HIGH RESOLUTION IMAGING OF NITROGEN OXIDES

DOES RISE IN POPULATION NECESSITATE RISE IN POLLUTION?

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By
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Global awareness of climate change issues and the necessity of pollution mitigation procedures has been on the rise for decades, especially since the Conference on Human Environment in Stockholm in 1972 (Chauhan & Chauhan, p. 209). Increased governmental regulations have led to new technologies and practices for reducing pollutant emissions around the world, but some regions and industries have been less affected than others. Nitrogen oxides (NO_x) are a convenient tracker of harmful emissions as they are easily quantifiable and contribute heavily to environmental hazards such as surface-level ozone and acid rain (Duncan et al., 2016, p. 976). Nitrogen oxides are emitted through combustion, generally through the burning of fuels in cars or industrial power plants, but also by natural processes in agriculture and weather events.

A United States Congressional study published in 1975 found that 51% of the total 53 million tons of nitrogen dioxide emissions around the world came from various coal burning processes, and another 41% from petroleum (p. 719). The United States Environmental Protection Agency (EPA) reported findings from the National Emissions Inventory that the US national average concentration of NO_x has decreased from 25.2 million tons in 1990 to 12.3 million tons in 2014 (2018, p. 2). On-road vehicles were the greatest contributor to the total emission, but these values are only estimates based on years of modeling (EPA 2018, p. 2). In contrast, industrial boiler emissions can be directly measured by on-site monitoring devices regularly reporting to the agency. These facts show both that transportation has replaced coal-burning as leading cause of NO_x emissions, and that more effective ways of measuring vehicular contributions are necessary. This provides the motivation for both the technical and STS research papers. The former will be a critical design review focused on a new monitoring satellite, and the latter an analysis of the factors leading to environmental action using Actor-Network Theory.

Global monitoring of harmful atmospheric pollutants has significantly increased in the last twenty years with the introduction of space-based observations from satellites. In many regions, ground-based pollutant measurements are insufficient for describing the characteristic emission profiles, as sensors are discrete and not evenly distributed (Ramachandran et al., 2013, p. 354). Previously launched satellites can provide the wide spatial coverage necessary to obtain the big picture of global emissions, but the low spatial resolution of these satellites makes it difficult to pinpoint the exact hot spots of production. Cracknell and Varatsos (2014) described the former tendency of agencies to launch large satellites housing multiple instruments in high-altitude orbits, which has now turned to smaller, more focused satellites in Low Earth Orbit (LEO) (p. 5567-5568). These smaller satellites have shorter-lifetimes, but are much cheaper and easier to build, and the lower orbit makes it easier to obtain images with higher spatial resolution. Cracknell and Varatsos also attribute the improved spatial resolution to the development of better image read-out detectors, noting that the combination of these improvements gives the Tropospheric Monitoring Instrument (TROPOMI) a spatial resolution of 7 km x 7 km (p. 5575). The newest satellite to be launched by the National Aeronautics and Space Administration (NASA), the Tropospheric Emissions: Monitoring of Pollution (TEMPO) satellite, is expected to have a spatial resolution of 2.4 km x 4.5 km (p. 2).

Spatial resolution is especially important for nitrogen dioxide measurements used in the tracking of vehicular emissions. The gas coming out of the exhaust pipe is initially nitric oxide (NO), but is quickly oxidized to form NO_2, which is then turned back into NO by photolysis. This process occurs on timescales of minutes during the day, resulting in relatively insignificant lateral movement of the gas, constraining the observed high concentrations to within roughly a kilometer of the roadway (EPA, 2016, p. 2-4). Thus, a new scientific instrument is necessary to monitor the NO_2 levels indicative of vehicular emission along roadways and separate their contribution from the environment around them.

