**Air Quality-Related Public Health Benefits of 100% Renewable Madison**

*A supplement to "100% Renewable Madison: Achieving 100% renewable energy & zero net carbon for city operations & leading the community"*

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*Key Point*: 100% Renewable Madison will save dollars and lives through reductions in air pollution.

*Summary*

The City of Madison has set a goal for achieving 100% renewable energy and zero net carbon emissions (City Council Res #45569 passed 3/21/2017). In reducing carbon emissions and promoting renewable energy, Madison has an opportunity to capitalize on many co-benefits – including health benefits from cleaning the air we breathe. By reducing energy consumption and relying on zero-emission sources of energy for local government operations, the city is leading the community by doing its part in reducing emissions of harmful pollutants including nitrogen oxides ($NO_X$), sulfur dioxide ($SO_2$), and fine particulates ($PM_{2.5}$) in addition to eliminating carbon dioxide ($CO_2$). These harmful pollutants are associated with a host of health consequences including life-threatening respiratory and cardiovascular outcomes that often disproportionally impact people in low-income communities and people of color – especially in the region [1]. In implementation, actions from changes to city operations alone could have regional benefits totaling $3.5 million annually in 2020 and $4.7 million by 2040. While these impacts would be felt regionally and not solely by Madison residents, this is equivalent to roughly $14-$18 per capita. By individual health endpoint, the impacts range from one avoided premature death every 2-3 years to 25-32 work-loss days and 150-190 mild reduced-activity days per year.

*Methods to Estimate the Air Quality Benefits of 100% Renewable Madison*

The U.S. Environmental Protection Agency provides guidance on quantifying the health impacts of exposure to $PM_{2.5}$ and its precursors ($NO_X$ and $SO_2$) using "benefit-per-ton" estimates [2,3]. This approach provides an estimate of the health benefits from reducing one ton of each pollutant from 17 different emissions sectors. The monetary valuation of these impacts is also quantified by the "benefit-per-ton" study and is used in regulatory analyses.

To quantify the emissions reductions of the 100% Renewable Madison plan, emissions factors are applied to each fuel type (electricity, natural gas, gasoline, and diesel) based on their most likely use – see Table 1. These emissions factors are combined with energy reduction estimates from the 100% Renewable Madison implementation plan to quantify avoided emissions of $NO_X$, $SO_2$, and $PM_{2.5}$ as shown in Table 2.

Emissions are categorized as direct reductions or reductions from investments in Renewable Energy Credits (RECs). Investment in carbon offsets is not expected to have any co-benefits to local or regional air quality, and investment in RECs will only have substantial benefits to Madison residents if the renewable energy purchased is supplied within the regional electric grid. The location of air quality improvement through renewable energy investment depends on the location of power plants where generation and emissions are offset and the transport and chemistry of pollutants in the atmosphere. Investment in rural solar developments in Wisconsin, including the approved investment in five arrays in Argyle, Cumberland, Elroy, Fennimore and New Lisbon, WI, are expected to meet the criteria to maximize the air quality benefits for Madison residents.

The health benefits from avoided emissions are given in Tables 3 and 4 for all health endpoints provided in the benefits per ton study. A significant portion of the benefits are from emissions avoided through investment in RECs, and thus the RECs should be purchased from sources within the regional electric grid whenever possible to maximize the benefit to Madison residents. Reductions in gasoline and diesel use for fuel may also have more substantial benefits than quantified here as only emissions in operation are considered. If emissions from well to pump were considered, emissions reductions would be as much as 2-20x higher per gallon of fuel.

