Vacuum Thermoformer for Fabrication of

Powered Air Purifying Respirators for Children

(Technical Paper)

Forces that Influence the Adoption of Renewable Energy Technologies in India
(STS Paper)

A Thesis Portfolio Submitted to the

Faculty of the School of Engineering and Applied Science
Department of Mechanical Engineering
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements of the Degree
Bachelor of Science, School of Engineering

Jacob St. Martin
Spring 2021

Technical Project Team Members
Noah Rempfer
Dale Midkiff
Jack Herrmann
Ryan Gibiser

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

Signature ____ Date __________
Jacob St. Martin
Approved ____ Date __________
Bryn Seabrook, Department of Engineering and Society
Approved ____ Date __________
Gavin Garner, Department of Mechanical Engineering

Sociotechnical Synthesis

Jacob St. Martin

Introduction:

Over the last few decades, the world has faced significant challenges that are complex in nature. Two such challenges are the coronavirus pandemic and global climate change. The STS research paper addresses the forces that influence the implementation of renewable energy in India and how those economic, political, and social forces influence renewable energy implementation more broadly, while the technical project involves the development of a Powered Air Purifying Respirator (PAPR) for children for use during the coronavirus pandemic and other future pandemics and the creation of a plastic thermoformer to facilitate construction of the PAPRs. While these two projects are not directly related, they both address technologies that are involved in major global sociotechnical systems that have changed drastically in recent years. Each of these projects seeks to better understand the sociotechnical systems and progress them to better face global challenges. `

Project Summaries

In my STS Research Paper, I investigated how social, economic, and political factors influence the implementation of renewable energy in developing countries. The electrification of

India was used as a case study because India went from 59% of the population having electricity in 2000 to 95% in 2018. This electrification coincides with the rise of renewable energy technologies as being cost effective alternative energy sources. Although renewable energy sources became cost effective in this time period, the electrification of India was largely accomplished through coal burning power plants. The social, economic, and political aspects of renewable energy implementation were studied to determine the causes for the use of coal over renewables and to establish a path for future developing countries to electrify sustainably. The sociotechnical frameworks of actor-network theory, technological momentum, and the SPEED framework were applied to analyze the energy systems of India. It was determined that in the case of India it was likely a combination of the easy access to coal deposits, a lack of sustainable policy goals, and the fact that no other major world nations have successfully converted to a sustainable grid (providing an example to follow) that caused India to electrify primarily using coal.

Originally, my capstone research project was going to be developing a PAPR designed for children. However, after a few weeks my capstone team and advisor decided to shift direction slightly and build a plastic thermoformer. A plastic thermoformer allows for the recreation of complex plastic shapes by heating plastic and placing it on top of a mold. The plastic thermoformer was still related to our original project concept because it is a tool that would have been necessary to complete the PAPR design we were considering. The thermoformer is composed of a wielded steel frame with clamps to secure a large sheet of plastic. A heating module is mounted to a computer controlled linear guide rail that moves the heating module back and forth along the plastic to heat it evenly. As the plastic heats it droops down onto a mold and then cools. After the heating and cooling process is complete the result is a piece of plastic bearing the shape of the mold. This can be down repeatedly to create large numbers of complex plastic pieces in a much more cost-effective way than other methods. The original PAPR design was intended to be easily reproducible, cheap, and fairly complex in shape meaning that the plastic thermoformer is the perfect tool for production. This piece of equipment is now a part of the mechatronics lab and will be available for other student groups to use in the future.

Conclusion:

As mankind has developed, we have faced problems seemingly more and more complex than those of our predecessors. Global climate change and the coronavirus pandemic represent two of the world's most recent and pressing problems. Solving problems like these requires technical, social, economic, and political solutions to work in unison. Through these two projects I learned a lot about the engineering process. I realized that even when the solution to a problem seems simple, it is often more complex, and issues will arise along the way. This means that engineers must be quick thinking and willing to adapt as problems arise in their own projects and in the world.