3U DESIGN AND DEVELOPMENT

As part of the Spacecraft Design class under the direction of Professor Chris Goyne of the Department of Mechanical and Aerospace Engineering, a team of twelve Mechanical and Aerospace Engineering (MAE) majors will design a 3U CubeSat to measure Nitrogen Dioxide emissions in the atmosphere above urban areas. The proposed design affords a spatial resolution of 200 x 800 meters, much finer than previous instruments and capable of tracking emissions along roadways in urban environments (Goyne, Pusede, & Skrutskie, 2018, p. 3). Professor Sally Pusede of the Environmental Sciences Department leads the project, aided by graduate student Angelique Demetillo. They are responsible for informing the scientific requirements and motivation for the project. Several members of the Astronomy Department also contribute to the project, including Professor Michael Skrutskie and researchers Matthew Nelson and John Wilson. These researchers are developing the scientific payload, the high-resolution spectrograph that will fly in the CubeSat bus. Researchers in the Electrical Engineering Department, including undergraduate Kathryn Wason, are helping to select or create electrical components, onboard computers, and some software packages to run the satellite.

At present, the MAE undergraduate students are split into five functional teams: Hannah Umansky on Program Management; Adelaide Pollard on Communications; Alex Brookes and William Schaefermeier on Software and Avionics; Genesis Brockett, Noah Dematteo, and Matt Moore on Power, Thermal, and Environment (PTE); Isabel Araujo and Sami Khatouri on Attitude Determination and Control System (ADACS) and Orbits; and Max Diamond, William

McNicholas, and Huy Tran on Structures and Integration. Each functional team is responsible for the design of their own sub-system, as well as communicating ideas and requirements to the other teams. The design of each sub-system depends on trade-offs with others, so it is important for each member to understand the needs and constraints of all the systems.

Collectively, the MAE undergraduates are responsible for ensuring the physical success of the mission. The Power, Thermal, and Environment team specifically is in charge of protecting the electrical components and the rest of the structure from the environment. This involves creating power budgets to ensure battery life, planning solar panel arrangements to ensure maximum power collection, and evaluating the temperatures of the components in each of the systems. The thermal evaluation is crucial for this project, where the sensitivity of the scientific instrument is tightly coupled to the temperatures of the components. Here, the optical system of the spectrograph consists of a series of lenses, gratings, and prisms, shown in Figure 1, that bend the incoming light into a spectrum fed into the detector. The distances between the optics is carefully calibrated at room temperature to create the sharpest images based on the focal length of each optic. When the temperatures change during the satellite's flight, the lenses and their mounts may expand or contract, which can change the alignment of the system, blurring the images. To avoid this image degradation, the PTE team will use thermal modelling software such as Thermal Desktop to predict

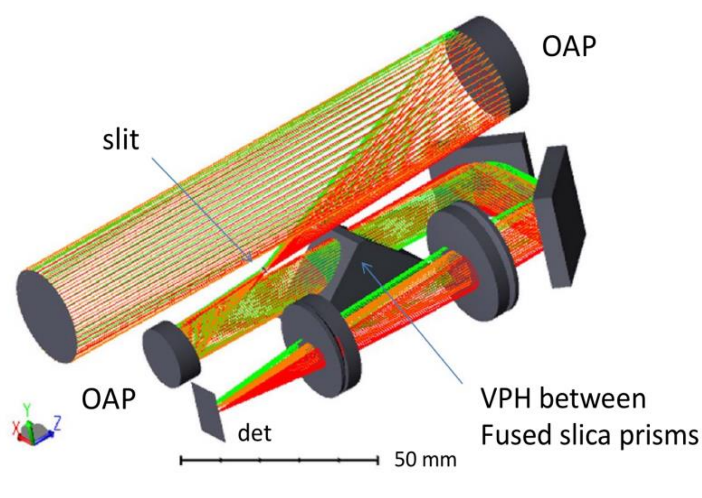

Figure 1. *Spectrograph Layout.* This figure shows the proposed lens placement for the spectrograph such that it fits within the 1.5 U satellite bus. Colored lines show the light path for differing wavelengths (Goyne et al., 2019).

the temperatures of the components and how they change throughout the orbit, so that those changes can be compensated for when constructing the instrument.

