissions from No. 4 oil, annual emissions[1] would potentially decrease as follows:

- $CO_2$ by 85%
- $N_2O$ by 82%
- $NO_x$ by 88%
- $SO_2$ by 99 to 100%
- $PM_{2.5}$ by 99 to 100%

[1] Biofuels are an evolving field of research. Emission reductions are based on research spanning the past 20 years and may change as further scientific research is conducted.

Compared to FY2021 emissions from No. 2 oil, annual emissions[1] would potentially decrease as follows:

- $CO_2$ by 85%[2]
- $N_2O$ by 74%
- $NO_x$ by 74%

In April of 2017, NYC enacted Local Laws 60 and 64 which created an Environmental Justice Advisory Board. They are tasked with creating the Environmental Justice for All Report, the City's first comprehensive study of environmental justice (EJ). This report will identify EJ areas within NYC and analyze environmental and climate issues [3, 4]. Environmental justice areas are defined as low-income or minority communities located in NYC that are vulnerable to a disproportionate amount of adverse environmental consequences. Residents in NYC EJ areas are exposed to higher amounts of airborne pollutants such as ozone and particulate matter, resulting in a higher prevalence of asthma. Replacing No. 2 and No. 4 oil with biofuel in school buildings will help to reduce GHG emissions and lower health risks.

Biofuels are an excellent energy alternative as an intermediate step to full electrification. The reductions in GHG emissions, reduced health risks in disadvantaged communities, lower implementation costs compared to electrification, and B99.9's similar fuel cost to No. 2 oil justify the replacement of No. 4 oil with biofuels in NYC schools.

[2] $CO_2$ emissions from #2 and #4 oil can be reduced by 99.9% based off of the biodiesel emission factor in the "Inventory of New York City Greenhouse Gas Emissions in 2016" report. Based on conversations between the NYCSCA, NORA, and REG, an 85% reduction in emissions would be a more conservative estimate since carbon emissions from feedstock production should be considered.

## 2. Introduction

### 2.1 Reducing Carbon Emissions

The City of New York acknowledges that global warming and climate change threaten the environment and human health. To mitigate one of the causes of these issues, the City is committed to reducing greenhouse gas (GHG) emissions 80% below 2005 levels and achieving carbon neutrality by 2050. NYC is also committed to the goals of the Paris Climate Agreement and will take action to limit the average global temperature rise to 2°C above pre-industrial levels.

According to the FY 2020 Inventory of New York City Greenhouse Gas Emissions, City government buildings generated 1.86 $MtCO_2e$, accounting for 66% of City government GHG emissions [5]. Figure 1 shows that buildings are the predominant cause of GHG emissions in the City government portfolio.

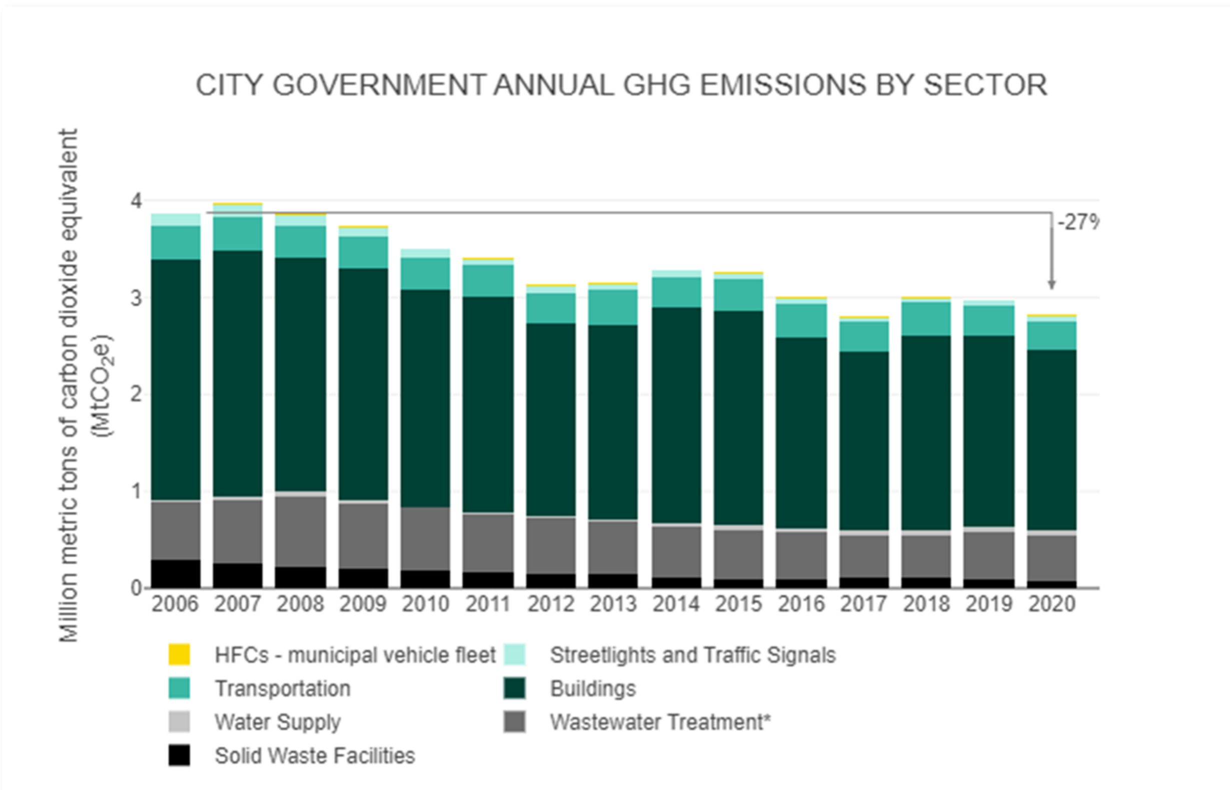


**Figure 1: City Government Annual GHG Emissions by Sector [5]**

Biodiesel use can help reduce City government building GHG emissions. In the case of DOE schools, biodiesel is not widely used. The GHG inventory shows that biodiesel is responsible for only 0.44% of source energy of NYC DOE schools – much less than oil No. 2 and No. 4. Figure 2 shows the source energy consumed per fuel type for NYC DOE schools.

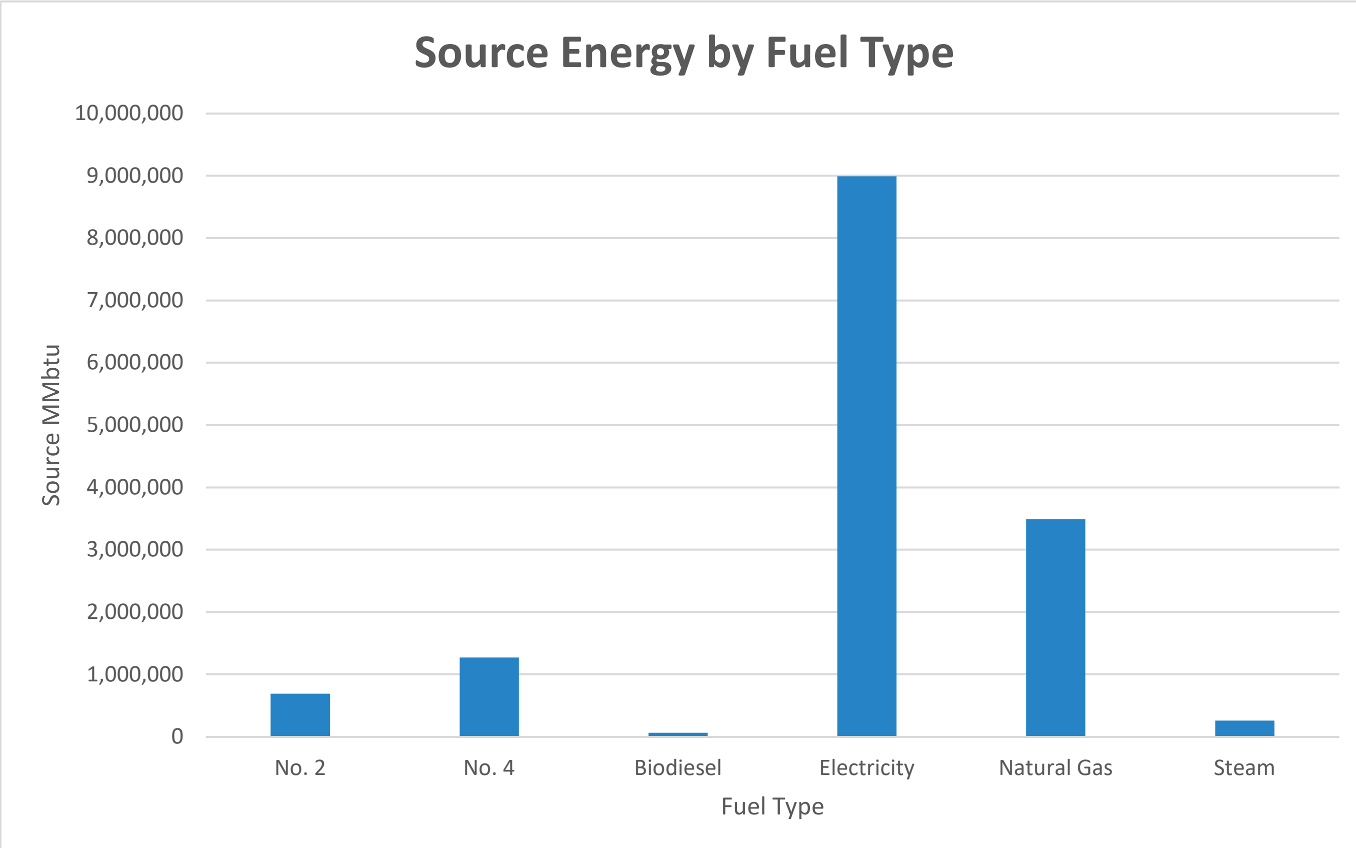


**Figure 2: FY 2020 New York City Source Energy [6]**

The current limited use of biodiesel is due to equipment compatibility with fuel blends that have more than 20% biodiesel, requirements for Underwriters Laboratories (UL) listed equipment [7], and unfamiliarity with the research-generated data on the biodiesel. Regarding the UL listing, the UL 296 standard applies to oil burners and its scope currently includes liquid-fuel-fired burners using biodiesel blends up to B100 as of November 2022.

## 2.2 State, Local Laws, and Building Code

Local Law 119/2016 does not permit No. 2 or No. 4 heating oil that does not contain [8]:

- No less than 10% biodiesel by volume (B10) by Oct 1, 2025
- No less than 15% biodiesel by volume (B15) by Oct 1, 2030
- No less than 20% biodiesel by volume (B20) by Oct 1, 2034

Local Law 43/2010 required heating oils to contain minimum 2% biodiesel by volume (B2) [9]. Currently, heating oils containing no less than 5% biodiesel by volume (B5) are being used since 2017, as per the Local Law 119/2016. The NYC Department of Environmental Protection had also instated a rule that regulates the emissions from using No. 4 and No. 6 fuel oils in heat and hot water boilers and burners.

As of January 1, 2030, boilers must use natural gas, No. 2 fuel oil or its equivalent [10]. Fuel oil grades No. 4 and No. 6 are only permitted if it can be demonstrated that these fuels will emit no more PM and NOx than No. 2 fuel oil on an annual basis.