In addition, this assessment only considers the impacts of exposure to $PM_{2.5}$, but reductions in other criteria pollutants – especially ozone ($O_3$) – as well as hazardous pollutants (also called air toxics) would be expected to have positive health impacts. In similar analyses, the monetary benefits of reduced $O_3$ exposure have been shown to be a little less than 20% of $PM_{2.5}$ impacts while asthma impacts are approximately 25 times higher. Additional phases of impact assessment could include consideration of other pollutants, spatial and temporal detail, and sophisticated emissions quantification beyond the scope of this supplement.

| Energy Carrier | Baseline (2018 use) | Emissions Rate $NO_X$ | Emission Rate $SO_2$ | Emissions Rate $PM_{2.5}$ | Emissions Rate Source |
|---|---|---|---|---|---|
| **Electricity (lb/MWh)** | 53,000 MWh/yr | 1.00 | 1.30 | 0.11 | 2016 eGRID MROE average for $NO_X$ and $SO_2$ (https://www.epa.gov/sites/production/files/2018-02/documents/egrid2016_summarytables.pdf). 2016 AVERT simulations for $PM_{2.5}$ (https://www.epa.gov/statelocalenergy/avoided-emissions-and-generation-tool-avert). |
| **Natural Gas (lb/therm)** | 1,182,000 Therms/yr | 0.0098 | 5.9E-5 | 7.4E-4 | Estimates taken from the U.S. EPA's AP-42 Fifth Edition (https://www3.epa.gov/ttn/chief/ap42/ch01/final/c01s04.pdf). |
| **Gasoline (lb/gallon)** | 534,473 Gallons/yr | 0.0144 | 1.2E-4 | 3.3E-4 | GREET model 2018 – Well to Wheel estimates (2017 technology year, operation only) - emissions factors are for medium/heavy-duty vocational vehicles (https://greet.es.anl.gov/). |
| **Diesel (lb/gallon)** | 2,088,088 Gallons/yr | 0.0161 | 1.7E-4 | 2.5E-4 | GREET model 2018 – Well to Wheel estimates (2017 technology year, operation only) - emissions factors are for medium/heavy-duty vocational vehicles ((ttps://greet.es.anl.gov/). |

Table 1: The emissions rates of different fuels used in this analysis and their sources. Also included are the baseline uses of each fuel for the year 2018.

| Emissions Benefits | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|
| **Direct $NO_X$ reduced (lbs)** | 16700 | 43900 | 57500 | 57700 | 57900 |
| **Direct $SO_2$ reduced (lbs)** | 8100 | 17100 | 14600 | 14400 | 14300 |
| **Direct $PM_{2.5}$ reduced (lbs)** | 1000 | 2200 | 2300 | 2300 | 2200 |
| **Direct $NO_X$ reduced + RECs (lbs)** | 63600 | 84000 | 99600 | 99900 | 100300 |
| **Direct $SO_2$ reduced + RECs (lbs)** | 69000 | 69200 | 69400 | 69400 | 69400 |
| **Direct $PM_{2.5}$ reduced + RECs (lbs)** | 6100 | 6600 | 6900 | 6900 | 6900 |

Table 2: Emissions reductions by pollutant for key years in implementation.

| Health Benefits (Direct Emissions) | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|
| **Value High Estimate ($ thousands)** | 789.8 | 1919.4 | 2227.7 | 2224.8 | 2221.8 |
| **Value Low Estimate ($ thousands)** | 345.3 | 874.5 | 991 | 989.7 | 988.4 |
| **Average Value ($ thousands)** | 567.6 | 1397 | 1609.4 | 1607.2 | 1605.1 |
| **Mortality High Estimate** | 0.083 | 0.207 | 0.23 | 0.229 | 0.229 |
| **Mortality Low Estimate** | 0.037 | 0.091 | 0.101 | 0.101 | 0.101 |
| **Mortality Average** | 0.06 | 0.149 | 0.165 | 0.165 | 0.165 |
| **Respiratory Emergency Room Visits** | 0.019 | 0.047 | 0.052 | 0.052 | 0.052 |
| **Bronchitis** | 0.048 | 0.115 | 0.134 | 0.134 | 0.134 |
| **Lower Respiratory Symptoms** | 0.608 | 1.483 | 1.714 | 1.713 | 1.711 |
| **Upper Respiratory Symptoms** | 0.879 | 2.077 | 2.416 | 2.414 | 2.412 |
| **Mild Reduced Activity Days** | 26.297 | 61.352 | 67.398 | 67.346 | 67.293 |
| **Work Loss Days** | 4.46 | 10.503 | 11.508 | 11.499 | 11.489 |
| **Asthma Exacerbation** | 1.041 | 2.457 | 2.838 | 2.836 | 2.833 |
| **Cardiovascular Hospital Admissions** | 0.009 | 0.023 | 0.027 | 0.027 | 0.027 |
| **Respiratory Hospital Admissions** | 0.009 | 0.023 | 0.026 | 0.026 | 0.026 |
| **Non-Fatal Heart Attack (High)** | 0.037 | 0.092 | 0.106 | 0.106 | 0.106 |
| **Non-Fatal Heart Attack (Low)** | 0.004 | 0.01 | 0.011 | 0.011 | 0.011 |