The project is currently funded through the 3 Cavaliers grant from the University of Virginia. The principle investigators submitted a funding proposal to the National Science Foundation (NSF) in 2018, but the proposal was returned with suggestions. The group will submit improved proposals to the NSF and potentially NASA after updating the design and demonstrating proof of concept for the scientific instrument in the next several months. The projected timeline includes a Preliminary Design Review and a Critical Design Review by the end of the 2020 academic year, with a written report on these reviews serving as the culmination of the capstone project. A proposed schedule is shown in Figure 2. Future work will include the physical integration of the components, final calibrations of the science instrument, and testing of the software, leading to the launch of the spacecraft anticipated in 2022.

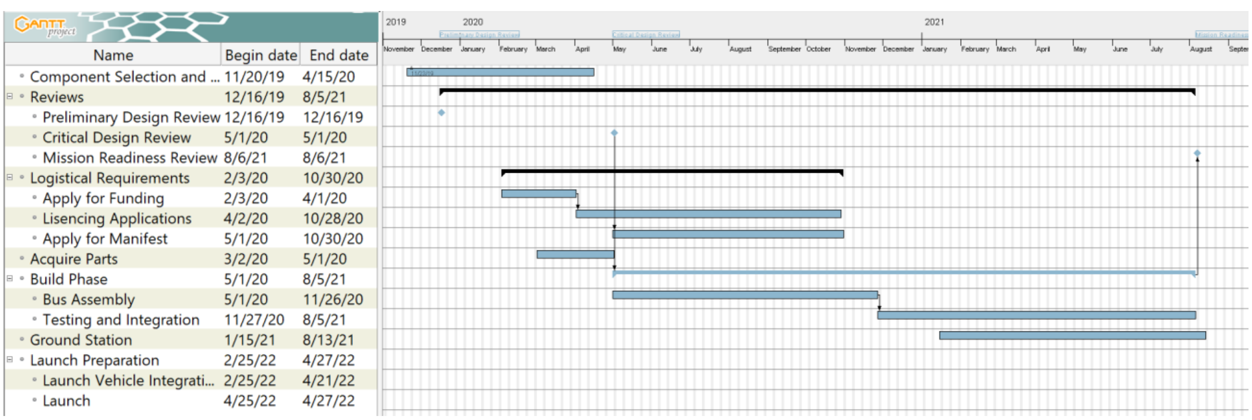

Figure 2. Project Schedule. A Gantt chart showing the critical stages of mission development (Brockett, 2019).

DOES RISE IN POPULATION NECESSITATE RISE IN POLLUTION?

An increase in readily available data from global pollution monitoring satellites has made it easier to understand the major geographic contributors to the mounting climate change epidemic. The data clearly shows the areas with higher than average concentrations of harmful substances such as carbon monoxide (CO) and dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxides (NO_x). While these data are useful, absolute concentrations cannot fully explain the state of pollution in the world, or the best ways to mitigate it. For that, it is necessary to explore the societal and technical factors influencing pollutant emission. This paper will analyze the major contributors in the context of Actor-Network Theory (ANT), described by Law and Callon.

While national efforts to curb harmful emissions in the United States are clearly working on some level, the same cannot be said for many other countries, especially those in the Middle East and Asia. There are even areas within the U.S. where atmospheric pollution concentrations have increased, contrary to national trends. Using data from the Ozone Monitoring Instrument (OMI), Duncan et al. reported dramatic increases in nitrogen oxide emissions above specific areas in North Dakota and Texas, which they attribute to the “rapid expansion of oil and natural gas extraction activities” in those areas (2016, p. 981). The authors also reasoned that countries such as India and China with rapidly rising Gross Domestic Product (GDP) and population statistics must also have great increases in pollution. As the energy and transportation demands rise, so do the emissions.