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Abstract
The ongoing Coronavirus pandemic demands innovation from scientists and engineers across all disciplines to develop solutions to save lives. As fourth year Mechanical Engineering students at the University of Virginia, our team wanted to contribute by developing a Powered Air Purifying Respirator (PAPR) designed for children as our technical capstone project. We initially set out to develop a PAPR designed for use by students in lower education schools, but as our semester-long project went on, focus shifted toward developing a vacuum thermoformer due to its key role in fabricating a physical prototype. After many trials and errors, we learned a lot about mechanical design, and have developed a relatively low-cost method for creating plastic molds that students can use for future capstone projects. Our work on the thermoformer could be continued in the future to improve its overall performance and ultimately create a more finished design.

1. Introduction: Our Initial Design Project - The Clean-19:

Grade school students staying home from school causes numerous problems. One problem is that parents no longer have a place to send their children while they are at work. Since the day cares are also closed because of Covid-19 they are left with two options: leave the kid home with a babysitter or work from home if their job allows. Compared to in-person classes, online classes are more difficult to stay focused during, especially when at home where there are endless distractions. Long-term gaps from in-person schooling can cause students to forget what they previously learned, like the “summer slump”. The phenomenon where, after summer break, children forget important concepts learned the year before (The Importance of Reopening, 2020). The longer students are kept from in-person classes the more they will slide down the slump. A solution is needed.

To solve this problem our team first designed a Powered Air Purifying Respirator (PAPR) that filters both inhalation and exhalation, the Clean-19. Providing students with a Clean-19 greatly reduces the risk of COVID-19 allowing schools to reopen in-person confidently. Alternatives to the Clean-19 are students wearing surgical, cloth, or N-95 masks. Not only are these masks uncomfortable, but each child will need to get fit tested to ensure the mask is airtight. Even if the masks fit correctly, transmission is still possible. The student can contract it through their eyes, they can take the masks off without the teacher knowing, and COVID-19 particles occasionally seep through the mask material. For reference, an appropriately worn PAPR has an assigned protection factor (APF) of 1000, while an N-95 mask only has an APF of 10 (Considerations for Optimizing, 2020). With kids only wearing masks, schools will still have to social distance, create COVID bubbles consisting of small groups of students, alter bus routes, and reduce the number of days students come to school, in accordance with the CDC guidelines (FAQ for School, 2020). To plan for these operations requires a lot of time and money.

The schools need a solution like the Clean-19. Unlike other PAPRs in its class it is cheap to manufacture. Other PAPRs cost hundreds of dollars, while Clean-19 could be made for $100. Thus far no PAPR systems have been designed to address the needs of children. Most importantly, Clean-19 will filter both the intake and outflow of air. Every PAPR on the market only filters the intake, and blows your unfiltered aerosolized particles through the air enabling you to spread COVID-19 to others (Considerations for Optimizing, 2020).

When we first designed the Clean-19 our team utilized SOLIDWORKS, a Computer Aided Design software. Our first prototype was going to be an iron man shaped helmet that functioned as a dual filtration PAPR (Figure 1).

Figure 1: Initial Iron man helmet design for the Clean-19. From left to right we have the three parts of the mask: The right side of the helmet, the face mask, and the left portion of the helmet.

The helmet was designed with fan holders, one for an intake fan and one for the outtake fan. Once printed the mask would be secured together using screws and nuts. All three pieces of the helmet were going to be 3-D printed and then we would thermoform a piece of plastic over the 3-D printed face mask. This would allow people to read the users facial expressions, something that cannot happen while wearing a usual mask.

Our fan was chosen to meet all necessary minimum PAPR specifications, pictured in Figure 2, is a 5 Volt PWM fan that moves enough air to create a positive pressure environment within our mask. The fans were projected to move 22 or more cfm of air, which is far beyond the necessary 10 cfm designated by the requirements for a loose PAPR system and accounting for the volume of air removed by the exhalation fan (Liverman, Domnitz, & McCoy, 2015). We successfully coded Pulse Width Modulation (PWM) for the fan, which gave us the ability to change the fan speed to maintain a positive pressure while breathing in and out. Our original idea for the mask was to incorporate these into a Proportional Integral Derivative (PID) control system to keep the positive pressure.

Figure 2: CAQL CPU Cooling Fan with PWM capability to be attached within the helmet.