Table 3: Health impacts annually by endpoint of emissions reductions excluding RECs following the 100% Renewable Madison implementation plan. Units are reduction in annual cases unless otherwise specified.

| Health Benefits (Including RECs) | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|
| **Value High Estimate ($ thousands)** | 4939.2 | 5642.3 | 6527.5 | 6535.6 | 6543.7 |
| **Value Low Estimate ($ thousands)** | 2154.3 | 2582.6 | 2901.7 | 2905.3 | 2909 |
| **Average Value ($ thousands)** | 3546.8 | 4112.4 | 4714.6 | 4720.5 | 4726.3 |
| **Mortality High Estimate** | 0.518 | 0.612 | 0.664 | 0.665 | 0.666 |
| **Mortality Low Estimate** | 0.23 | 0.267 | 0.298 | 0.299 | 0.299 |
| **Mortality Average** | 0.374 | 0.44 | 0.481 | 0.482 | 0.482 |
| **Respiratory Emergency Room Visits** | 0.117 | 0.134 | 0.147 | 0.148 | 0.148 |
| **Bronchitis** | 0.289 | 0.33 | 0.38 | 0.38 | 0.381 |
| **Lower Respiratory Symptoms** | 3.69 | 4.245 | 4.849 | 4.855 | 4.862 |
| **Upper Respiratory Symptoms** | 5.3 | 5.908 | 6.806 | 6.815 | 6.825 |
| **Mild Reduced Activity Days** | 159.2 | 175.2 | 189.8 | 190.1 | 190.3 |
| **Work Loss Days** | 26.9 | 30.0 | 32.5 | 32.6 | 32.6 |
| **Asthma Exacerbation** | 6.297 | 7.024 | 8.001 | 8.012 | 8.023 |
| **Cardiovascular Hospital Admissions** | 0.057 | 0.067 | 0.081 | 0.081 | 0.081 |
| **Respiratory Hospital Admissions** | 0.056 | 0.067 | 0.076 | 0.076 | 0.076 |
| **Non-Fatal Heart Attack (High)** | 0.229 | 0.273 | 0.311 | 0.312 | 0.312 |
| **Non-Fatal Heart Attack (Low)** | 0.025 | 0.03 | 0.034 | 0.034 | 0.034 |

Table 4: Health impacts annually by endpoint of emissions reductions including RECs following the 100% Renewable Madison implementation plan. Units are reduction in annual cases unless otherwise specified.

*References*


1. Clark, L. P., Millet, D. B. & Marshall, J. D. National Patterns in Environmental Injustice and Inequality: Outdoor NO2 Air Pollution in the United States. *PLOS ONE* **9**, e94431 (2014).
2. Fann, N., Baker, K. R. & Fulcher, C. M. Characterizing the PM2.5-related health benefits of emission reductions for 17 industrial, area and mobile emission sectors across the U.S. *Environ. Int.* **49**, 141–151 (2012).
3. U.S. EPA. *Technical Support Document: Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors*. (2018).