The State of New York will ban the use of No. 6 heating oil in buildings in 2023 [11]. In 2014, New York launched its energy policy, “Reforming the Energy Vision (REV)”, which sets three main energy goals for 2030 [12]:

- 40% reduction in GHG emissions from 1990 levels
- 50% generation of NY’s electricity must come from renewable energy sources
- 23% decrease in building energy consumption from 2012 levels

In addition, the Climate Leadership and Community Protection Act (CLCPA) went into effect on January 1, 2020. This set more stringent energy and emission targets [13]:

- 85% reduction in GHG emissions by 2050 from 1990 levels
- 70% renewable energy by 2030
- 100% zero-emission electricity by 2040

### 2.3 Environmental Justice and Social Prioritization

On September 27, 2021, the United States filed suit under the Clean Air Act against the City of New York and the NYC Department of Education (NYCDOE) [14]. The consent judgement filed required NYCDOE to:

- Conduct regular tune-ups to monitor and repair its boilers as required by the Clean Air Act to control emissions
- Reduce boiler emissions by converting seven of NYCDOE’s largest oil-fired boilers to natural gas boilers by 2023
- Pay a civil penalty of $1 million to the United States

Many of NYCDOE’s boilers are located in communities identified by the EPA as an environmental justice area. This designation is due to the many low-income and minority residents that are being disproportionately exposed to air pollution. The regular tune-ups and boiler fuel conversion programs are aiming to mitigate air pollution and improve environmental and human health in these communities.

## 3. Overview of Biofuels

### 3.1 Biodiesel

Biodiesel is a form of diesel fuel that is the product of refined organic matter such as animal fats, waste vegetable oils, soybean oil, and algae. It can be mixed with other fuels to create blends. B100 refers to pure 100% biodiesel. B99.9 refers to a blend with 99-100% biodiesel by volume. B20 refers to a blend that is 20% biodiesel by volume. Biodiesel is usually blended with petroleum fuel oil. For consistency, this report will refer to B99.9 as the highest blend that the NYCSCA will pursue. The lower cost of B99.9 compared to B100 and its similar cost to No. 2 oil are determining factors for use of B99.9.

Biodiesel is produced through a transesterification process where lipids react with alcohol in the presence of a strong catalyst to form fatty acid methyl esters. These esters are the biodiesel [15]. Glycerin is produced as a byproduct. After refinement, the biodiesel is ready for blending or direct use [16].

### 3.2 Renewable Diesel (RD)

Renewable diesel (RD) is made from similar feedstocks as those employed for biodiesel, particularly vegetable oils and animal fats, as well as cellulosic biomass such as wood biomass and crop residues. Renewable diesel is also known as green diesel, renewable hydrocarbon diesel, hydrotreated vegetable oil (HVO), hydrogenation derived renewable diesel (HDRD), Fischer-Tropsch renewable diesel (FTRD), and non-ester renewable diesel [17].

The production process for RD is different than that for biodiesel and can include chemically different components. RD can be made by one of three different processes: hydrotreating, thermal conversion, and biomass-to-liquid process [18].

- Hydrotreating, or hydrogenation, utilizes triglycerides. It adds hydrogen to lipids to eliminate elements of oxygen, nitrogen, and metal.
- Thermal conversion, also known as depolymerization, creates oil out of carbonized biomass. It uses pressure and heat to decompose long-chain polymers of hydrogen, oxygen, and carbon into short-chain hydrocarbons [19].
- Biomass-to-liquid process involves gasification which is the conversion of biomass into synthetic, hydrogen-rich gas mixtures using high temperatures [20].

As a result of these different production processes RD has no oxygen content, unlike biodiesel.

# 4. Emissions and Environmental Effect of Biofuels

## 4.1 Carbon Accounting

**Emission Scopes**
Emissions are grouped into three scopes:

- *Scope 1 Emissions:* These are direct emissions that are controlled or owned by an organization. For example, boiler emissions would be a scope 1 emission for school facilities.
- *Scope 2 Emissions:* These are indirect emissions from purchased energy such as electricity, steam, heat, or cooling.
- *Scope 3 Emissions:* Also known as value chain emissions, these are indirect emissions from assets not owned or controlled by the organization. Any emissions outside the boundaries of the first two scopes would fall under the third scope. Examples of scope 3 emissions include employee commuting, transportation, distribution, processing of sold products, and use of sold products. The boiler emissions from burning biodiesel would be counted as a scope 3 emission for the manufacturers of biodiesel, since it is the use of a sold product.

**Greenhouse Gas Accounting Methodologies**
There are two ways to quantify GHG emissions: lifecycle GHG accounting and GHG inventories. Lifecycle accounting evaluates the GHG emissions throughout a product's life from raw material extraction all the way to its use and end-of-life management. GHG inventories are an accounting of overall emissions for a specific entity such as an organization or municipality [21].

NYC uses GHG inventories to track emissions. There is the Citywide Inventory which reports emissions within the 5 boroughs and there is the City Government Inventory which only reports emissions associated with NYC government operations. These inventories are an accounting of consumption-based emissions which are defined as (a) emissions within the City, plus (b) emissions from goods and services produced outside the City, but imported for consumption by City residents, and (c) minus emissions from productions of goods and services exported outside the City [22]. This is intended to reflect supply chains and life cycle emissions within the boundary of NYC.

The "Inventory of New York City Greenhouse Gas Emissions in 2016" report lists fuel emission factors for $CO_2$, $CH_4$, $N_2O$, and $CO_2e$. It should be noted that this inventory has an emission factor for fossil fuel $CO_2$ and one for biogenic $CO_2$. According to Matt Herman, the Director of Environmental Science at Clean Fuels, reporting biogenic emissions separately allows the inventory to distinguish between biomass and fossil fuels as being the emission source [23]. He also says this allows climate scientists to compare the emissions to carbon uptake and losses in land and forestry. If the amount of biogenic $CO_2$ emitted is less than or equal to the amount of $CO_2$ in plants, animals, and soils, then that would indicate biofuels are being created and used sustainably.

The $CO_2e$ factor for biodiesel is 0.002 kg/liter which is much smaller than its biogenic $CO_2$ factor of 2.0094 kg/liter, indicating that the biogenic $CO_2$ is not being factored in with the $CH_4$ and $N_2O$ emissions to get the $CO_2e$ factor. Based on this $CO_2e$ factor, biodiesel can potentially reduce GHG emissions by over 99% compared to No. 4 oil.

### 4.2 Emission Reductions

This section focuses on the potential emission reductions from the use of biofuels in school heating plants.

**Definitions**

*Flash point* – the lowest liquid temperature at which the vapors near the surface of the fuel will ignite when exposed to an open flame.

*Cloud point* – the temperature at which a fuel starts to form wax crystals which causes the fuel to look cloudy [24]. This solid wax can clog filters and fuel atomizers. This parameter is important for determining a fuel's performance in winter conditions.

*Pour point* – describes the tendency of a fuel to resist flow due to the formation of wax. It is measured as 5°F above the temperature at which the fuel does not flow [25]. This parameter is important for determining a fuel's performance in winter conditions.

*Cetane number* – a measurement of combustion quality or ignition delay of diesel fuel during compression ignition [26]. Fuels with higher cetane numbers will have shorter ignition delays.

**Fuel Comparison Tables**

Table 1 presents select thermochemical properties, as well as values from ASTM standards. Exact values are dependent on the manufacturer. Tables 2, 3 and 4 compare the quantities of key types of pollutants that result from burning each type of fuel. Data is taken from various sources such as the 2016 NYC GHG Inventory, the EPA's Compilation of Air Pollutant Emission Factors, and research studies from the National Oilheat Research Alliance and Brookhaven National Laboratory. A comparison between more fuels can be found in **Appendix A**.

The NYCSCA uses this data to estimate emissions reductions in their boiler conversion projects [1]. More conservative emission factors are used for biodiesel instead of the emission factors from the NYC GHG Inventory, since those suggest a 99.9% reduction in emissions compared to No. 4 fuel oil. A life cycle analysis by Argonne National Laboratory found that emissions for B99.9 are between 57 to 74% lower than those of petroleum diesel [27].

It should be noted that the $PM_{2.5}$ emissions in Table 3 for B20 and B99.9 are the same as those for No. 2 oil. According to a research paper by Brookhaven National Laboratory, there is a strong correlation between $PM_{2.5}$ emissions and the sulfur ppm in the fuel [28]. Dr. Tom Butcher, a researcher at the National Oilheat Research Alliance (NORA), has recommended using the same emission rates for No. 2 oil and blends of biodiesel, since their sulfur levels are similar and both are capped at 15 ppm per their relevant fuel standards [29]. Additionally, it should be noted that $SO_2$ emissions for B99.9 can be as high as that for No. 2 oil indicated in Table 2, but this is dependent on the manufacturer as the sulfur content within the fuel ranges between 0-15 ppm.

The $CO_2$ and $N_2O$ emission factors for electricity are from the 2016 report on NYC's GHG inventory [22]. The $NO_x$ and $SO_2$ emission factors are based on the statewide electricity profile for NYS in 2021 [30]. While the emission factors for electricity are higher than those for biodiesel, New York City will be powered by wind, solar, and hydropower from upstate New York and Canada. This will result in 100% clean power for New York City government operations by 2025 [31].

**Table 1: Key Fuel Properties Comparison**

| PROPERTY | UNITS | NO. 2 FUEL OIL | NO. 4 FUEL OIL | NATURAL GAS | B20 | B99.9 |
|---|---|---|---|---|---|---|
| Heating Value | Btu/gal | 138,490[33] | 146,000[32] | n/a | 136,384 | 127,960[33] |
| Carbon | weight % | 84.15[17] | 86.1[32] | 65-80[34] | 82.67 | 77[33] |
| Sulfur (max) | PPM | 15[35] | 1500[36] | < 0.0229[88] | 15[33] | 0 - 15[33] |

**Table 2: Key Gaseous Pollutant Emissions**

| POLLUTANT | NO. 2 FUEL OIL | NO. 4 FUEL OIL | NATURAL GAS | ELECTRICITY | B20 | B99.9 |
|---|---|---|---|---|---|---|
| Carbon Dioxide $CO_2$ ($tCO_2e$/MMBtu) | 0.07414[22] | 0.07617[22] | 0.05[22] | 0.07632[22] | 0.05799 | 0.01118 |
| Nitrogen Oxides $NO_x$ (kg/MMBtu) | 0.0783[37] | 0.172[37] | 0.0445[91] | 0.0665[30] | 0.0674 | 0.0206[38] |
| Sulfur Dioxide $SO_2$ (kg/MMBtu) | 0.000695[37] | 0.0704[37] | 0.0002668[91] | 0.01329[30] | 0.000563 - 0.000695 | 0[38] - 0.000695 |

**Table 3: Particulate Matter Emissions**

| POLLUTANT | NO. 2 FUEL OIL | NO. 4 FUEL OIL | NATURAL GAS | B20 | B99.9 |
|---|---|---|---|---|---|
| Particulate Matter $PM_{2.5}$ (kg/MMBtu) | 0.000027[28] | 0.01247[1] | 0.0008449[91] | 0.000027[28] | 0.000027[28] |

**Table 4: Volatile Organic Compound Emissions**

| POLLUTANT | NO. 2 FUEL OIL | B99.9 | NATURAL GAS |
|---|---|---|---|
| 1,2-Dichlorobenzene (kg/MMBtu) | 5.49E-04 | 1.09E-03 | n/a |
| Acetone (kg/MMBtu) | 2.47E-05 | 2.96E-05 | n/a |
| Carbon Disulfide (kg/MMBtu) | 2.03E-05 | 7.21E-05 | n/a |
| Ethanol (kg/MMBtu) | 1.34E-05 | 4.5E-05 | n/a |
| Formaldehyde (kg/MMBtu) | 3.16E-05 | 1.4E-03 | 3.34E-05 |

**NYCSCA Emissions Profile for No. 2 and No. 4 Oil Conversion Projects**

There are 175 NYCDOE schools using No. 4 oil burners and 640 schools using No. 2 oil burners. In FY2021, they consumed over 10.5 million gallons of No. 4 oil and over 7.9 million gallons of No. 2 oil. The plan is to convert all No. 4 oil burning schools to a cleaner fuel by 2027. The DSF plans to initially replace No. 4 oil in some schools with 2B20, a blend of biodiesel and No. 2 oil. The goal is to replace No. 2 and No. 4 oil with B99.9 in all schools. Table 5 shows the total FY2021 emissions from No. 2 and No. 4 oil-burning schools. The $SO_2$ and $PM_{2.5}$ emissions for No. 2 oil are less than those for No. 4 oil due to No. 2 oil's lower emission factors as shown in Table 2 and Table 3. These lower emission factors are a result of No. 2 oil's lower sulfur content compared to that of No. 4 oil as explained earlier.

