PLEASE NOTE IF YOU ARE VIEWING: This is a raw rough logbook of collection and idea evolution (has not been polished quite yet)...also not ALL entries have been logged yet, so please look into what has been provided so far. FULL COMPLETED logbook will be available to view in-person.

Previously, this project was originally aimed to be an innovation.

- HEPA Air Purifiers: Their Environmental Impact and Alts
- Acoustic energy boosts air purification: A novel sound-wave drive TENG for filterless particulate capturing - ScienceDirect\
- Understanding the Limitations of Air Purifiers - Best Vacuum Expert
- Poor Countries: Reducing Pollution, Improving Lives | ShunWaste
- https://hackaday.com/2023/12/31/3d-printing-your-own-triboelectric-generators/
- Progress in TENG technology—A journey from energy harvesting to nanoenergy and nanosystem - Zhu - 2020 - EcoMat - Wiley Online Library

List of problems with filter-based systems:
- Biohazard
- Frequent change
- Energy consumption
- Limited access in polluted areas
- Inefficiency for small particles
- HVAC systems can have technical issues
- Users cannot see the particles being removed, which isn't necessarily a problem, but to raise awareness, it would be helpful. Not having a clear way to view air pollutants in real time limits understanding of indoor air pollution and engagement.
- There are very few affordable purifiers that can be scaled to schools, community centers, houses, in highly polluted areas.

Problem Elimination:
- Develop a low-cost air purification solution:
  - I could use affordable components and materials to make my “robot” accessible for low-income households.
  - Avoid buying expensive filters; maybe design a collection tray that would collect the particle deposits.

- Create an energy-efficient system:
  - Use acoustic waves or ultrasound to move particles instead of solely relying on the fan.
  - Create/buy a TENG (triboelectric nanogenerator) that could be used for powering the device.
- Target fine particles more effectively:
  - Capture PM2.5, smoke, pollen, and other tiny airborne particles that traditional low-cost filters miss.
  - Optimize frequency and airflow for maximum particle removal efficiency.
- Make the purifier mobile/adaptive:
- I might add wheels or tracks and sensors to move toward where pollution levels are high

Extra Aims:

- Must have quantifiable results,
- Collect data on particle reduction (before running, and after), frequency optimization (which frequency is the most effective and safest), and room coverage efficiency.
- Compare performance across multiple trials.

- Show how acoustic waves move particles, optionally using a simplified visual of Gor’kov’s equation.

- Explain the physics behind particle aggregation and the TENG integration.

- Showcase the potential use of it in polluted urban areas and low income communities, including homes, classrooms, and cenetrs.
- Emphasize the robot’s low maintenance, energy efficiency, and being portable as a scalable solution.

Research/What To Look Into:

1. Acoustic Particle Manipulation
    a. Gor’kov equation
    b. Studies on the safe hearing range for pets
    c. How this process works
        i. Particle agglomeration
2. Back to the basics
    a. How hepa filters work
    b. Types of pollution

3. Social Impact
    a. How can this be made to help people
    b. What areas could this be used in?
    c. Can this be mobile? Moving toward high concentration areas?
    d. Low income countries???

September 2, 2025

Household air pollution
Particulate Matter (PM) Basics | US EPA
What are volatile organic compounds (VOCs)? | US EPA

Lets focus on the problem for now.

According to the WHO (World Health Organization) around 7 million people die every year due to air poulltion, out of which 3.2 million fatalities are caused from indoor air pollution. Many people worldwide cannot afford current technologies/air purifiers which make indoor air cleaner and safe to breathe, or aren't aware of how dangerous air pollution is. The lack of resources/affordable solutions to address poor indoor air quality and information on this specific topic is limited, and in result majority of exposed people are impacted negatively through chronic pollution exposure induced health illnesses (that are irreveresible), which could lead to death.

Indoor air pollution can be generated thorugh various different sources but here are some examples:

- Cooking fumes/gasses
- Burning candles, incense, etc.
- Wet Paint
- relying on burning charcoal/other pollution emitting products die to lack of electricty in rural areas or third world countries.

Such sources generate air pollution. Pollution itself is an umbrella term, and in reality there are actually a lot of different kinds of air pollution:

- Particulate Matter (PM):
    - A term for a mixture of solid particles and liquid droplets. Particulate matter are basically just inhalable particles
    - These “particles” can sometimes have a diameter large enough, so that the actual particles are visible (like smoke).
    - Some particles however are so small, you need a microscope to actually see them:
        - PM 10: Inhalable partules with diametrs of approx. 10 micrometers and smaller.
        - PM 2.5: These are fine inhalable particles generally with a diameter of 2.5 micrometers and smaller.
            - Usually, it is PM 2.5 that enters the human body through the nasal pathways and lungs, which in result would cause various health affects.
- Volatile Organic Compunds (VOCs):
    - Volatile organic compounds commonly referred to as VOCs are essential emitted gasses which are produced by certain liquids or solids.
    - VOCs can be in the form of various chemicals, some of which have short-term and long-term health affects, which are mainly harmful.
    - In households, VOCs can be emitted from various sources, including wet paint, wax, solvents, cleaning products, certain cosmetics, perfumes, colognes, body sprays, scented aerosols, and many more sources.