A CLOSER LOOK AT INDIAN ENVIRONMENTAL POLICY

Multiple studies have shown that the greatest contributor to urban CO and NO_x emissions in India and around the world are motor vehicles. The Indian government has adopted a series of regulations on the sulfur content of petroleum and diesel fuels modeled after European policies. The timeline of the implementation of these regulations has sped up as the pollution situation becomes more dire, forcing the fuel and automobile industries to comply. Without new automobiles built to take this low-sulfur fuel, consumers and motorists are forced to feed their incompatible engines, which can decrease fuel efficiency (Dutta, 2018). Consequently, the consumer is unhappy with their car and the pressure to buy a new one, the auto industry is unhappy with the government for increasing pressure for more efficient engines, and the gas and oil companies are placing the blame for the delay in rollout on the auto industry (Karunakaren). The issue here is the lack of consideration for other stakeholders. Decisions about the future of environmental policy and the industries related to it should be made with all actors in mind.

Similar cases can be found in all areas of energy and environmental policy-making. Jolivet and Heiskanan (2010) described the problems arising from a proposed wind farm in France. While the original idea was well-framed and accepted by those closest to the issue, the creative team faced resistance from citizens of the towns surrounding the intended site who claimed the turbines would compromise the aesthetic that appealed to tourists. Since those planning the project did not consult all the affected parties before the proposal period, they were blocked at a critical stage in the process leading to an indefinite halt of the development of the wind farm. In the United States, President Obama's commitment to reducing carbon emissions was taken as a war on coal since the proposed regulations disproportionately affected the coal industry. Coal supporters argued that the cuts would force coal workers out of business completely due to the severe economic impact and this would cost Americans thousands of jobs in coal mining states. Again, lack of consideration and input from all actors thwarts even the noblest intentions.

Figure 3 shows the current technology transfer model demonstrated by this situation. The figure is an adaptation of the transfer of technology model originally pictured by WB Carlson as an interpretation of the Social Construction of Technology (Pinch & Bijker, 1987). It represents the environmental policy created by the government (center) that is forced onto all other associated parties. This transfer is shown by unidirectional arrows to signify the actors having no control or input to the central issue. Notice that there is also no communication between the actors.