**Table 5: FY2021 Total Emissions Profile of Schools with No. 2 and No. 4 Oil Burners [1]**

| FUEL | CARBON DIOXIDE $CO_2$ [$tCO_2e$] | NITROUS OXIDE $N_2O$ [KG] | SULFUR DIOXIDE $SO_2$ [KG] | PARTICULATE MATTER $PM_{2.5}$ [KG] |
|---|---|---|---|---|
| No. 4 Oil | 116,095 | 916 | 107,283 | 19,007 |
| No. 2 Oil | 85,073 | 688 | 797 | 31 |

Table 6 shows the potential emission reductions if all No. 4 oil burning schools switched to a blend of biodiesel. B99.9 can reduce GHG emissions by over 80%. There is also an extreme reduction in $SO_2$ and $PM_{2.5}$ emissions when switching to either B20 or B99.9.

**Table 6: Potential Emission Reductions from Using Biodiesel vs. No. 4 Oil**

| FUEL TYPE BEING USED | CARBON DIOXIDE $CO_2$ REDUCTION [$tCO_2e$] | NITROGEN OXIDE $NO_X$ REDUCTION [KG] | NITROUS OXIDE $N_2O$ REDUCTION [KG] | SULFUR DIOXIDE $SO_2$ REDUCTION [KG] | PARTICULATE MATTER $PM_{2.5}$ REDUCTION [KG] |
|---|---|---|---|---|---|
| B20 | 23.9% | 60.8% | 21.6% | 99% | 99.78% |
| B99.9 | 85.3% | 88% | 81.9% | 99% | 99.78% |

**Table 7** shows the potential emission reductions if all No. 2 oil burning schools switched to a blend of biodiesel. There are similarly large reductions in $CO_2$, $NO_x$, and $N_2O$ emissions.

There will be little to no reduction in $SO_2$ and $PM_{2.5}$ emissions when switching from No. 2 oil to biodiesel because they have very similar sulfur content. As mentioned previously, both No. 2 oil and biodiesel can have at most 15 ppm of sulfur. Having similar sulfur content means that these fuels will have similar $SO_2$ and $PM_{2.5}$ emissions.

**Table 7: Potential Emission Reductions from Using Biodiesel vs. No. 2 Oil**

| FUEL TYPE BEING USED | CARBON DIOXIDE $CO_2$ REDUCTION [$tCO_2e$] | NITROGEN OXIDE $NO_x$ REDUCTION [KG] | NITROUS OXIDE $N_2O$ REDUCTION [KG] | SULFUR DIOXIDE $SO_2$ REDUCTION [KG] | PARTICULATE MATTER $PM_{2.5}$ REDUCTION [KG] |
|---|---|---|---|---|---|
| B20 | 21.8% | 13.9% | 21.6% | 0% | 0% |
| B99.9 | 84.9% | 73.7% | 81.8% | 0% | 0% |

## 4.5 Biodiesel Capacity, Costs, and Demand

### Capacity

The U.S. had a production capacity of 2,476 million gallons of biodiesel in 2020 and produced a total of 1,817 million gallons which is a 73% utilization rate [39]. A 2014 biodiesel report found that biodiesel plants in the region that supplies NYC were only operating at 30% of available capacity [7]. Plant utilization will likely increase to meet biodiesel demand in the future so biodiesel supply will not be a concern.

Based on EIA data, there are no producers of biodiesel within New York state [40]. Iowa has 10 producers with a production capacity of 459 million gallons of biodiesel, the largest for a single state in 2020. Renewable Energy Group (REG), which is headquartered in Iowa, is the largest producer of biodiesel in the U.S. as shown in Figure 3.

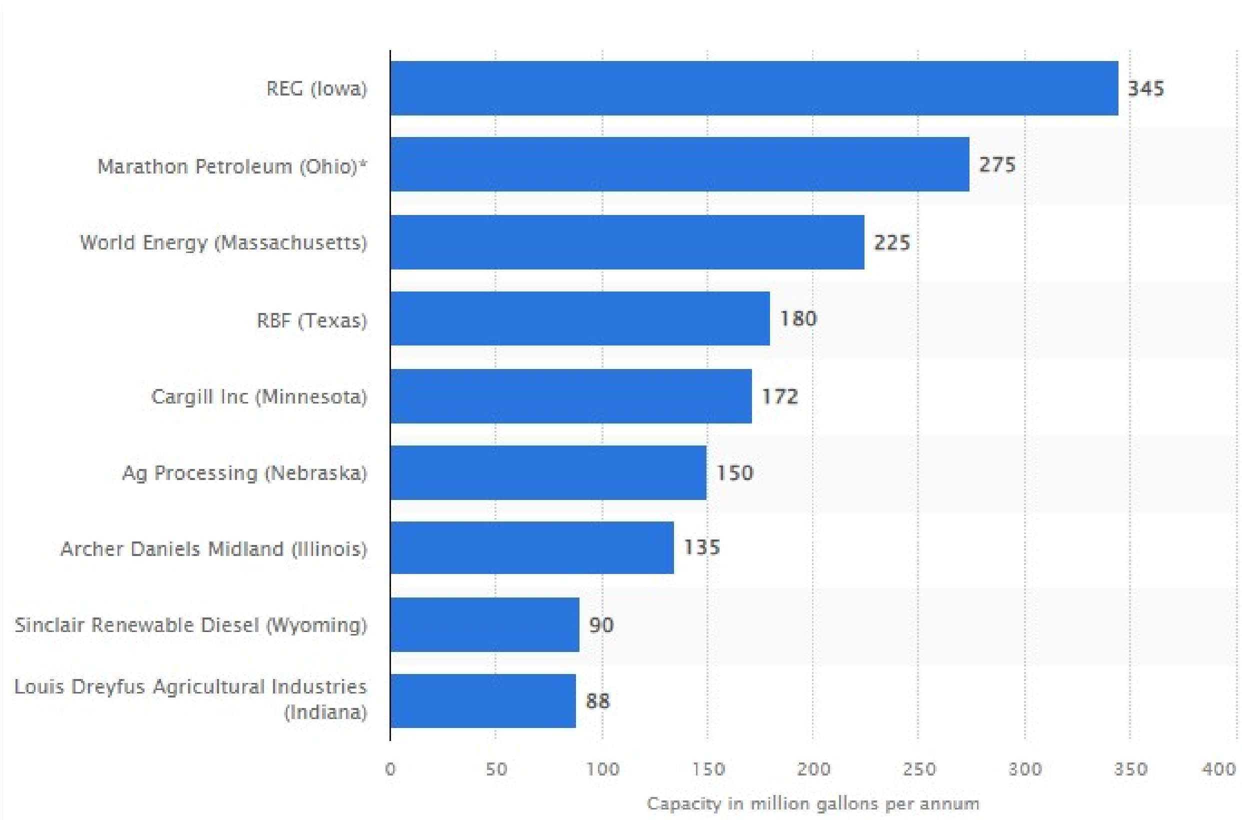


**Figure 3: Leading Producers of Biodiesel by Capacity in the United States as of 2022 [41]**

The NYCSCA has had correspondence with Renewable Energy Group (REG) regarding their capability to supply NYC schools with B20-B99.9 blends of biodiesel. REG has confirmed it is capable of delivering about 20 million gallons/yr of B99.9 based on previous fuel volumes delivered to NYC schools [42].

| Sum of Qty Received | 2018 | 2019 | 2020 |
|---|---|---|---|
| 2 B10 | 6,078,640.27 | 6,256,952.50 | 4,399,878.60 |
| 2 B5 | 2,672,218.23 | 2,250,784.63 | 1,017,940.80 |
| 4 | 15,095,714.74 | 13,448,301.62 | 8,670,981.50 |

**Table 8: Annual Fuel Use by NYC Schools in Gallons [42]**

The U.S. exported a total of 4,342 thousand barrels of biodiesel in 2021 which is over 182 million gallons [43]. Figure 4 shows exports by Petroleum Administration for Defense Districts (PADD) region. The Midwest exports 48% of all biodiesel exports. It is possible that these fuel volumes could be made available for consumption in NYC schools if biodiesel demand requires it in the future.

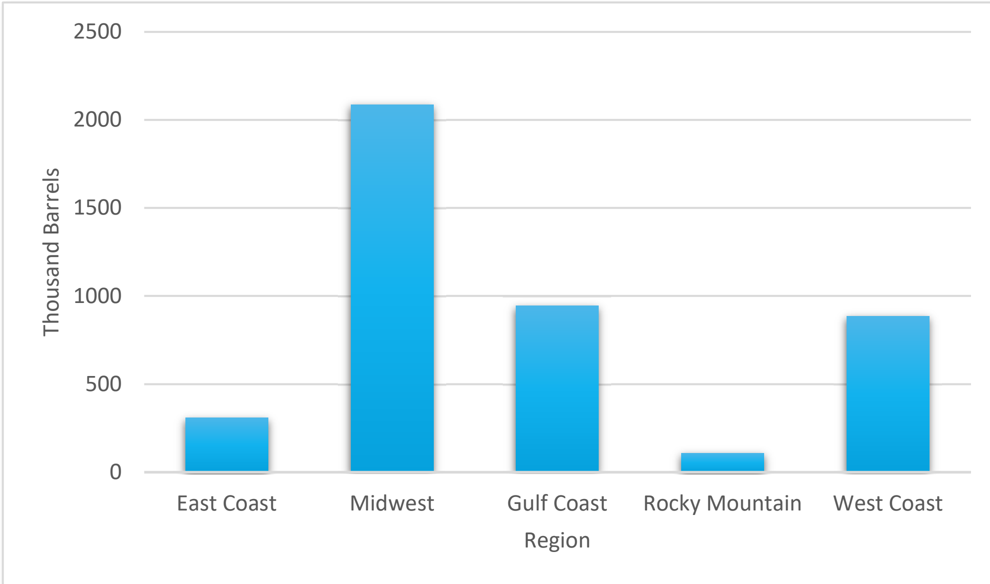


**Figure 4: Annual Biodiesel Exports by PADD Region [43]**

**Costs**

Sprague Energy is a distributor for REG. Sprague currently sells B10 at $4.1802 per gallon, delivered as part of its contract with NYC DCAS. Using the same costing metrics, they estimate B99.9 to cost $3.96 per gallon [44]. It should be noted that B99.9 is less expensive than B100 due to IRS credit incentives. Biodiesel blenders may be eligible for a tax incentive for pure biodiesel or renewable diesel blended with petroleum diesel to produce a mixture containing at least 0.1% diesel fuel [45].

Sprague provided New York Harbor fuel price data shown in Figure 5 [46]. The price of B20 is extrapolated from B99.9 and ultra-low sulfur No. 2 heating oil prices. B100 is shown to be much more expensive than ULSHO, whereas B99.9 is around the same price as ULSHO.