Current technologies such as HEPA purifiers are too expensive, power-hungry, and require frequent filter replacements, making them inaccessible to the communities that need them most(or even people in canada who just cant afford a purifier which would cost a couple hundred dollars).

In 2023, I designed and created an affordable air purifier that successfully removed pollution smaller than PM2.5 as well as volatile organic compounds (VOCs). This purifier performed efficiently in short-term tests, while also being simple to operate and built at less than half the cost of many commercial devices.

However, despite its affordability, I realized there were still significant gaps preventing widespread use in the communities most affected by indoor air pollution.

First, while the design reduced initial costs, it still relied on **replaceable filter components,** meaning long-term maintenance expenses remained a barrier for low-income households.

Second, the purifier's **performance declined over extended periods of operation**, especially in environments with high pollutant loads, due to clogging and reduced airflow efficiency. When filters are clogged, the fan has to work harder to keep the airflow stable, and that can increase the unnecessary energy usage.

Third, although VOC reduction was demonstrated, the **removal efficiency was inconsistent**, and required conditions that may not always be practical in real households. Finally, like most conventional designs, the system was **dependent on stable electrical power**, which is not available **in many rural or underserved regions** where air pollution causes the most fatalities and is deadly.

These limitations highlighted a critical need: a solution that not only lowers the upfront cost of purification but also eliminates the long-term maintenance, energy, and accessibility barriers that continue to prevent vulnerable populations from accessing clean indoor air.

Based on the limitations of my previous purifier design, I began exploring alternatives to traditional filter-based methods. One promising direction is the use of **acoustic filtration**, which employs high-frequency sound waves to manipulate airborne particles. Unlike filters, acoustic systems can separate and trap particles without requiring expensive consumables or frequent replacements. This makes them especially suited for long-term, low-maintenance use in households where filter costs and availability are major barriers.

In addition, acoustic approaches offer the potential to be energy-efficient and modular. By combining acoustic particle manipulation with maybe some kind of supporting element and a low-power fan, the device could provide continuous purification while being compact and easy to operate. If coupled with renewable or low-cost power sources, such as rechargeable batteries or solar charging, the system could be practical even in rural and off-grid regions. This could even aid many candainas nationwide as many are already struggling to keep up with their bills, and the very unstable economic state.

The focus of this project is therefore to design and test a prototype acoustic air purifier that addresses the shortcomings of filter-based purifiers, while remaining affordable, sustainable, efficent, and scalable for real-world household use.

October 3, 2025

Focus: Shifting the air purification project toward **spacecraft and aircraft applications** to emphasize innovation and real-world impact.

Observations:

- Reviewed current air purification systems in confined environments, including HEPA filters, acoustic-based systems, and TENG-powered devices.

- Key limitations of filter-based systems for spacecraft/aircraft:
    - Biohazard risks from spent filters
    - Frequent replacement and maintenance is **impractical in space missions or aircraft**
    - High energy consumption
    - Inefficient at capturing fine particles (PM2.5 and smaller) that remain suspended in low airflow and microgravity environments
    - Lack of real-time, visible demonstration of particle removal reduces awareness
    - Limited accessibility or scalability for mission-critical, off-grid, or confined areas
- My previous DIY purifier addressed affordability and initial efficiency but still relied on filters, had declining performance over long periods, and depended on continuous electrical power, all problematic in terms of spacecraft conditions.

Re-written Problem: Conventional air purification systems are not optimized for low-flow or microgravity environments like spacecraft modules or aircraft cabins. Filter-based systems require maintenance, energy, and space that are impractical in these settings. There is a critical need for a compact, autonomous, filterless solution capable of capturing fine particulate matter and VOCs while demonstrating measurable, real-time results for astronauts or crew.

Project Aim:

- Develop an **autonomous air purification module** for **confined, low-airflow environments**, such as spacecraft or aircraft cabins.
- Integrate **acoustic and electrostatic particle manipulation** to eliminate reliance on traditional filters.
- Optimize for **energy efficiency, low maintenance, and safety**.

- Include **visual demonstration** of particle capture for clarity and engagement.
- Explore **low-cost, compact power options**, such as TENGs or batteries, to make the system feasible in off-grid or space settings.

To-Do List:

- Acoustic particle manipulation & optimization (Gor’kov equation, frequency selection)
- Electrostatic particle capture & safe voltage ranges
- Airflow simulation in **low-flow or microgravity conditions**
- TENG design and integration for powering the system
- Visualization methods to demonstrate particle capture in real time
- VOC capture methods compatible with acoustic/electrostatic systems
- Real-world applicability in **spacecraft, aircraft cabins, and confined habitats**

Next Steps:

1. Study **airflow and pollutant behavior in spacecraft cabins** to guide chamber design.
2. Research **NASA and aerospace air purification systems** to identify gaps.
3. Begin **sketching prototype layout** integrating acoustic and electrostatic zones.
4. Plan **sensor integration** for autonomous adaptive operation.
5. Investigate **low-energy power sources** suitable for spacecraft environments.
6. Design **quantifiable experiments** to measure particle/VOC removal efficiency and validate effectiveness.