In order to have a PID, we needed to integrate a pressure sensor into the system using a Propeller chip. We first used two iterations of the BMP 280 chip, one by SongHe and one by Adafruit. Before trying anything, we were told to read and re-read the BMP 280 data sheet. The BMP 280 sensor can communicate with the chip using SPI or I2C. We were focused on using SPI because of its simplicity when using one sensor. To read the pressure register from the BMP 280 we were given a specific high/low pattern to follow across 4 pins (See Figure 3). First we had to pull the Chip Select pin (CSB) on the sensor low to start the communication between the microcontroller and the sensor. Once the CSB pin is low, we send high low pulses on the clock pin (SCK) to the sensor. At the same time we are sending clock pulses, we also send the byte of the register address we want to read from to the SDI pin on the sensor. In our case we wanted to read the data in the pressure register which is 0xF7 or 11110111 in binary format. After the sensor receives the register address from the SDI pin it should send that register's data out to the chip from the SDO pin. This was how it was supposed to work in theory, but the sensor did not send pressure data to the chip. However, we did successfully read the chip id register from the sensor, which proved our SPI communication protocol was working.

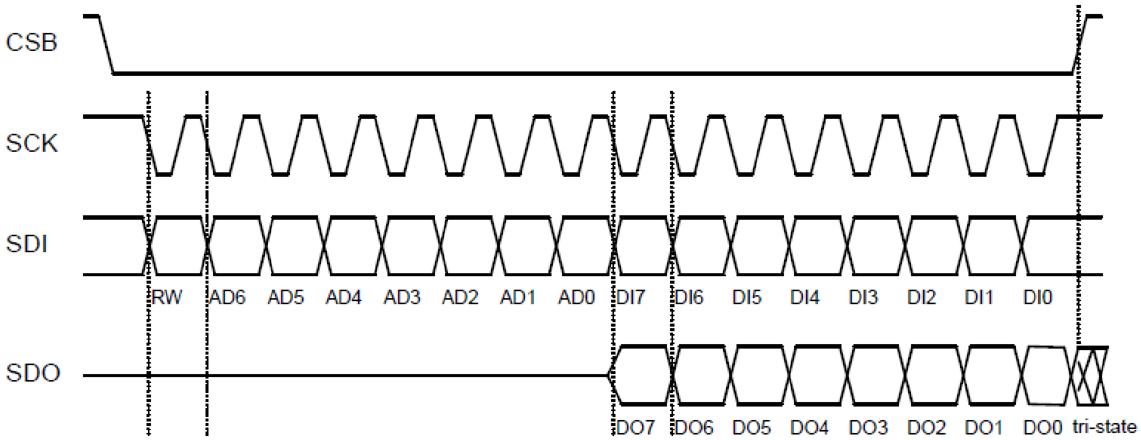

Figure 3: SPI protocol for the BMP 280 sensor.

After erring, erring and erring again we still were unsuccessful in integrating the Adafruit sensor with the Propeller chip. We then switched to an Arduino Nano microcontroller and were able to read pressure data off of the Adafruit BMP 280. With the Arduino Nano we would not accomplish a PID control system, but we could still use the pressure data to alter the fan speeds to maintain positive pressure.

While part of our team was working on the electronics to go inside the helmet the other part was working on the creation of the iron man helmet. This was initially done by downloading an iron man .stl file from github and then converting them back into SOLIDWORKS part file. Once in a part file we could edit the drawing to incorporate our fans and electronics as seen in Figure 1. Our plan was to first 3-D print and assemble the model, then incorporate the electronics and adjustable head strap into the helmet. After that was completed, we would then attach the filters to the fans using a 3-D attachment pictured in Figure 4, and sew on filter material around the bottom of the helmet to create a semi-airtight seal.

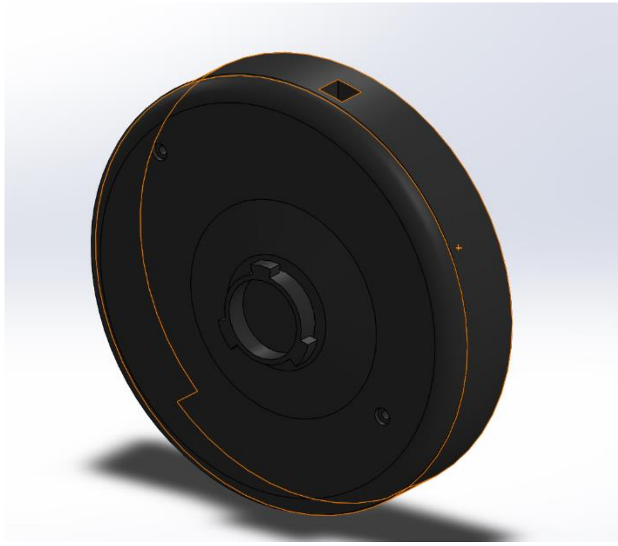

Figure 4: 3-D model of the fan casing to allow filter attachment.