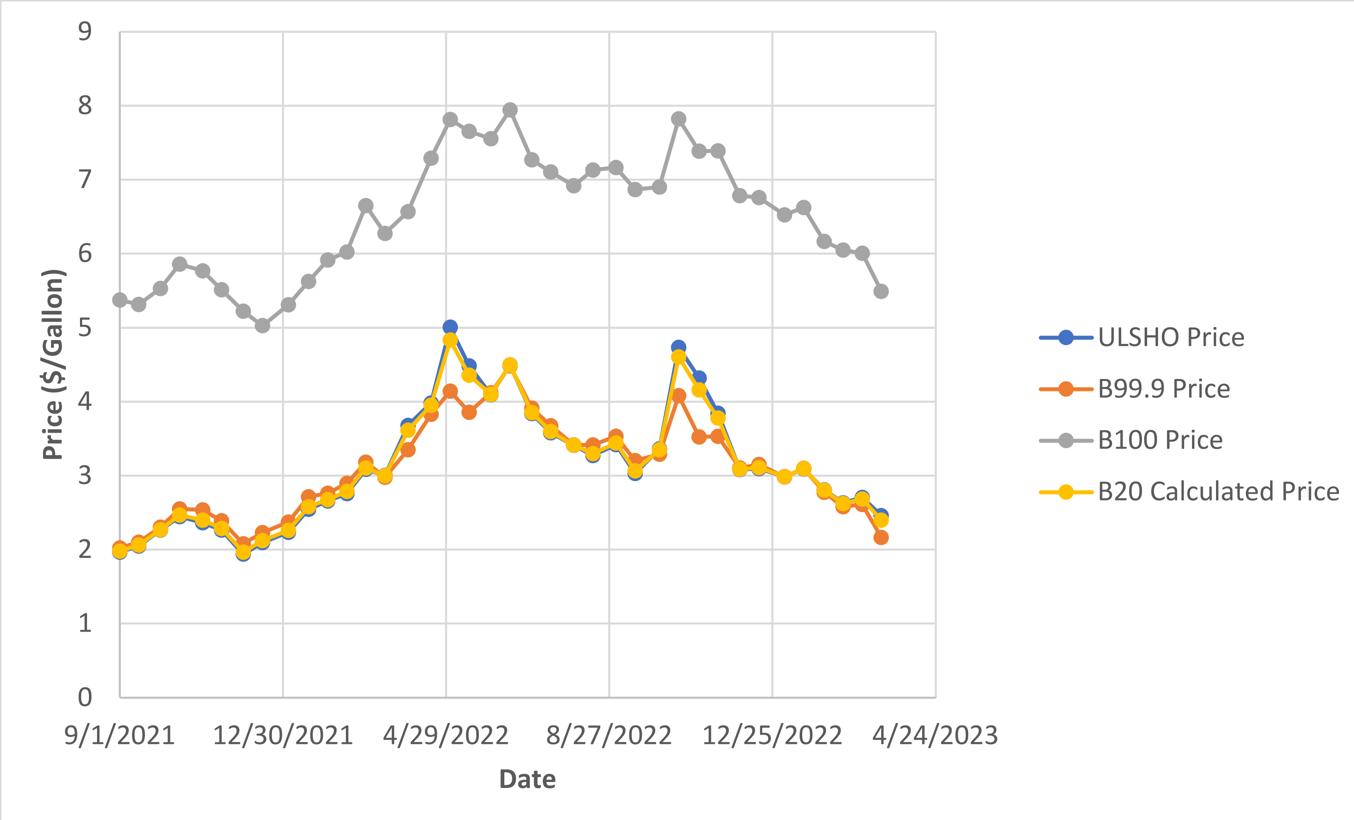


**Figure 5: Historic Fuel Prices at New York Harbor [46]**

### 4.6 Impact on Food Supply and Land Usage

Figure 6 shows the amount of feedstocks used in 2019. Vegetable oils accounted for 77% of the total pounds of feedstock in 2019. Soybean oil is the most predominate feedstock in the U.S. for biodiesel, at 55% feedstock in 2016 [47] and 57% in 2019 [48].

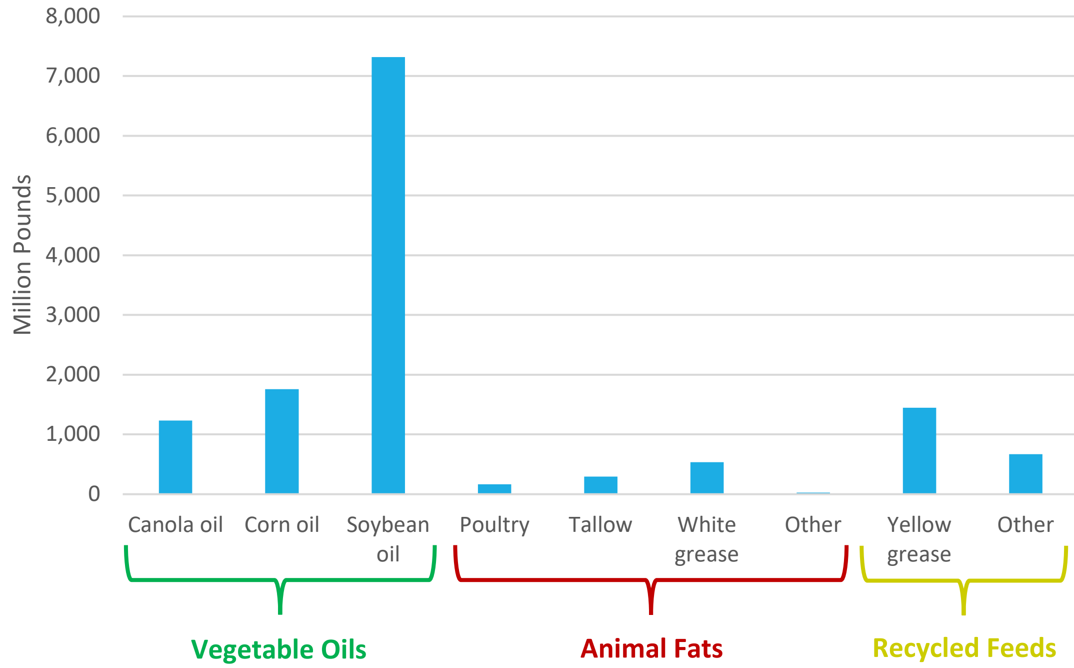


**Figure 6: Annual Total Feedstock Inputs in 2019 [48]**

Farmers in the state of New York can supply some but not all the feedstock requirements for a statewide biodiesel industry. The feedstock would need to be sent to biodiesel production plants out of state, since there are no such plants within New York. Currently REG supplies 20 million gallons to NYC schools [49]. To meet increased demands, feedstock from other states will also need to be used. More than 81% of U.S. soybean acreage in 2020 was located in the upper Midwest states such as Iowa and Minnesota [50]. It's also important to note that the production of biodiesel also requires alcohols such as methanol and ethanol.

*Land needed in NYS for provide 20 million gallons biofuel B99.9*

According to the 2017 Census of Agriculture, 2,055 farms across 282,453 acres of land in New York produced 12,701,246 bushels of soybeans [51]. Only 246 acres were irrigated. The average yield per acre in 2017 was 45 bushels per acre. One bushel is 60 lbs of soybeans. To produce a gallon of soybean-based biodiesel, 41 pounds of soybean is required [52]. The calculations below estimate the amount of land required to produce 20 million gallons of biodiesel if 57% of the feedstock came from soybean oil. Over 7 million bushels produced from 173,111 acres of land is required to meet the demand of 20 million gallons of biodiesel. That's 61% of the land currently being cultivated in New York for soybeans.

$$0.57 \cdot 20 \times 10^6 gallons \cdot 41 \frac{lbs}{gallon} \cdot \frac{1\ bushel}{60\ lbs} = 7.79 \times 10^6\ bushels$$

$$7.79 \times 10^6\ bushels \times \frac{1\ acre}{45\ bushels} = 173{,}111\ acres$$

When biodiesel is produced from food crops, a potential conflict between land use and food supply could occur. The U.S. Renewable Fuel Standard (RFS), introduced in 2005, is a national policy that requires certain volumes of renewable fuel to replace or reduce the quantity of petroleum-based transportation fuel, heating oil, or jet fuel [53].

This has caused an increase in the demand of biofuels from two main agricultural sources: corn (for ethanol, used as an additive for gasoline) and soybean (used as a fuel oil additive or replacement). While crop farmers have benefited the most from this situation, US livestock farmers have lost an estimated $3 billion in revenue in 2019 relative to a “no RFS” scenario. The economic impact of the transition to biofuels for household consumers is negative, although small on average. The impact is more significant for domestic and international consumers that are food insecure [54].

| Product | Increase in feed cost | Feed: production cost ratio | Increase in production cost (farmer) | Marketing margin* | Increase in product cost (consumer) | Reduction in consumer demand |
|---|---|---|---|---|---|---|
| Beef | 3.7% | 0.65 | 2.4% | 0.54 | 1.1% | 0.8% |
| Dairy | 1.4% | 0.50 | 0.7% | 0.75 | 0.2% | 0.1% |
| Pork | 6.1% | 0.65 | 4.0% | 0.69 | 1.2% | 0.9% |
| Poultry/Eggs | 6.3% | 0.69 | 4.4% | 0.58 | 1.8% | 0.9% |

*Notes:* Feed:production cost ratio factors drawn from National Research Council, Renewable Fuel Standard. Price elasticity data drawn from Andreyeva et al., “The Impact of Food Prices on Consumption: A Systematic Review of Research on the Price Elasticity of Demand for Food.”

**Table 9: Impact of RFS across the supply chain [53]**

Since biofuels can also be produced from algae, there is research being conducted on creating large scale algae and kelp farms. If these endeavors prove to be successful, the resulting algae-based biofuel supply chains could alleviate the land use conflict between food crops and biofuel crops.

**Land Use Changes**

Clearing large areas of forest land for agricultural purposes can result in GHG emissions [55]. Federal regulations currently do not recognize palm oil in biodiesel production in the RFS, thus reducing deforestation [56]. To be considered a renewable fuel under RFS, the required lifecycle GHG reduction compared to petroleum fuel must be 20% or more [57]. The EPA has evaluated that biodiesel made from palm oil only has a lifecycle GHG reduction of 17% [58]. This lifecycle GHG assessment also accounts for land use changes and agricultural impacts. Biodiesel made from soybean oil has an average lifecycle GHG reduction of 57-70% depending on the yield per acre [58].

## 5. Environmental Justice and Social Prioritization

Environmental justice (EJ) addresses the unfair exposure of disadvantaged communities to poor environmental conditions. EJ areas are defined as low-income or minority communities based on US Census data [59]. A low-income community is an area where the population below the poverty line is greater than or equal to 23.59% of the total population of that area. A minority community is an area where the minority population is greater than or equal to 51.1% of the total population. Local laws 60/2017 and 64/2017 established the Environmental Justice Interagency Working Group which will conduct an EJ study to describe the environmental concerns affecting EJ areas [3, 4]. An environmental justice plan will also be developed to incorporate it into City decision-making.

Figure 7 shows that large areas of Brooklyn, Queens, the Bronx, and upper Manhattan are classified as EJ areas. Figure 8 and Figure 9 show that asthma prevalence primarily in these EJ areas, especially in Harlem and the Bronx. Ozone is an air pollutant at the ground level that can cause asthma development as well as exacerbate asthma after long periods of exposure [60]. Figure 10 shows ozone concentrations in NYC zones. Concentrations of ozone are particularly high in EJ areas such as the Bronx and some zones in Brooklyn and Queens.

Fine particulate matter, $PM_{2.5}$, is emitted by vehicles, building boilers, and other combustion [66]. It is small enough to be inhaled and cause respiratory and cardiovascular issues. Figure 11 shows average $PM_{2.5}$ concentrations during the winter season between 2018 and 2019. Fine particulate matter is very concentrated in lower and Midtown Manhattan. Some EJ areas such as Harlem and the Bronx have slightly higher $PM_{2.5}$ concentrations compared to Staten Island and certain districts in Brooklyn and Queens.

Ozone isn't a direct emission, but it is formed from a chemical reaction between $NO_x$ and volatile organic compound (VOC) emissions and UV radiation from sunlight [61]. These emissions can come from burning residual fuel oils. A study from the International Journal of Environmental Research and Public Health found that "a substantial proportion of buildings were still burning residual fuel oil in Northern Manhattan (north of 110$^{th}$ Street) and the Bronx [62]." Part of NYC's Clean Heat Program banned use of No. 6 oil in 2015 and will ban use of No. 4 oil in 2027. Buildings will have to transition to cleaner fuels. The study found that 53% of the yet-to-convert buildings are using No. 4 oil and are located in northern Manhattan and the Bronx which are EJ areas.