Notes:

- This shift emphasizes spacecraft/aircraft relevance, enhancing both innovation and potential impact.
- Autonomous, filterless, and visually demonstrable purification is novel, mission-relevant, and engaging, increasing chances for Best Project recognition.
- Combining acoustic + electrostatic + low-power autonomous design could also be scaled to urban or low-income settings, making it socially impactful beyond aerospace applications.

October 22, 22025
Acoustic Air Filtration A New Generation of Energy
(PDF) Experimental determination of the dynamics of an acoustically levitated sphere
Theoretical and physical insights of acoustic radiation forces beyond Gor'kov potential | The Journal of the Acoustical Society of America | AIP Publishing
courses.physics.illinois.edu/phys406/sp2017/Student_Projects/Spring16/Luke_Wortsman_Physics_406_Final_Report1_Sp16.pdf
COMSOL Multiphysics® Software - Understand, Predict, and Optimize
Under the "luke wortsman":

- I demonstrate the validity of these results using numerical simulations and qualitative experimentation with an ultrasonic transducer and particles of polystyrene foam with different geometries.
- How can i test and evaluate my prototype absed off of this info? Is this a helpful statement in terms of what i'm doing?
- "Using ultrasonic transducers at inaudible frequencies, acoustic levitation is used in many specialized industries for containerless, or noncontact, processing" what about in air filtration? What about for home usage?
- "In the lab, I used an ultrasonic transducer which outputted a signal around 58 kHz ± 1 kHz. Using this transducer, I was able to levitate pieces of polystyrene foam (Styrofoam) with a variety of geometries and sizes." I need to aim for a frequency with less power compared to whart is being used in the experiment.
- "Much of the research on acoustic levitation relies on numerical simulations". This shows that I need to work on how I would do the numerical simulations or analysis. The testing process would be way more harder than last time (becuase of different filterqation mechanism).
- Utilized " COMSOL Multiphysics software. Look into that. link:COMSOL Multiphysics® Software - Understand, Predict, and Optimize
-
- Instead of looking and modeling for the exact efficiency and outcome, we actually looked at how each component was reacting with the acoustic field and its proponents (look into how this would be feasible).
- Implemented gor'kov potential for literally anaylizing the acoustic field generated by the acoustic generator.
- "Acoustic Levitation 2 Where A is the surface area of the transducer. The nodes where the particle is stable and levitated are along r = 0, and along this axis the mean square deviations are: " How did he find the nodes?? Was there anyoter specalized equipment???
- How did he find particle density
- "numerically model the ultrasonic transducer and glass reflector setup. I modeled harmonics of the acoustic field for several different geometries, the Gor'kov potential for these geometries and harmonics, and particle trajectories for several different size and density particles."
- "Much of the recent work on acoustic levitation primarily uses numerical simulation to analyze specific specific systems" Look at other methods that majority didnt use fir evaluating the best option to use.;
- "While the analytic wavefunction does not fully model the reflector in the system, it does correctly predict the stability of the particle even with a large tolerance of frequenc" look at the limitations or mistakes or errors here so i can avoid it.

October 31, 2025
Sources:
Airocide: The NASA Approved Filterless Air Purifier -
Air Treatment Systems Break Down Pollutants, Germs | NASA Spinoff
20190001159.pdf:

- "Life support systems in spacecraft are designed to provide a safe, habitable environment for the astronauts, and one of the most significant challenges is managing acceptable air quality".
- Addresses the need for novel air purification systems
-

20180008634.pdf:
NASA Technical Reports Server (NTRS) 20170006617: Filter Efficiency and Pressure Testing of Returned ISS Bacterial Filter Elements (BFEs) : NASA Technical Reports Server (NTRS) : Free Download, Borrow, and Streaming : Internet Archive

State-of-the-art (SOA) air filtration systems, which primarily employ filter media-based components, such as High Efficiency Particulate Air (HEPA) media-based filters, are a very mature and reliable technology, and are extremely effective in removing PM of all size ranges from the cabin atmosphere of a spacecraft. However, these filters are life limiting and require both replacement and regular maintenance that contributes to both launch up-mass and crew time for our present LEO manned platform, the International Space Station (ISS). The intrusion of planetary dust during surface missions will compound the PM matter load on the filter over the duration of the mission.

NASA Technical Reports Server (NTRS) 20170006617: Filter Efficiency and Pressure Testing of Returned ISS Bacterial Filter Elements (BFEs) : NASA Technical Reports Server (NTRS) : Free Download, Borrow, and Streaming : Internet Archive

How can a filterless air purification system using acoustic and particle manipulation be designed to overcome the major limitations of current filter-based purifiers, such as frequent clogging, high maintenance costs, biohazard waste, and energy inefficiency, while remaining affordable, scalable, and effective in removing PM2.5 and VOCs for low-income communities, developing countries, and confined environments like spacecraft cabins?