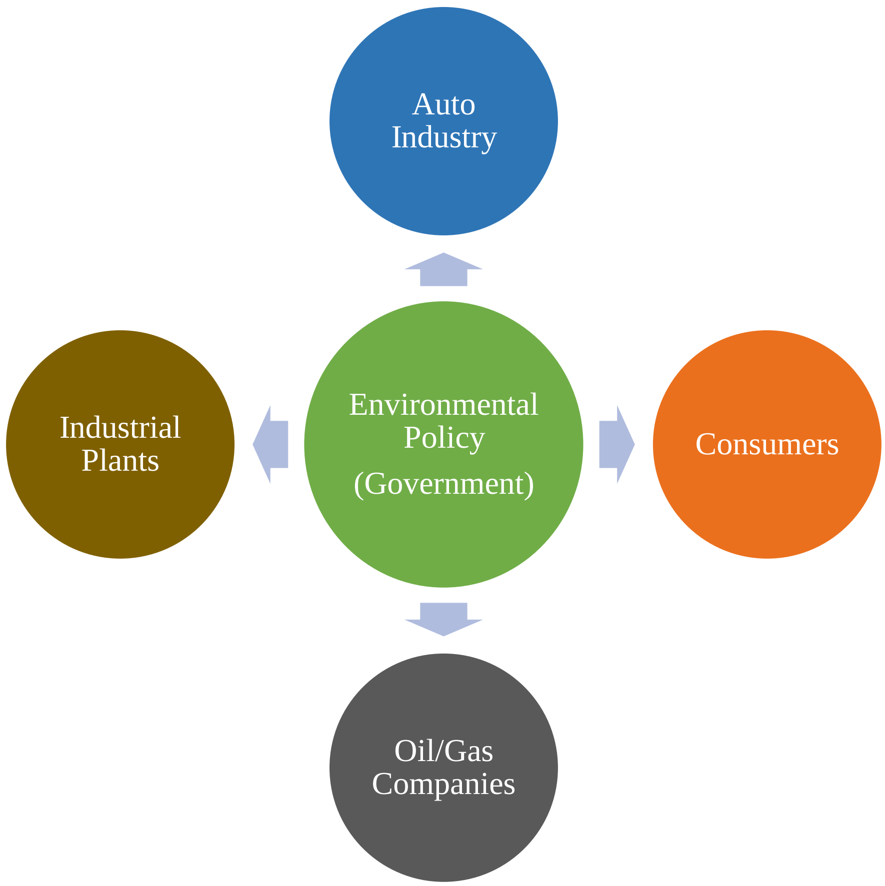

Figure 3. Transfer of Environmental Policy. The current model of environmental policy decisions (Adapted by Genesis Brockett from B. Carlson, 2019).

PROPOSED SOLUTIONS

There is one feature of the Indian environmental regulations system that seems to be a suitable fix for the lack of public input. Many environmental regulation decisions are decided or interpreted by the Supreme Court, which allows interested parties to voice their opinions and inspires regular people to take action (Chauhan & Chauhan, 2009). Since 1984, both local and federal courts in India have taken a stance and an interest in public interest litigation cases to try to save the environment. For example, the Supreme Court ordered a group of mining companies to close after their appointed committee found their practices unsafe, and cited a desire to preserve the natural resources for future generations (Chauhan & Chauhan, 2009). However, words and ideas alone cannot stop the rise in pollution. The real solution requires personal initiative; every actor needs to take it upon themselves to do their part. There are many existing technologies meant to stop or reduce NO_x emissions before they reach the atmosphere, but people must implement them. There are alternative modes of public transportation that would produce less exhaust overall, but commuters have to choose to use them instead of personal vehicles. Numerous alternatives to coal-powered generation have been introduced and proven effective, but still the industry does not switch to renewable energy. All of these options exist, but if the technology is not being used, it cannot have its intended effect.

The proposed model consists of a system where each group has input in the implementation of environmental policy so that everyone benefits, as long as they adopt the technologies that allow them to comply. This is similar to the cap and trade system established in the U.S. currently. In this system, combustion facilities are given certain allowances for emissions that are less than their baseline. They may purchase or trade allowances with other companies to cover their emissions, or they may reduce emissions in whatever way they deem most cost effective in order to avoid federally imposed fines and penalties if they fail to meet the allowance caps (EPA, 2009). However, this still relies on government agencies regulating and checking in on those affected by the policies. There needs to be some kind of personal accountability that makes people want to cut back on emissions on their own. Each group needs to have a stake in the outcome, and be personally invested in how their performance impacts others and the Earth as a whole. A graphic of these ideas can be seen in Figure 4, where personal accountability surrounds and pressures all the actors within the network.