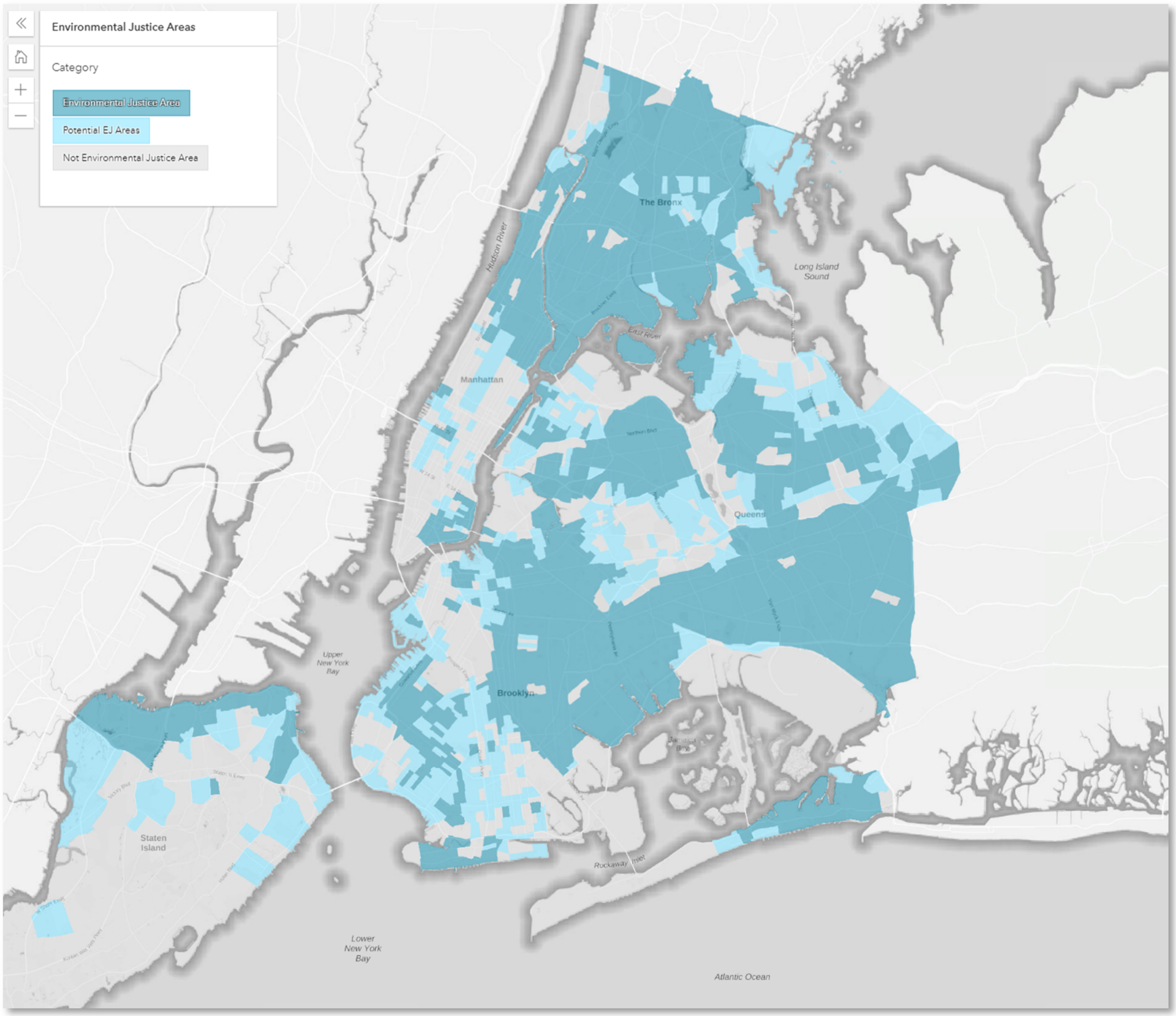


**Figure 7: NYC Environmental Justice Areas [59]**

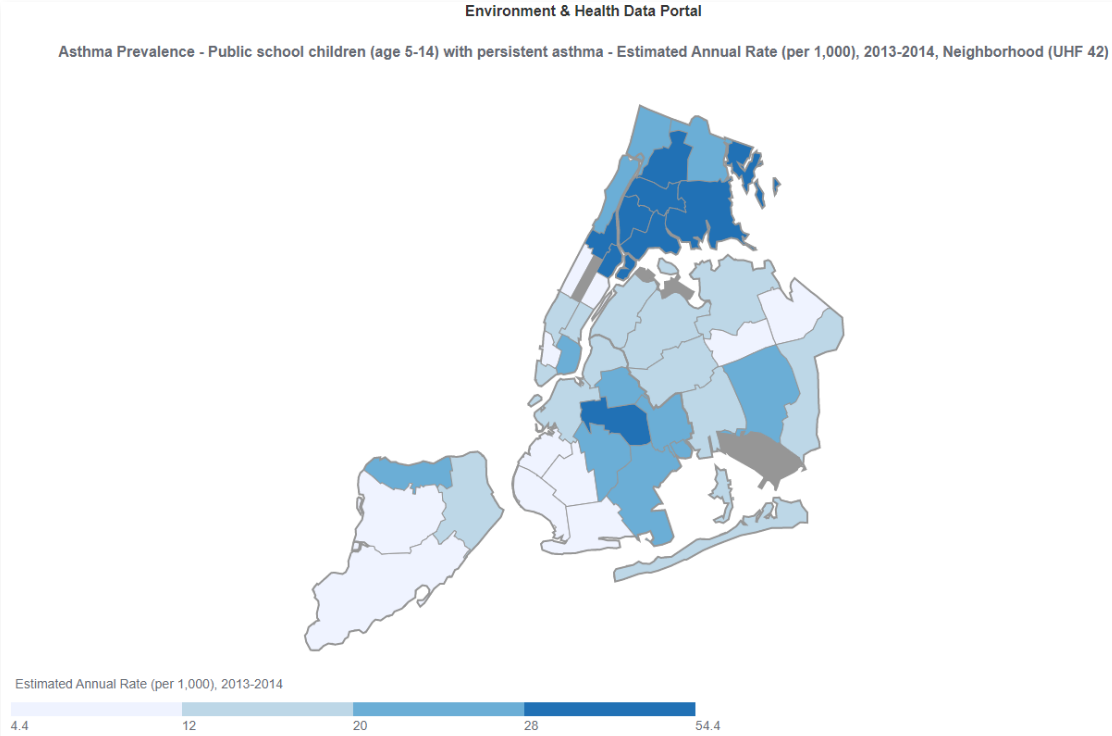


**Figure 8: Asthma Prevalence in Public School Children [63]**

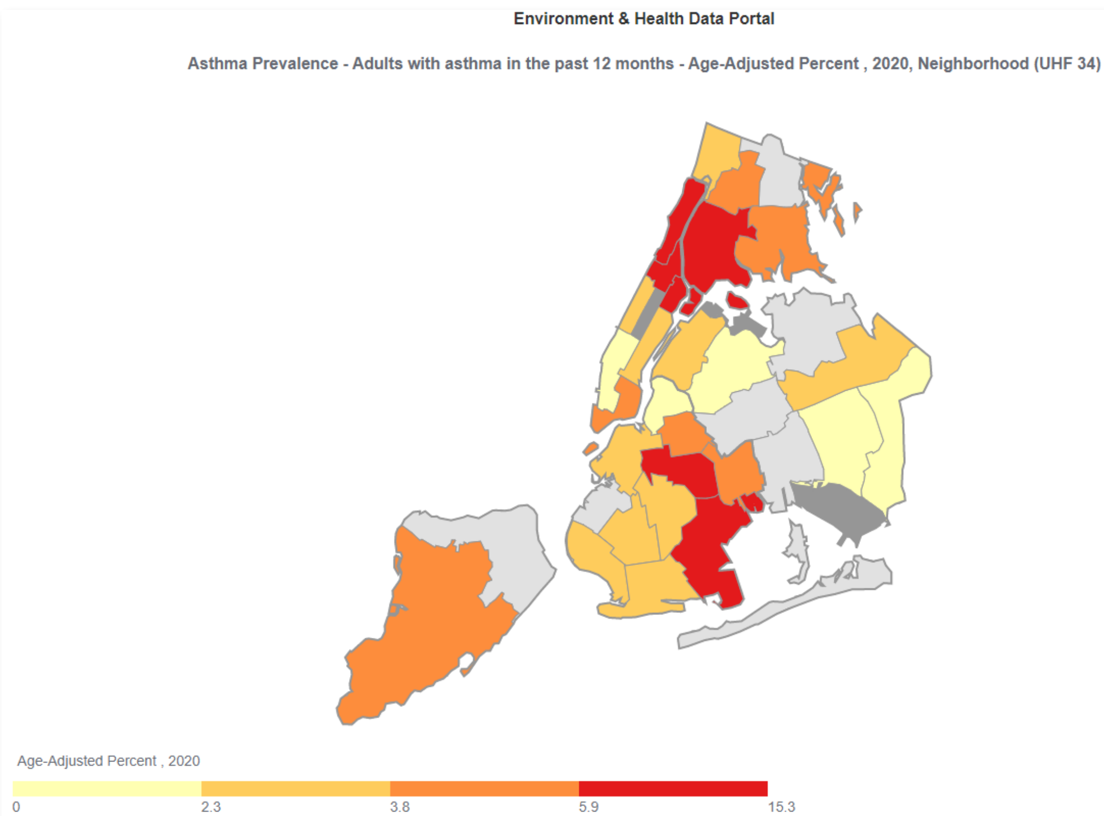


**Figure 9: Asthma Prevalence in Adults [64]**

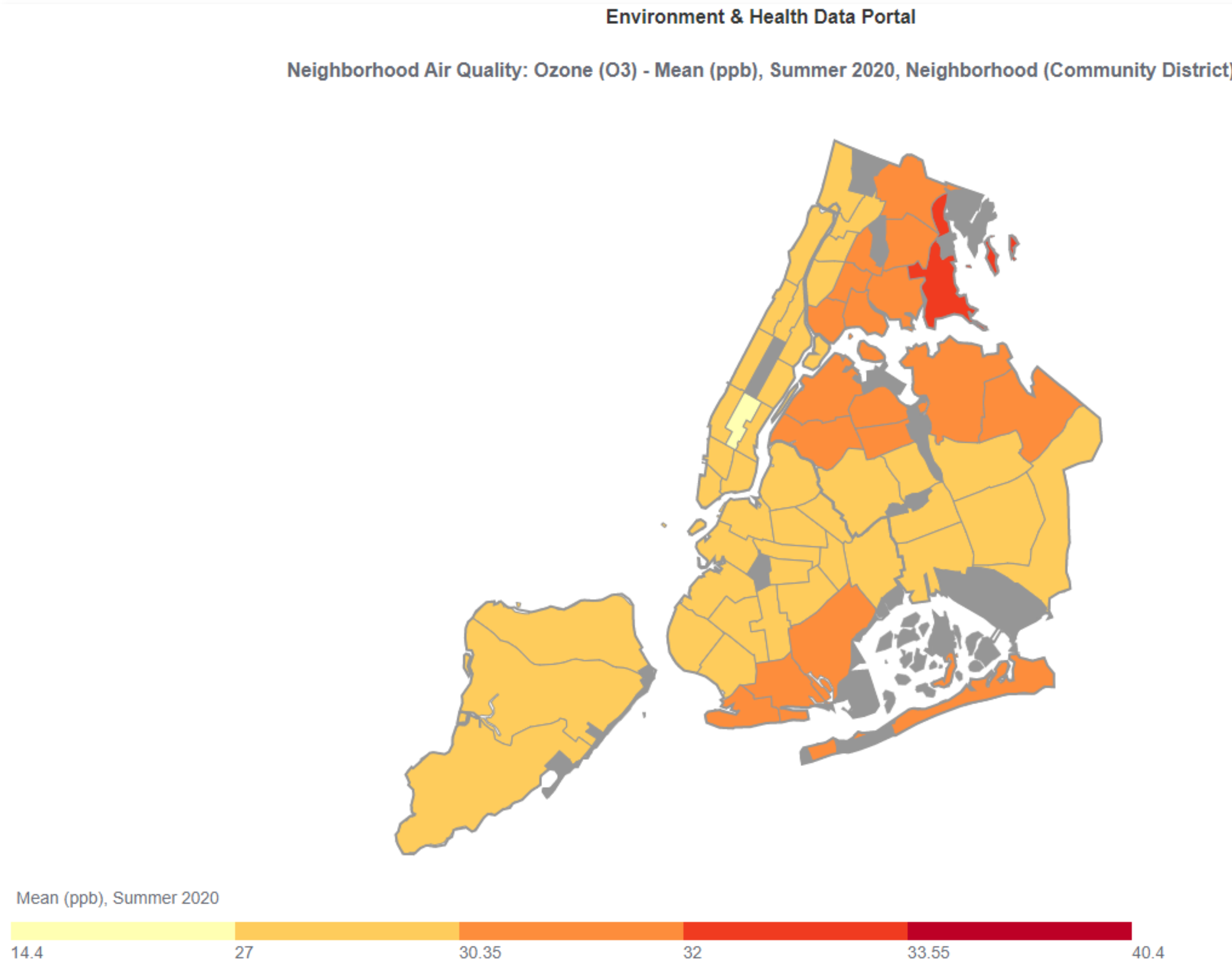


**Figure 10: Ozone Concentrations [65]**

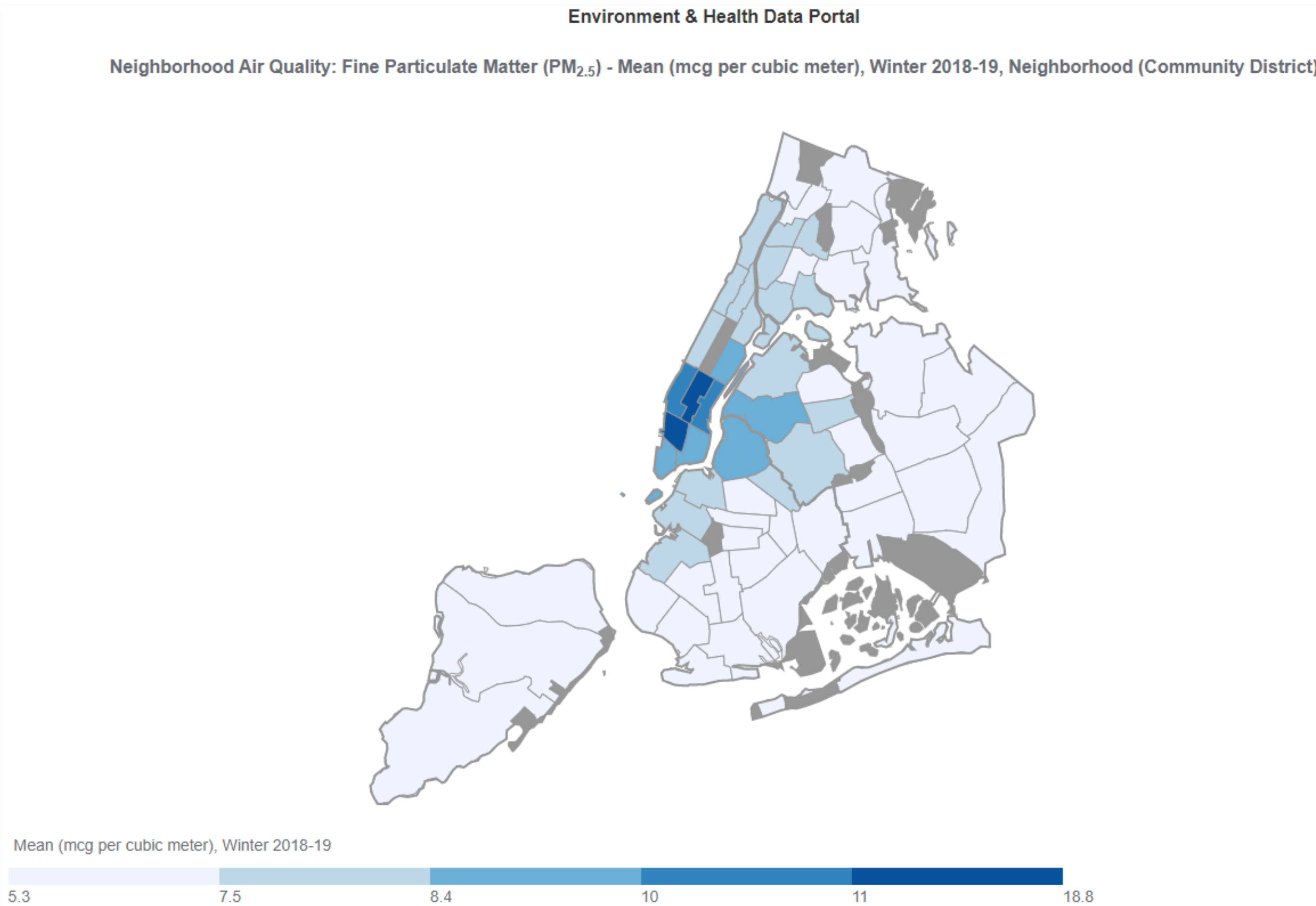


**Figure 11: $PM_{2.5}$ Concentrations [66]**

## 6. Regulations and Building Code Implications

Currently, under Local Law 119/2016, all buildings in the City must use a minimum of 5% biodiesel by volume (B5) for heating systems burning No. 2 or No. 4 heating oil. The volume of biodiesel increases to 10% (B10) in 2025, 15% (B15) in 2030, and 20% (B20) in 2034.

Buildings burning No. 4 oil or residual petroleum fuels must comply with the current mandate of burning B5 heating oil.

The local laws do not apply to emergency generators or boilers that are dual use in that it supplies the boiler and an emergency generator. A waiver may be granted if the fuel is not available in the City for the boiler type, the price of the fuel is at least 15% more than that of a comparable fuel grade, or the fuel would void the manufacturer's warranty for that boiler type [8].

Regulations by the NYC Department of Environmental Protection state that all buildings burning No. 4 oil must convert to one of the cleanest fuels upon boiler or burner retirement or by January 1, 2027, whichever is sooner. Buildings that currently burn No. 4 heating oil have several conversion options to choose from when switching to cleaner fuels.

Per NYC Mechanical Code Chapter 10 Boilers, Water Heaters and Pressure Vessels, Section 1004 Boilers (MC 1004) states that oil-fired boilers and their control systems shall be listed and labeled in accordance with UL 726. UL726 is a publication by Underwriters Laboratories (UL)[3], and UL726 is entitled "Standards for Oil-Fired Boiler Assemblies". Additionally, per MC 1004 and Fuel Gas Code (FGC) Section 631.1 Boilers, both UL795-Standard for Commercial-Industrial Gas Heating Equipment and American National Standards Institute (ANSI) Z21.13-Gas-Fired Low-Pressure Steam and Hot Water Boilers listings are required for gas burning boilers.

MC 1004.1.1 - Field Erected Boiler Requirements does list the exception that unlisted equipment shall obtain Department (of buildings – DOB) approval.

Per NYC Mechanical Code Chapter 13 Fuel-Oil Piping and Storage, Section 1301.3 Fuel Type states that appliances shall be designed for use with the type of fuel to which they will be connected. The section also states that such appliances shall not be converted from the fuel specified on the rating plate for use with a different fuel without conforming with its listing and manufacturers specifications and securing reapproval from the commissioner.

It should be noted that neither UL 296- Standard for Oil Burners nor UL295-Standard for Commercial-Industrial Gas Burners is referenced in the Mechanical Code or the Fuel Gas Code. However, the Department of Environment protection (DEP) requires that all oil-fired boilers and associated burners, boiler/burner assemblies, and control equipment installed must comply with the following equipment acceptance requirements, so that such equipment meets the minimum design and performance standards of the department. See chapter which refers to Department of Environmental Protection Promulgation of Revised Chapter 2 of Title 15 of the Rules of the City of New York

[3] The UL is a nationally recognized testing authority (in the US and Canada) that ensures products are constructed properly to provide safe function. Manufacturers submit products for UL testing. If it passes, the manufacturer can stamp the product with an official UL mark. A UL listing ensures a certain quality of safety.