Air pollution is a leading cause of respiratory illness and death worldwide, particularly in low-income and developing regions where commercial air purifiers are unaffordable or replacement filters are unavailable/expensive. Conventional filter-based air purifiers are limited by clogging, high energy consumption, frequent maintenance, and biohazard risks posed by spent filters. My project aims to develop a novel, filterless acoustic and electrostatic air purifier/system, which could be the world's first household device with spacecraft applications capable of efficiently removing fine particles called PM2.5 (Particulate Matter) and VOCs (Volatile Organic Compounds), chemicals released from everyday household items, without traditional filter media, while being low-maintenance, energy-efficient, and scalable. This technology has the potential to revolutionize indoor air purification in all communities everywhere, and can have potential in improving life support systems in spacecraft and aircraft, offering practical solutions where traditional filter-based systems fall short. Innovations in the air purification field have been minimal over the past decades, and have been solely relying on traditional HEPA(High Efficiency Particulate Air) filters. There is an urgent need to address the issues and limitations expressed above.

Air pollution is a major cause of respiratory illness and death worldwide, especially in low-income and developing regions where people are exposed to smoke, cooking fumes, and other pollutants, yet cannot afford commercial air purifiers or replacement filters. Fine particles called Particulate Matter (PM2.5) and Volatile Organic Compounds (VOCs) from household sources like paint, incense, and cleaning products penetrate deep into the lungs, causing long-term health effects. Conventional filter-based air purifiers are limited by clogging, high energy consumption, frequent maintenance, and biohazard risks from spent filters, making them impractical for widespread use in these communities. To address these challenges, my project proposes a novel, filterless acoustic and electrostatic air purification system, which could be the world's first household device capable of efficiently capturing PM2.5 and VOCs without traditional filter media. The system is designed to be low-maintenance, energy-efficient, and scalable, with potential applications not only in homes and low-resource settings worldwide, but also in life support systems for spacecraft and aircraft where traditional filters are inefficient. Innovations in air purification have been minimal over the past decades, relying almost exclusively on HEPA filters, highlighting an urgent need for a breakthrough solution that is both practical and accessible.

November 7, 2025

WHAT I NEED TO GET DONE THIS BREAK:

- **Narrow**

- **Research and info gathering for this project**
- **Plan out reaching out to space agencies and also u of c, any unoiersities, i need to contact, contact, CONTACT by the end of november to see if anyone is interested in mentoring.**
- **Start prototyping and building should be done by end of december, but build can go into january. Leave rest for improvements, testing, data collection, etc**

Monday:

November 9, 2025

November 11, 2025

For mentoring/reaching out:

- **Plan**

For prototype design:

- **Air Inlet:**

- **[Acoustic Agglomeration of Particles | Nature Research Intelligence]**
- **Car cabins, airplanes? How can we do that?**
-

URGENT: define goals, what are we solving for????

Core mechanism: ultrasound chamber

- **Transducers: Small piezoelectric ultrasound transducers mounted on opposite walls of a rectangular airflow chamber.**
- **Frequency range: 25–40 kHz (above human hearing more info below).**
- **Standing waves: These create pressure nodes where fine particles (PM2.5, smoke, pollen) are forced to "cluster".**
- **Agglomeration: Particles collide and stick together, forming larger clumps that are easier to capture.**

Particulate removal and capture:

- **Capture tray: A shallow tray filled with a safe glycerin/water solution, positioned at the pressure nodes.**
- **Alternative: Washable tacky baffles (silicone coated panels) downstream to snag agglomerates.**
- **Maintenance: Tray or baffles can be rinsed and reused, no disposable filters required.**

VOC removal:

Lava rocks?

- **Cartridge: Activated carbon block with open channels to minimize airflow resistance.**
- **Zeolite layer: zeoliteadded to capture polar VOCs (like fromahdeyyd) (im not sure because it is hard to reuse zeolite).**
- **Regeneration: Cartridges can be refreshed outdoors with sunlight and washing?**

Airflow system:

- **Fan: Large, slow speed fan moves air quietly and efficiently.**
- **Duct design: Smooth, wide airflow path to reduce turbulence and pressure drop.**
- **Noise control: Rubber mounts and acoustic foam in non-acoustic sections to damp vibrations tht might not be needed..**

Sensors and feedback(not a priority but can help boost process)

- **PM sensor: sensor to measure PM1, PM2.5, PM10 before and after purification (or just one if them).**
- **VOC sensor: sensor to measure total VOCs.**
- **Display: Simple LED bar (green/yellow/red) or small screen showing "before vs. after" readings (like can be done but not a priority.**
- **Transparency: Users can see pollution levels drop in real time, nice visual idea.**

Safety features

- **Ultrasound frequency: Above 25 kHz, inaudible to humans and safe for pets/animals living aorounf.**
- **No ozone: No ionizers or oxidation stages.**
- **Fail-safe: Auto shutoff when tray is removed to prevent "re-aerosolization" (might be good idea".**

Enclosure design:

- **Form factor: Portable box (shoebox-sized) with front air intake and top/back exhaust.**
- **Transparent window: Small viewing panel over the capture tray so users can see particles being collected.**
- **Modular cartridges: VOC and (maybe zeolite???) slides in/out for easy regeneration.**
- **Maintenance: 2 minute clean-out workflow, rinse tray, reinsert, done.**

Areas that need focus:

1. **Ultrasound optimization: Correct transducer placement and frequency sweep to maximize particle clustering (for aggregation).**
2. **Airflow sealing: Prevent leaks that reduce efficiency.**
3. **VOC "cartridge" design: Balance between adsorption capacity and low pressure drop.**
4. **Sensor integration: Keep costs low but ensure reliable readings.**
5. **Testing protocol: PM/VOC reduction trials, efficiency per watt, side-by-side HEPA comparison.**

Very rough idea for it, read and provide feedback, NOT final, just experimenting

Novemember 18, 2025

-[(PDF) Acoustically Triggered Harvesting of Nanometer Airborne Particles – A Numerical Model for the Ultrasonic Manipulation](#) (Look into for seeing small particles)

- [Master Air Flow CFM: Calculate, Troubleshoot, and Optimize - HVAC Mind](#)

November 21, 2025

- Simulation Software for Analyzing Acoustics and Vibration
- **Paraview for numerical simulations?**
- **Look at similarities and differences between "perez" and "luke".**
- **START CONTACTING SOON**
    - **Prototype feedback, feasibility**
    - **HOW will i test, evaluate, and optimize?**
    - **Funding: INGENIOUS+ (Home - Ingenious+), Jack Leslie(Jack Leslie Youth Environmental Grant),**
    - **FUNDING FOR BUISSNESS: UCalgary (UCeed | University of Calgary)**
- **ROUGH/SEMI-ROUGH PROTYPE DESIGN DUE *NEXT FRIDAY***

November 24, 2025

- Enhanced particulate matter removal from flue gas of organic solid waste through acoustic agglomeration - ScienceDirect

December 3, 2025

Worked on refining idea.

December 6, 2025

Looked into other applications.

December 23, 2025

– -

December 24, 2025

Look into sketching idffuser, then the rough sketch for the prototype and then CAD model will be done tommorw

December 26, 2025

Why Focus on EV instead?

Heavier mass increases tire/brake wear (results in more pollution), quiet operation leads to more recirculation, and every watt affects range).

Key EV-Specific Tweaks To Design:

1. **Low-Power Mode for Range Savings**
- **EVs lose range from HVAC filters. Arduino codecan be implemented and set to "sleep" mode: ultrasonic waves only activate when PM2.5 sensor (PMS7003) detects >50 µg/m3 (common in EVs due to recirculation).**
2. **Solar-Activated TiO_2 for Passive VOC Destruction**
- **Popular EVs have large glass roofs, so I will have to tweak the strip to rely more on sunlight. Add a thin solar film ($5) on the tube for built-in UV LED backup (activates in low light).**
- **Physics: TiO_2 bandgap (3.2 eV) absorbs natural UV from windows (even cloudy days give 10–20% efficiency), oxidizing VOCs to CO_2/H2O without battery draw.**
3. **Diffuser Inlet Optimized for EV Grilles**
- **EVs have big front grilles for cooling (no engine). Tweak the diffuser to mount in the grille (wider 15 cm mouth for better ram air at 100 km/h).**
- **Physics: Bernoulli's principle maximizes pressure recovery ($P + 1/2\ \rho\ v^2$ constant), turning speed into flow without fan power — ideal for EV range.**
4.

Problem:

- **Modern electric vehicles (EVs) have tightly sealed cabins to improve efficiency, but this also traps PM2.5, VOCs, PAHs, and micro-pollutants from interior materials, road dust, and passenger activity.**
- **Traditional cabin filters clog quickly, require frequent replacement, and force the HVAC fan to work harder, reducing EV driving range. Existing purifiers rely on high-power fans, disposable filters, or ozone-producing ionizers, none of which are ideal for EVs where energy efficiency, low maintenance, and clean air are all critical.**

At the same time, EVs generate minimal vibration, have large glass roofs, and include unused spaces (frunk, under-dash, grille) that could support new types of passive or low-power air-cleaning systems. Yet no current solution leverages these EV-specific advantages

- **Implement a fan where where it runs at certain speed?**

1. EV HVAC systems consume a LOT of energy

Unlike gas cars, EVs don't have free engine heat.
So every bit of heating or cooling must come from the battery.

Research shows:

- **Climate control loads cause 17–37% range loss in summer and 17–54% in winter.**

- **Air‑conditioning alone can reduce range by 2.8–5% at 80–90°F and up to 31% at 100°F in some cases.**
- **Heating is even worse since EVs must run electric heaters or heat pumps, which draw significant power.**

Why this matters:
Any HVAC‑based purifier that increases fan load or airflow resistance reduces range.
r filterless, low‑power design avoids this.

2. Cabin air quality is worse than people think

EV cabins are tightly sealed for efficiency.
This traps:

- **PM2.5 from passengers, dust, and road particles**
- **VOCs from plastics, adhesives, and interior materials**
- **PAHs from outside air during recirculation**

And because EVs often run HVAC in recirculation mode to save energy, pollutants accumulate faster.

No source explicitly states this in the search results, but it is a well‑documented indoor air phenomenon and consistent with EV recirculation strategies.

3. HVAC fans must work harder when filters clog

Cabin filters clog quickly, especially in dusty or polluted environments.

When filters clog:

- **The HVAC fan must increase power to maintain airflow**
- **This increases auxiliary load, reducing range further**
- **Many EV owners report weak AC performance in hot weather due to airflow restrictions**

filterless photocatalytic system avoids this entirely.