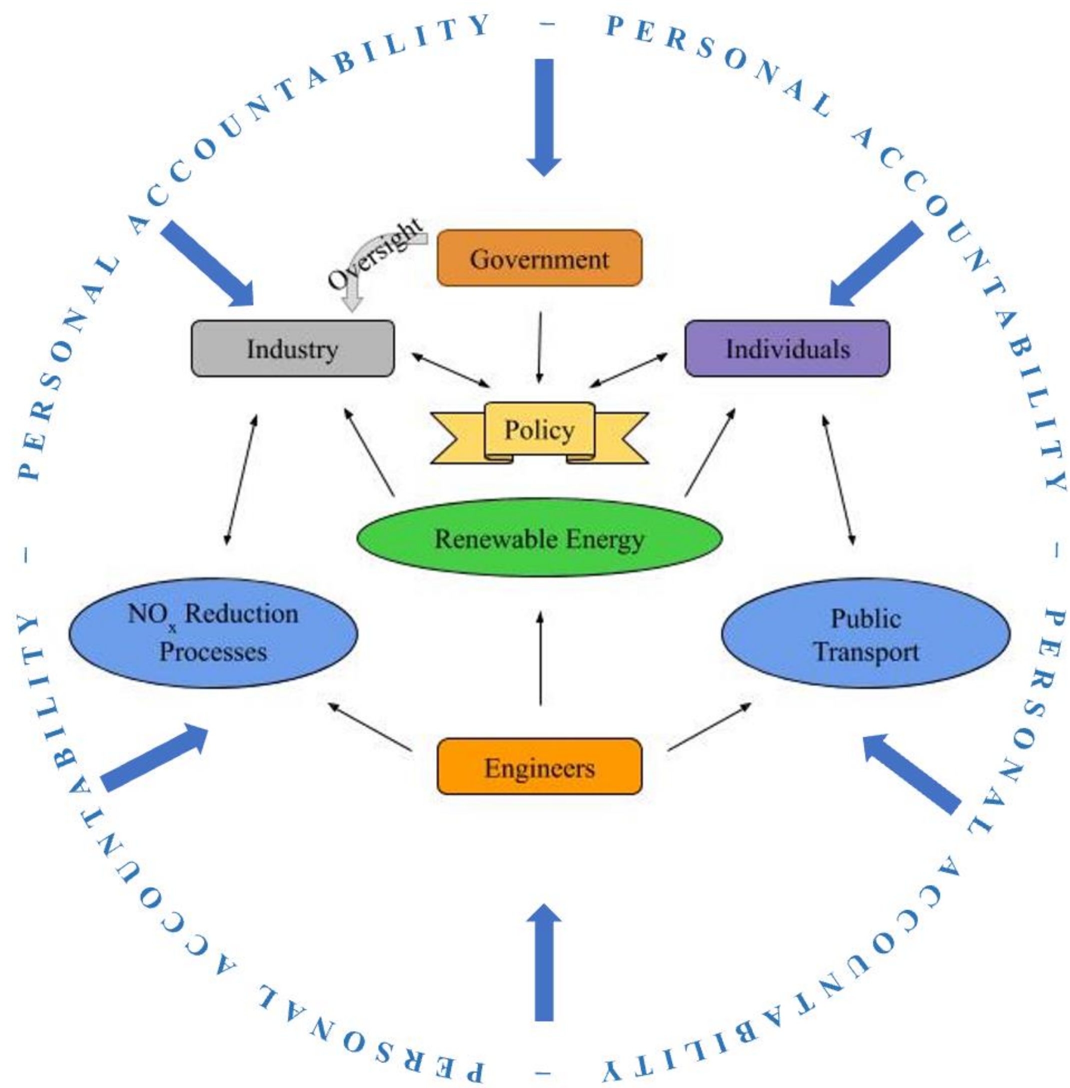

Figure 4. Proposed Network. Concept map shows the relationships different groups have with the environmental policy and the technologies that help adhere to it (Created by Brockett, 2019).

This self-awareness and responsibility comes from education on the issue of emission mitigation and an understanding of the global effects individual decisions can have. The STS research paper will expand on these concepts and involve deeper analysis using a combination of Pacey's Triangle and Actor-Network Theory (Callon, 1986).

The STS and technical research works are closely coupled. The technical project will culminate in a satellite that provides data to supplement the current pool of knowledge about pollution levels around the world. The detailed study of nitrogen oxide mapping within cities will provide insight into the exact causes of increased or excess pollution. In turn, this research can be used to further the development of procedures to limit or eliminate emissions in the areas studied. Scientists may then work with local governments and industry officials in the area to develop a mitigation plan that is specifically targeted to the needs and concerns of that particular area in order to have the greatest impact. The final STS paper will make suggestions on the best ways to achieve these goals using the available technology.

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