Concerning Performance Standards and Other Engineering Criteria For Fossil Fuel Burning Boilers & Water Heaters - §2-04 Application for Work Permit/Certificate of Operation - (5) Certificate of Compliance – d.

NYC DEP Equipment Acceptance Requirements:

(a) List of accepted equipment. If the application for the work permit is to install equipment that appears on the list of accepted equipment, no additional certification is required.

(b) UL/CSA/ETL listed equipment. If the application for the work permit is to install equipment that is listed by UL, CSA Group, or ETL, a certification of compliance from a professional engineer must be submitted on a form prescribed by the department.

(c) Unlisted and custom equipment. If the application for the work permit is to install custom equipment, or equipment that is not on the department's list of accepted equipment and is not UL, CSA Group, or ETL-listed, a certification of compliance from a professional engineer must be submitted on a form prescribed by the department.

As of November 2022, UL 296 includes B100 in its scope and allows manufacturers to certify their burners to use biodiesel blends up to B100.

**SCA Standards**

The SCA Standard Specifications Division 15h Section 15595 is applicable to retrofit/replacement of burners that will burn No. 2 fuel oil and be B100 ready. DEP permits, certifications of compliance and operation, and UL 296 listings are required. The standard also lists approved burner manufacturers:

- Preferred
- Weishaupt
- Power Flame
- Webster
- Industrial Combustion

The standard specifies burner features, atomizing systems, control systems, and relevant equipment and devices involved in operating and maintaining the burner. There are also standard details for the control architecture of a burner pump set heater and a burner polisher system that use fuel oil. These details can be used for biofuel as well.

Sprague Energy or a similar company can work with the NYC DOE to create specifications for fuel polishing and for maintaining fuel storage tanks. In schools where a permanent fuel polisher system cannot be installed, a mobile fuel polisher can be used. This service can be provided twice a year.

## 7. Maintenance & Operations when Using Biodiesel

### 7.1 Biofuel Compatibility with Existing Equipment

Use of B20 and B99.9 may require retrofitting of the heating plant. Equipment changes such as replacing gaskets, replacing burners where necessary, and installing fuel polishers (devices that recirculate the fuel and remove the accumulated water from the tank) are recommended by burner manufacturers to ensure biodiesel compatibility. Burner manufacturers listed in SCA Standard 15595 plan to include use of biodiesel up to B100 in their warranties.

Excess air increases with biodiesel blend level since biodiesel contains some oxygen. Experiments performed by Brookhaven National Laboratory have shown that burners that were previously operating with No. 2 fuel oil can operate appropriately without changes to the air/fuel ratio [75]. While biodiesel is readily usable with existing NYC school burners, the air/fuel ratio should be adjusted to decrease excess air to ensure flame sensors are able to detect the presence of a flame.

Renewable diesel can be used immediately in existing heating plants. It will be considered for use in the SCA Non-Destructive Testing Boiler Program. Heating plants will be inspected to determine the viability of biofuel use and viability of being retrofitted. In the spring of 2023, NYCSCA and DSF are planning to conduct multiple pilots to test B100 at schools currently using lower biofuel blends such as #4B5 and #2B10.