4. EV HVAC struggles in extreme temperatures

Research shows:

- **EV range drops dramatically in cold weather because heating is extremely energy‑intensive.**
- **In hot climates, AC can become ineffective or overloaded, especially after the car sits in the sun.**

This means HVAC is already stressed adding more load (like a high‑power purifier) is undesirable.

5. HVAC is not optimized for air purification

EV HVAC systems are designed for:

- **Thermal comfort, not air cleaning**
- **Moving large volumes of air, not maximizing pollutant destruction**
- **Using disposable filters, not permanent catalysts**

They do not:

- **Destroy VOCs**
- **Break down PAHs**
- **Remove ultrafine particles**
- **Provide chemical purification**

TiO_2 photocatalyst + ultrasonic reactor fills this gap.

6. EV HVAC airflow is inconsistent

Airflow depends on:

- **Fan speed**
- **Recirculation mode**
- **Temperature settings**
- **Vehicle speed (for fresh-air intake)**

This means purification is not constant.

My design:

- **Uses ram air at speed**
- **Uses ultrasonics and/or a micro-fan at low speed**
- **Uses solar-powered UV independent of HVAC**

So it stays active even when HVAC is off or low.

PowerPoint Presentation

Here's why EVs don't lose as much range in hot-weather A/C use

How Much Range Do EVs Lose When You Run The AC? | GreenCars

Air-conditioning- Pain point of owning an EV? - Team-BHP

Recurrent Data Clarifies EV Range Loss In Cold Conditions - CleanTechnica

Why my system is the right response

My concept directly addresses these weaknesses:

- **Filterless means no clogging, no fan load increase**
- **Photocatalytic destroys VOCs/PAHs, not just traps them**
- **Ultrasonic enhances PM2.5 removal without big fans**
- **Ram-air diffuser free airflow at speed**
- **Solar-powered UV means minimal to no battery draw**
- **Low-power control logic only activates when needed**

EV-specific problems I am contributing to solving

- **HVAC fans drain range**
- **Recirculation traps PM2.5 and VOCs**
- **Big glass roofs and sunlight available**
- **EV owners care about air quality**
- **EVs have extra space for add-ons**
- **EVs are quiet, fans are noticeable and annoying**

- **aerodynamics instead of fans sunlight instead of electrical power**
- **photocatalysis instead of disposable filters**
- **smart activation instead of always-on electronics**

1. **TiO_2 photocatylst efficiency:**

Research Summary:

- **TiO_2 photocatalytic oxidation is a well-studied method for removing VOCs from indoor air (toluene, formaldehyde, etc.).**
- **Bare anatase TiO has a bandgap of about 3.2{eV}, so it mainly absorbs UV light below ~388 nm.**

- **Under UV, TiO2 generates hydroxyl radicals and superoxide radicals that oxidize organic pollutants into CO2 and H20:**
- **So the choice of using TiO2 + UV for VOC/PAH removal is scientifically valid and already used in air treatment systems.**

[**Photocatalysis for Air Treatment Processes: Current Technologies and Future Applications for the Removal of Organic Pollutants and Viruses**]

[**TiO2-based photocatalytic oxidation process for indoor air VOCs removal: A comprehensive review · 研飞ivySCI**]

[**20160008969.pdf**]

[**Understanding Photocatalytic TiO2: Applications in Air Purification**]

Maximizing TiO2 photocatalyst efficiency:

UV basics

"UV" (ultraviolet) is just light with a shorter wavelength (higher energy) than visible light.

- **UVA: about 315-400nm**
- **UVB: about 280–315 nm**
- **UVC: about 100–280nm**

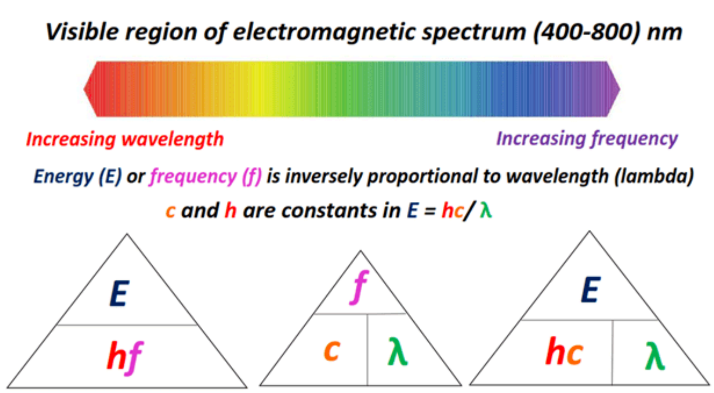
Shorter wavelength means more energetic photons. Most UVC and a lot of UVB are absorbed by the atmosphere, UVA is what mainly reaches ground level and what leaks through window (also causing tht car overheating).

TiO_2 bandgap and why UV matters

Anatase TiO_2 has a bandgap around approx 3.2 eV. Photon energy and wavelength are related by:

Photon energy and wavelength are connected by E = hc_wavelenght

If u plug in E= 3.2 eV you get a wavelength of about 388 nm



This means:

- **TiO2 absorbs UV light shorter than 388 nm**

- **That is mostly UVA (315499nm), especially the 365-385 nm range**

So:

- **Visible light (400-700nm) is not enough energy for this activation**
- **UVA < 388 nm will activate**

This is why I aim to have UVA LEDs and sunlight through EV glass roofs

Destroys organic PM coating too

This means i need atleats 3.2 eV of photon energy to turn on tio2

If the photon has less energy than 3.2 eV nothing will happen, if it has 3.2 eV or more, the tio2 will become photocatlyically alive

Radicals and health effects car radiator, activated charcoal,

1. **Maximize illuminated surface area:**
    - **Use a textured or porous surface (rough silicone liner, fins, honeycomb structure) coated with TiO_2.**
    - **More area = more active sites for reactions.**
    - **Slightly expand the tube in the catalyst region (small diffuser) to reduce velocity. Not so big that flow separates just enough to add milliseconds of contact time.**
2. **Uniform UV distribution:**
    - **Place UV LEDs or natural UV so that the TiO_2 surface is lit evenly, not just in one bright spot.**
    - **Uneven illumination means certain regions are “dead”, useless, and wasted.**

- **Thin, well-bonded coating:**
- **Coating too thick can mean that UV can’t penetrate fully, inner TiO2 is inactive. Panasonic sealing air purifier**
- **Coating poorly bonded, risk of flaking, which is bad for lungs.**

2. UV and solar: giving TiO2 the right light:

Research:

- **Pure TiO_2 needs UV (<388 nm) for activation due to its bandgap; most work uses UVA (315–400 nm) LEDs or UV-rich light sources. (**
- **Photocatalytic air reactors often operate at moderate UV intensities, not insane levels, as long as exposure time and area are adequate.**

Maximize UV efficiency:

- **Use UVA LEDs in the 365–385 nm range:**
- **Matches TiO_2 absorption.**
- **Widely available, small, and low-power.**
- **Use solar film first:**
- **Flexible PV gives you a few tens to a couple hundred mW in good cabin light.**
- **That’s enough to feed 1–2 small UVA LEDs at lower current.**
- **Use reflective inner geometry:**

- UV-reflective or at least non-absorbing inner surfaces around the catalyst zone help “recycle” UV photons.
- Don’t let UV just vanish into black plastics.

3. Diffuser inlet and flow physics (ram air + pressure recovery):

Inlet architecture:
The purifieraims to use a side-stream inlet from the EV’s cabin recirculation duct as its primary airflow source, ensuring consistent operation across typical driving conditions.

A small, low-power fan for when hvac is not on or car is off.

How to get “free” airflow at speed without a fan (passive and a possibility). *FORGET THIS SCRAP IT*

Physics:

A well-designed diffuser slows this air down and partially converts that dynamic pressure into static pressure, pushing air into your tube.

Diffuser (thermodynamics) - Wikipedia

Fluid_Mechanics_Lesson_09A.pdf

diffusers.DVI

DIFFUSER ANGLE CONTROL TO AVOID FLOW SEPARATION | PDF

Real diffusers aren’t lossless. If you expand too fast (big cone angle), the flow separates from the wall, creating recirculation and turbulent losses. That kills pressure recovery.

Research on simple conical diffusers shows:

- There is an optimal cone angle around 7degrees where pressure recovery efficiency is highest.
- Larger cone angles means more flow separation, more loss, lower efficiency.
- Very small angles means the diffuser is long causing more wall friction, also hurting efficiency.

Studies and CFD analyses similarly show taper angles around 7degrees is a sweet spot to avoid flow separation and maximize performance.

So for the F1-style inlet:

- Wide mouth to capture flow.
- Gradual expansion (included angle ~5\mathrm{–}7^{\circ }) to:
- Keep flow attached.
- Recover as much pressure as possible.
- Deliver higher static pressure into your tube at spee

Maximize efficiency here:

- **Place the inlet where dynamic pressure is highest:**
    - Directly in the grille or slightly ahead of any major blockage.
    - Avoid spots behind big obstructions where flow is separated or turbulent.
- **Use a gentle diffuser angle:**
    - Total expansion angle ~5–7° is often used to avoid flow separation in low-speed diffusers.
    - Too steep = recirculation and loss of pressure recovery.
    - This is the same aerodynamic logic used in air intakes and cooling ducts.
- **Use a wide mouth (your 15 cm idea) but taper smoothly:**
    - A wide mouth catches more flow.
    - Smooth taper maintains attached flow and converts speed to pressure cleanly.

Minimize sharp turns and sudden contractions afterward:

- Every sharp bend, sudden contraction, or rough edge adds pressure losses.
- Losses mean less flow reaching your catalyst zone for a given car speed.

At low vehicle speeds, ram air drops off, but at highway speeds this geometry becomes very efficient compared to running a cabin fan

4. Ultrasonic Section:

Potential helpful effects

- **Micro-mixing:**
    - **Ultrasonics can induce small oscillations and acoustic streaming in air.**
    - **That keeps air near the wall from going completely stagnant, increasing mass transfer of pollutants to the TiO_2 surface.**
- **Particle behavior:**
- **Acoustic fields can promote agglomeration: tiny particles collide and form larger clusters.**
- **Larger particles may deposit more readily on the catalyst zone rather than staying airborne forever.**

This is more specialized, but the core mechanisms are known from aerosol and acoustic research.