### 7.2 Cold Weather Considerations

Biodiesel performance in cold weather depends on the blend of biodiesel, the feedstock, and the petroleum diesel characteristics. B99.9 is saturated with fatty methyl esters (FAME) which are responsible for the cold flow and operability problems in the cold. Upon cooling, around 45°F, FAME will begin to crystallize and eventually drop out of solution [67]. The macrocrystalline structures can block filter screens and can sometimes permeate through the whole of the fuel, causing it to form a solid gel [67].

Cold flow additives will not work as well in B99.9 due to the high quantity of FAME, so a biodiesel flow-improver should be installed to hinder the crystals from forming large solids [67]. Blends with smaller percentages of biodiesel perform better in cold temperatures. Typically, regular No. 2 diesel and B5 perform about the same in cold weather. Both biodiesel and No. 2 diesel have some compounds that crystallize in very cold temperatures [33].

Like petroleum diesel, biodiesel may freeze or gel at low temperature; however, petroleum diesel can withstand lower temperatures, as its cloud point (or the point of crystallization) is significantly lower than that of biodiesel. For example, the most common type of biodiesel, from soy, has a cloud point of 32°F, while petroleum diesels can range from -49°F to 19°F. In cold climates, biodiesel needs to be accommodated with low-temperature petroleum diesels and flow additives (or both), or lowering the biodiesel percentage in the blend, or maintaining any exterior tanks and pipes above the critical temperatures.

### 7.3 Storage and Transportation

**Concerns**

Biodiesel contains oxygen which allows microbes to live in the storage tank and contaminate the fuel. It also contains polar molecules that subject the fuel to water contamination. The water comes from atmospheric moisture (as the storage tanks are required to be vented to the atmosphere) or improper treatment after processing [68]. Water accumulation can lead to corrosion and stress cracking of mild steel [69]. Serious damage to heating equipment may occur if an improper blend or pure B99.9/B100 were to be used without modification and adjustments to existing heating systems [70].

For B99.9, storage stability is a paramount consideration. Fuel aging and oxidation can lead to high acid numbers, high viscosity, and the formation of gums and sediments that clog filters. Standard ASTM D671 requires that B99.9 be stable enough to withstand, during oxidation stability testing, an induction time of three hours before degradation to the point where it is out of specification. This requirement applies at the time of blending, so many biodiesel producers make B99.9 with higher induction times.

B99.9 that is intended to be stored longer than four months must be treated with synthetic antioxidants and have a minimum oxidation stability of six hours. Biodiesels are produced with natural antioxidants, but these antioxidants can be removed through some types of feedstock and biodiesel processing, such as bleaching, deodorizing, or distilling oils and fats. Oxidation can be accelerated by high levels of unsaturation, heat, sunlight, and certain types of metals and rust.

**Solutions**

Precautions need to be taken if biodiesel is going to be stored for more than a few months due to microbial degradation in storage tanks. Regular maintenance such as removal of excess water and microbial testing for quality assurance purposes are recommended [33]. Injecting biocides will mitigate microbial contamination. Fuel polisher systems can also be installed to regularly filter out water and particulates from the fuel.

NORA has stated that a fuel polisher or water separator is good to have, but not a critical system. Cycling once a week if the tank is not full and when the boiler is not running will eliminate the buildup of water and other contaminants. Preferred has stated that they can provide a water separator system that removes water from the tank and injects biocides to prevent microbial growth [71].

Alternatively, mobile fuel polishers can be used in schools where a permanent fuel polisher system cannot be installed. Sprague Energy or a similar company can work with the NYC DOE to create specifications for the polishing and maintenance of fuel storage tanks. The fuel polishing service should be provided twice per year. The cost is dependent on tank capacity, ease of access to the tank, and fuel transportation costs. Sprague recommends that school locations near Sprague's fuel terminal are selected for any future pilot projects involving use of mobile fuel polishers. This will lower the trucking transportation cost [72].

The National Renewable Energy Laboratory (NREL) completed studies on recent samples of B20 and they found the shelf life of all the samples to be over one year. The makeup of the fuel is important when determining the shelf life. The more unsaturated a fuel is the lower the oxidation, so biodiesel from unsaturated oils will not last as long as more saturated oils without additives. For fuels going into long term storage, antioxidant additives along with monitoring the tank properties will greatly increase the shelf life [73].

This will not be an issue with NYC schools. According to DSF, biodiesel fuel will never be stored over a long period. DSF is also open to the possibility of scheduling more deliveries at fewer gallons per delivery to guarantee that the fuel does not sit idle in the tank for an extended duration. DSF currently does not perform regular oil tank cleanings, but will conduct them annually if deemed necessary [74].

The National Oilheat Research Alliance (NORA) had recently completed a study concerning storage of B100 in outside residential tanks. The study found that in-tank heaters and tank insulation helped to keep the biodiesel as a fluid [75].

The SCA will need few heated storage tanks since most storage tanks in NYC schools are located indoors and many of them are semi to fully recessed below the basement floor slab.

Similar solutions apply to transportation. Proper inspection should ensure there is no residual water or other potential contaminants in the truck. In cold weather, the trucks should be kept warm and potentially insulated to prevent gelling. The trucks and railcars should also be made of aluminum, carbon steel, or stainless steel which are metals that do not oxidize easily [33].

## 7.4 Impact on Piping and Pumps

**Concerns**

B99.9/B100 may soften and degrade certain types of rubber compounds used for hoses and gaskets and may cause them to leak and degrade to the point where they crumble and become useless. For bulk handling of B100, seals, gaskets, and hoses must be compatible with B100 [73]. Biodiesel will degrade and form high sediment levels if contacted for long periods by copper or copper-containing metals (brass, bronze) or with lead, tin, or zinc (galvanized surfaces) [33]. B100 may also permeate some common plastics (polyethylene, polypropylene) over time, so these should not be used for storing B100.

**Solutions**

Acid numbers should be kept lower than 0.5 mg KOH/g to prevent fuel system deposits and reduced filter and pump life. This is the requirement set by ASTM D6751.

Experiments at Brookhaven National Laboratory have tested seal material exposure to different blends of biodiesel as well as degraded biodiesel with high acid numbers [75]. Nitrile is a common material used in pump shaft seals. Samples of nitrile were immersed in B0, B20, B50, and B100. The B0 in this case was ultra-low sulfur diesel. For tests with degraded biodiesel, samples were immersed in B100 with acid levels of 2, 4, and 8. All samples were immersed for 670 hours at 125°F. The tensile strength, hardness, volume swell, and compression set were tested after immersion.

The study showed that the blend of biodiesel appeared to have little impact on the nitrile properties that were evaluated. However, elevated acid numbers of 2 and above had significant impact on the nitrile material. Such high acid numbers are unlikely to occur in practice, and biodiesel that meets ASTM D6751 will only have acid numbers up to 0.5 mg KOH/g.

Brookhaven National Laboratory also tested the exposure of yellow metals with different blends of biodiesel [75]. A set of metal tubes were filled with biodiesel were sealed and kept at 70°F for six months. These test conditions model the summer shut-down of an oil-fired heating plant. The metals tested were stainless steel, new copper, and old copper that had previously been in service for around 30 years.

The starting acid number for each blend was approximately 0.4. Figure 12 shows the resulting acid numbers of the fuels after six months. B20 and B100 biodiesel blends in new copper had lower acid numbers than those in stainless steel and even performed better than B0 in new copper. All acid numbers were also below 2 where significant degradation of seal materials may occur.

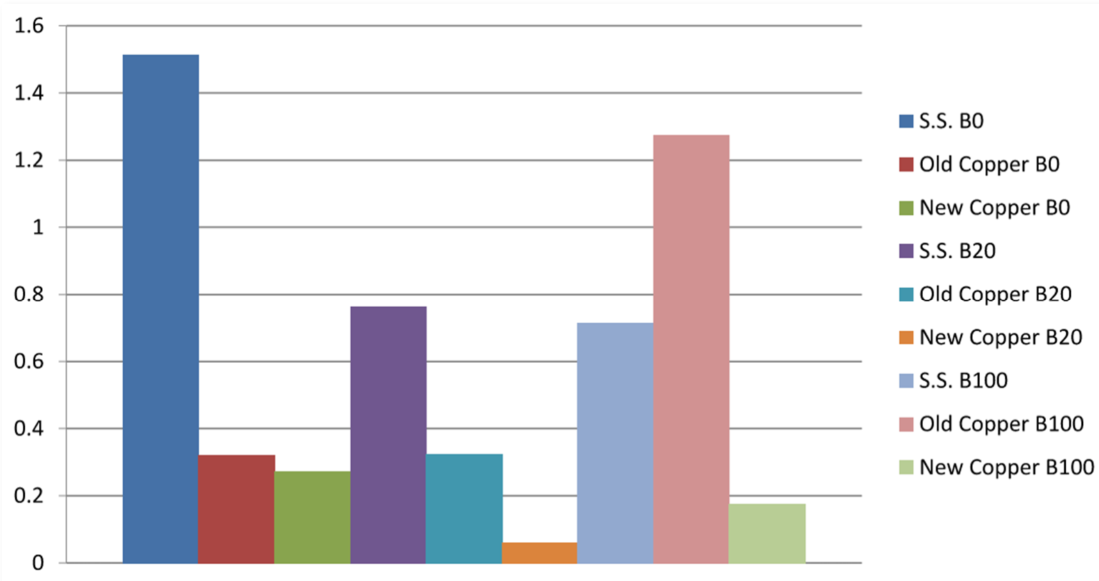


**Figure 12: Acid Numbers of the Test Fuels after the Six-Month Period [75]**

The SCA can manage issues with B100 in existing copper tubing with minimal effort. NORA's testing was conducted with high acid numbers that rarely occur in typical use cases. It is recommended to use UL 296 certified equipment. Testing guided by UL 296 incorporates material compatibility tests so that the equipment can withstand the acidity of degraded biodiesel. Existing gaskets and seals should be replaced with elastomers such as Teflon, Viton, fluorinated plastics, and nylon which are compatible with B100 [33].

### 7.5 Health and Safety

Biodiesel is a nontoxic substance [76]. It is safe to handle according to the manufacturer's instructions. No dangerous reactions are known and it is stable at room temperature in closed containers under normal storage and handling conditions [77, 78]. REG's B99.9 is also not listed as a carcinogen or considered hazardous waste.

To prevent potential boiler issues, the following steps should be taken:

1) A comprehensive annual and semi-annual inspection of [79]:
   a) All safety circuits.
   b) The proper operation of all boilers and boiler-monitoring components.
2) Visual inspection of all components for possible signs of improper operation or installation.
3) A review of the current Standard Operating Procedure (SOP) when it comes to devices being removed or jumped out.
4) An onsite logbook to make note of the date and time the equipment is inspected, tested, or had changes in operation.
5) Replace obsolete Preferred Panel controls.
6) Factory training of all custodial and maintenance staff for Cleaver Brooks boilers and their associated controls.

### 7.6 SCA Non-Destructive Testing (NDT) Boiler Program

For existing schools where burner replacement is necessary, heating plants will undergo a 2-phase inspection consisting of an on-site visual inspection followed by non-destructive diagnostic testing. The testing and evaluation will determine the condition of the heating plant and its viability to be retrofitted for biofuel use.

**Phase One**

The first phase of the inspection will be a visual inspection performed by a State of New York licensed professional engineer or non-destructive examination technician in the presence of a National Board Inspection Code inspector. The personnel will examine all boilers, fuel tanks, system components, and identify heating system components that require further investigation and testing. The first phase of inspection will also consist of an interview with the school's custodian and the collection of original drawings and historical documentation of boiler operational records and repairs.