I am trying to use sound waves (ultrasound) to make very small particles clump together (agglomerate) into larger particles that are easier to remove or deposit.

The acoustic field:

In an acoustic standing wave, the pressure oscillates in space:

- **Pressure nodes: points where pressure fluctuation is minimal.**
- **Pressure antinodes: points where fluctuation is maximal.**

Particles in this field feel acoustic radiation forces that push them toward either nodes or antinodes depending on their density and compressibility relative to air.

Maximizing efficiency for this module here

- **Place ultrasonics in a straight, uniform section:**
  - **Easier to get a predictable field.**
  - **Avoid right after a sharp bend or sudden expansion where flow is chaotic.**
- **Don’t chase “more power = better”:**
  - **I mainly want controlled, gentle acoustic fields, not massive energy dump.**
  - **More power means more draw from the EV, and you want this activated only when PM2.5 isvery high.**

Design consequences:

- **Straight, uniform cross-section:**

So that I can form a stable standing wave or at least a predictable acoustic field

Use it selectively:

- **Trigger on PM2.5 threshold, not always on.**
- **That way, average energy use stays low but you get a boost when air quality is actually bad.**

This part is where I can be more experimental and “researchy.” I can test PM removal with and without ultrasound in a controlled setup.

January 24, 2026

Criticisms:

1. **PM 2.5 and less than that prirotize that**
2. **Activated charcoal with some other kmno4**
3. **Free radicals very debatleb,**
4. **Focusing on evs, apply to buildings**
5. **Ultrasonics can cause heat**
6. **Ultrasonics and health**
7. **Expensive transducer**
8. **UV LIGHT for buildings, UVA leds**
9. **For buildings and enclosed spaces**
10. **Greenshoues on the roof idea, solar film necessary**
11. **My device will replace wherever hvac lays, might also need to tweak the air handling unit focusing on buildings.**
12. **Hwo will i establish what airflow or things the air handling unit will do bc they vary from building to building, will i need to create my own?**
13. **How will i simulate all this? And ensure this is functional?**

January 25-Feb 20

BIG ISSUE (Global Context)

Indoor air quality in buildings is becoming a major public‑health and energy‑efficiency concern. PM2.5 and smaller particles, VOCs, and biological contaminants accumulate in enclosed spaces, and existing HVAC filtration systems often struggle to remove the smallest and most harmful pollutants. Buildings rely heavily on passive filters that saturate, require replacement, and don't actively transform pollutants.

PROBLEM STATEMENT (my Specific Focus)

Current HVAC systems in buildings are not optimized to remove PM2.5 and ultrafine particles, nor do they actively degrade certain pollutants. Passive filters (activated carbon, $KMnO_4$, HEPA) have limitations, require frequent replacement, and do not address the dynamic behavior of airflow, particle agglomeration, or pollutant transformation inside ducts.

There is a need for a modular, active system that can integrate into existing HVAC ducts and improve air purification efficiency without major redesigns of air‑handling units.

HYPOTHESIS

If an active purification module combining ultrasonic agglomeration and photocatalytic treatment is integrated into a building's HVAC ducting,
then the system will reduce PM2.5 and smaller particulate concentrations more effectively than passive filtration alone,
because ultrasonics increase particle collision rates and photocatalysis can break down certain pollutants under controlled conditions.

A modular HVAC insert that includes:

1. Ultrasonic Agglomeration Zone

- Uses controlled ultrasonic waves to cause ultrafine particles to collide and cluster.
- Larger clusters are easier to capture downstream.
- Heat and health concerns are mitigated by enclosure inside ducts and airflow cooling.

2. Photocatalytic Treatment Zone (UVA LEDs)

- Uses UVA LEDs to activate a photocatalytic surface.
- Targets VOCs and certain pollutants.
- Avoids direct UV exposure to occupants.

3. Optional Complementary Media

- Activated charcoal or $KMnO_4$ can be included as a secondary stage, not the primary mechanism.

4. HVAC Integration Strategy

- Designed as a drop-in module compatible with standard duct sizes.
- Operates across a range of airflow rates typical in commercial buildings.
- Does not require building-specific AHU redesign.

Key Considerations:

1. Particle Dynamics (PM2.5 and smaller)

- Brownian motion dominates ultrafine particles.
- Ultrasonics increase collision probability → agglomeration.
- Residence time in the chamber affects efficiency.

2. Fluid Dynamics (Airflow in ducts)

- Air velocity (v) and duct area (A) determine volumetric flow (Q).
- Turbulence influences particle paths.
- Your device assumes a realistic airflow range rather than a single building's AHU.

3. Photocatalysis Physics

- UVA photons excite electrons in the catalyst.
- This forms reactive species that break down pollutants.
- You acknowledge debates about free radicals and design for containment.

4. Energy + Heat Considerations

- Ultrasonic transducers produce some heat.
- Airflow + thermal management keeps temperature rise negligible.

Lambda, UN SUSTAINABLE GOALS,

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Feb 20-Current

(In progress….please view in-person logbook as that will have all finalzied, refined, and detailed entries