**Phase Two**

The second phase of the inspection involves non-destructive diagnostic testing to be performed by a State of New York licensed professional engineer. Assessment of the heating plant equipment will be based on appropriate testing procedures determined by SCA engineers and the consultant. Examples of testing procedures include:

- Ultrasonic Testing
- Magnetic Particle Examination
- Portable Hardness Testing
- Hydrostatic/Pressure Testing
- Petroleum Bulk Storage Tank Tightness Testing
- Metallurgical Condition Assessment/Testing
- Vacuum Testing

Boilers, boiler tubes, and oil tanks will all be tested. An engineering economic analysis will be conducted to evaluate the feasibility of repairs. Evaluation reports will make recommendations for retrofitting the heating plant with a B99.9 compatible burner. In the case of salvageable No. 4 burners, DSF will determine if RD is viable to use.

# 8. Recent Industry Developments

## 8.1 SCA B100 Ready Standard

The scope of UL 296 was updated in November 2022 to include liquid-fuel-fired burners using biodiesel blends from B20 up to B100 [80].

The strategy for B100 conversion will include gasket replacements, oil filters and fuel polishing systems, and stack emission monitoring systems. UL 157 rated Viton or Teflon seals are required for fuel piping per the standard to prevent gasket degradation. Oil filters and fuel polishers separate water and microbial contaminants from the fuel. Monitoring $CO_2$, $NO_x$, $SO_x$, and $PM_{2.5}$ emissions will help benchmark GHG emission reductions and help diagnose potential issues such as incomplete combustion.

With the inclusion of B100 in UL 296, the DSF and the SCA have begun discussions on testing B100 on multiple schools (recently #4B5 and #2B10), starting in May 2023 after the end of the heating season so that testing does not interfere with space conditioning during the heating season.

## 9. Conclusion

Replacing fossil fuel oils with biofuels is an effective carbon reduction strategy for NYC schools that can be executed in the interim as schools move to full electrification. Transitioning to biofuels can be done with minimal capital costs and effort. Existing heating plants primarily require gasket replacements and burner replacements in the case of non-functioning burners. Additionally, B99.9 can be purchased at a similar price to No. 2 oil.

Schools will see immediate and significant GHG emission reductions when switching from fuel oils to B99.9. The transition from No. 4 oil to B99.9 will reduce emissions as follows:

- $CO_2$ by 85%
- $N_2O$ by 82%
- $NO_x$ by 88%
- $SO_2$ by 99 to 100%
- $PM_{2.5}$ by 99 to 100%

Switching from No. 2 oil to B99.9 will reduce emissions as follows:

- CO2 by 85%[4]
- $N_2O$ by 74%
- $NO_x$ by 74%

The reductions in $NO_x$ and $PM_{2.5}$ will benefit the health of disadvantaged communities since those particular emissions can lead to asthma and negatively affect the respiratory system. Use of biofuels will help the City move away from fossil fuels, reducing its carbon footprint and put it on the path to achieve carbon neutrality.

[4] $CO_2$ emissions from #2 and #4 oil can be reduced by 99.9% based off of the biodiesel emission factor in the "Inventory of New York City Greenhouse Gas Emissions in 2016" report. Based on conversations between the NYCSCA, NORA, and REG, an 85% reduction in emissions would be a more conservative estimate since carbon emissions from feedstock production should be considered.

## Appendix A – Fuel Property Tables

**Table 10: Fuel Properties Comparison**

| PROPERTY | UNITS | NO. 2 FUEL OIL | NO. 4 FUEL OIL | RENEWABLE DIESEL (R100) | NATURAL GAS | B20 | B99.9 |
|---|---|---|---|---|---|---|---|
| Fuel Standard | Unitless | ASTM D396 | ASTM D396 | ASTM D975 and D396[17] | n/a | ASTM D7467[33] | ASTM D6751[81] |
| Heating Value | Btu/gal | 129,488 to 138,490[33] | 146,000[82] | 123,604 | n/a | 136,384 | 119,550 to 127,960[83] |
| Kinematic Viscosity | cSt | 1.3 to 4.1 @ 104°F[17] | > 4[84] | 1.9 to 4.1 @ 104°F[17] | 18.72 @ 104°F[85] | 1.9 to 4.1 @ 104°F [33] | 4 - 6[33] |
| Specific Gravity | Unitless | 0.85[33] | 0.876 to 0.979[84] | 0.78 | 0.554[89] | 0.856 | 0.88[33] |
| Density | lb/gal | 7.1[33] | | 6.5 | 0.00548[89] | 7.14 | 7.3[33] |
| Carbon | weight % | 84.15[17] | 86.1[32] | 84.6 | 65-80[34] | 82.67 | 77[33] |
| Hydrogen | weight % | 12.67[17] | 11.9[32] | 15.4 | 1-25[34] | 12.53 | 12[33] |
| Oxygen (by difference) | weight % | 2.93[17] | < 0.48[32] | 0 | 0[34] | 4.59 | 11[33] |
| Sulfur (max) | PPM | 15[86] | 1500[87] | < 1 | < 0.0229[88] | 15[33] | 0 - 15[33] |
| Boiling Point | °F | 356 to 644[33] | 350 to 700[84] | 250 to 310 | -259[89] | n/a | 599 to 662[33] |
| Flash Point | °F | 140 to 176[33] | > 131[84] | < 126[17] | -306[89] | 125.6[33] | 212 to 338[33] |
| Cloud Point | °F | -31 to 41[33] | -8 to 2 | -29 to 23[17] | n/a | -13 to 12 | 26 to 59[33] |
| Pour Point | °F | -31 to 5[33] | 10[32] | -13 | n/a | n/a | 23 to 50[33] |
| Cetane Number | Unitless | 40 to 55[33] | 40 minimum | 84 to 99 | n/a | 40 minimum | 47 to 65[33] |

**Table 11: Gaseous Pollutant Emissions**

| POLLUTANT | NO. 2 FUEL OIL | NO. 4 FUEL OIL | RENEWABLE DIESEL (R100) | NATURAL GAS | ELECTRICITY | B20 | B99.9 |
|---|---|---|---|---|---|---|---|
| Carbon Dioxide $CO_2$ ($tCO_2e$/MMBtu) | 0.07414[22] | 0.07617[22] | 0.03165[90] | 0.05[22] | 0.07632[22] | 0.05799 | 0.01118 |
| Nitrogen Oxides $NO_x$ (kg/MMBtu) | 0.0783[37] | 0.172[37] | 0.0713[17] | 0.0445[91] | 0.0665[30] | 0.0674 | 0.0206[92] |
| Nitrous Oxide $N_2O$ (kg/MMBtu) | 0.000600[22] | 0.000601[22] | n/a | 0.000106[22] | 0.000205[22] | 0.000471 | 0.000109[22] |
| Sulfur Dioxide $SO_2$ (kg/MMBtu) | 0.000695[37] | 0.0704[37] | Almost 0[17] | 0.0002668[91] | 0.01329[30] | 0.000563 - 0.000695 | 0[38] – 0.000695 |

**Table 12: Particulate Matter Emissions**

| POLLUTANT | NO. 2 FUEL OIL [KG/MMBTU] | NO. 4 FUEL OIL [KG/MMBTU] | RENEWABLE DIESEL (R100) [KG/MMBTU] | NATURAL GAS [KG/MMBTU] | B20 [KG/MMBTU] | B99.9 [KG/MMBTU] |
|---|---|---|---|---|---|---|
| Particulate matter $PM_{2.5}$ | 0.000027[28] | 0.1247 | 0.000547[17] | 0.0008449[91] | 0.000027[28] | 0.000027[28] |

**Table 13: Volatile Organic Compound Emissions**

| POLLUTANT | NO. 2 FUEL OIL[81] [KG/MMBTU] | NO. 4 FUEL OIL [KG/MMBTU] | RENEWABLE DIESEL (R100) [KG/MMBTU] | NATURAL GAS [KG/MMBTU] | B20 [KG/MMBTU] | B99.9[81] [KG/MMBTU] |
|---|---|---|---|---|---|---|
| 1,1,2,2-Tetrachloroethane | Not Detected | n/a | n/a | n/a | n/a | Not Detected |
| 1,2,4-Trimethylbenzene | 1.71E-06 | n/a | n/a | n/a | n/a | 3.52E-07 |
| 1,2-Dichlorobenzene | 5.49E-04 | n/a | n/a | n/a | n/a | 1.09E-03 |
| 1,3,5-Trimethylbenzene | < 7.80E-07 | n/a | n/a | n/a | n/a | < 2.66E-07 |
| 1,3-Dichlorobenezene | 2.03E-06 | n/a | n/a | n/a | n/a | Not Detected |
| 1,4 Dioxane | Not Detected | n/a | n/a | n/a | n/a | Not Detected |
| 1,4-Dichlorobenezene | 2.10E-06 | n/a | n/a | n/a | n/a | Not Detected |
| 1-Ethyl-4-Methyl | < 7.57E-07 | n/a | n/a | n/a | n/a | < 2.66E-07 |
| 2-Butanone | 5.44E-06 | n/a | n/a | n/a | n/a | 2.40E-06 |
| 2-Hexanone | 8.03E-06 | n/a | n/a | n/a | n/a | 4.12E-06 |
| 4-Methyl-2-Pentanone | 1.71E-06 | n/a | n/a | n/a | n/a | 1.61E-05 |
| Acetone | 2.47E-05 | n/a | n/a | n/a | n/a | 2.96E-05 |
| Benzene | 3.15E-06 | n/a | n/a | 9.34E-07[91] | n/a | 3.27E-06 |
| Bromomethane | 3.32E-07 | n/a | n/a | n/a | n/a | Not Detected |
| Carbon Disulfide | 2.03E-05 | n/a | n/a | n/a | n/a | 7.21E-05 |
| Chlorobenzene | 1.40E-06 | n/a | n/a | n/a | n/a | 8.44E-07 |
| Chloroethane | 4.37E-07 | n/a | n/a | n/a | n/a | 8.80E-07 |
| Chloroform | 8.62E-07 | n/a | n/a | n/a | n/a | < 1.64E-06 |

**Continuation of Table 13**

| POLLUTANT | NO. 2 FUEL OIL[81] [KG/MMBTU] | NO. 4 FUEL OIL [KG/MMBTU] | RENEWABLE DIESEL (R100) [KG/MMBTU] | NATURAL GAS [KG/MMBTU] | B20 [KG/MMBTU] | B99.9[81] [KG/MMBTU] |
|---|---|---|---|---|---|---|
| Chloromethane | 5.26E-07 | n/a | n/a | n/a | n/a | Not Detected |
| Cyclohexane | < 1.87E-06 | n/a | n/a | n/a | n/a | 5.40E-06 |
| Ethanol | 1.34E-05 | n/a | n/a | n/a | n/a | 4.50E-05 |
| Ethyl Acetate | 6.17E-06 | n/a | n/a | n/a | n/a | 4.67E-06 |
| Ethylbenzene | < 1.17E-06 | n/a | n/a | n/a | n/a | < 1.22E-06 |
| Formaldehyde | 3.16E-05 | n/a | n/a | 3.34E-05[91] | n/a | 1.40E-03 |
| Isopropyl Alcohol | 1.97E-06 | n/a | n/a | n/a | n/a | 1.49E-06 |
| M,p-Xylene | 2.09E-06 | n/a | n/a | n/a | n/a | 2.38E-06 |
| Methyl-t-Butyl Ether | Not Detected | n/a | n/a | n/a | n/a | 4.67E-07 |
| o-Xylene | < 7.08E-07 | n/a | n/a | n/a | n/a | Not Detected |
| Styrene | < 6.58E-07 | n/a | n/a | n/a | n/a | 1.02E-06 |
| Tetrahydrofuran | 1.69E-06 | n/a | n/a | n/a | n/a | 1.23E-05 |
| Toluene | 1.05E-06 | n/a | n/a | 1.51E-06[91] | n/a | 3.67E-07 |
| Tribromomethane | 2.93E-06 | n/a | n/a | n/a | n/a | 6.53E-06 |
| Trichloroethylene | 2.33E-06 | n/a | n/a | n/a | n/a | 2.83E-06 |
| Vinyl Acetate | Not Detected | n/a | n/a | n/a | n/a | Not Detected |

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