Our initial timeline was to have a fully functional design by Halloween for a child to wear. However, we underestimated the cost and scalability of 3-D printing each helmet making this deadline unobtainable. After a group discussion between ourselves and Professor Garner, we decided the best option would be to thermoform the masks. Thermoforming the masks would make manufacturing the masks at scale more feasible and less expensive. We then switched our main focus of our project to creating a vacuum thermoformer that would aid in creating our Clean-19.

2. Vacuum Thermoformer:

The vacuum thermoformer design forewent many professional upgrades throughout the semester. The base design was drawn from a prototype featured in the YouTube video "How to Make a Larger Vacuum Thermoformer" (iliketomakestuff, 2018). The device assembled in the video, shown in Figure 5 below, performed well and had already solved many of the design challenges. Additionally, we compared and contrasted the prototype with professional thermoformers. From the comparison, we took the base design and improved further upon it by first exchanging all parts that were made from wood with steel. This upgrade served the purpose of making the device safer for users since the heater could reach temperatures over 1000 °F. Along this thinking, we also made sure that all of the parts that would be in close proximity of direct heat would function safely with a 350 °F heat tolerance. Safety was an important factor in our design, which is why we decided to use a premade heater and used materials that would not emit toxic fumes upon heating such as not using galvanized steel. Another important upgrade was using a linear actuator to move the heater along the length of the plastic sheet so that it heated the sheet entirely. This idea originated from a flaw in the YouTube version of the thermoformer that only created about 8 inches by 10 inches melted area. Using the linear actuator, we were able to increase the melted area to about 10 inches by 22 inches. Other professional upgrades from the base design included using toggle clamps for clasping the plastic into the frame, bolts instead of screws so that the device could be disassembled if needed, and using linear guide rods so that the plastic sheet would lower evenly. Lastly, we used a dual stage rotary vane vacuum pump rather than a shop vacuum.

Figure 5: Base design for the vacuum thermoformer.

The ½ horse power vacuum air pump had all its parts connected with quick disconnect fittings. We found that the pre-assembled quick disconnect tubing was quite expensive, so we decided to make our own using plain tubing and attached the quick disconnects ourselves. From the pump, the hose connected to a T-split valve that measured pressure in mmHg, while the other end connected directly to the lower box of the thermoformer.

Many of the design constraints were based upon making sure the size and cost of the device were within certain limits. The overall size of the vacuum thermoformer matched that of the base design from the YouTube video. We changed the sizes of the metal portions of the frame and thermoformer to be sufficiently strong enough for proper function as well as minimizing the cost of the build. Additionally, we made sure that the height of the build area was sufficient for the face shield to be built overtop of a buck, which is a small object that rests beneath the object to be molded so that the plastic wraps well around its edges.

3 CAD Modeling:

After planning out and ordering all the parts that were needed, we first wanted to model everything in CAD. We first began by modelling all of the individual parts, consisting of the specific pieces of metal composing the frames, spacers, the guide rods, clamp platforms, and everything else in SOLIDWORKS. Bolted connections were assembled with previously modeled parts downloaded from McMaster-Carr. In total, there were 36 SOLIDWORKS part files comprising 3 sub-assemblies and one complete assembly. We went through a couple of design iterations to create our final model. We had originally designed the top assembly holding the linear actuator and heat lamp to be an A-frame, shown in Figure 6. There were a few problems with this model, however. The first problem was that it would be hard to weld with acute interior angles like those in the top frame. Also, it was necessary to add one more toggle clamp platform on each side so that we could secure the plastic sheet firmly in the racking frame. A square steel tubing was substituted in the final design provided more structural support compared to the initial thin steel sheets from the first iteration.

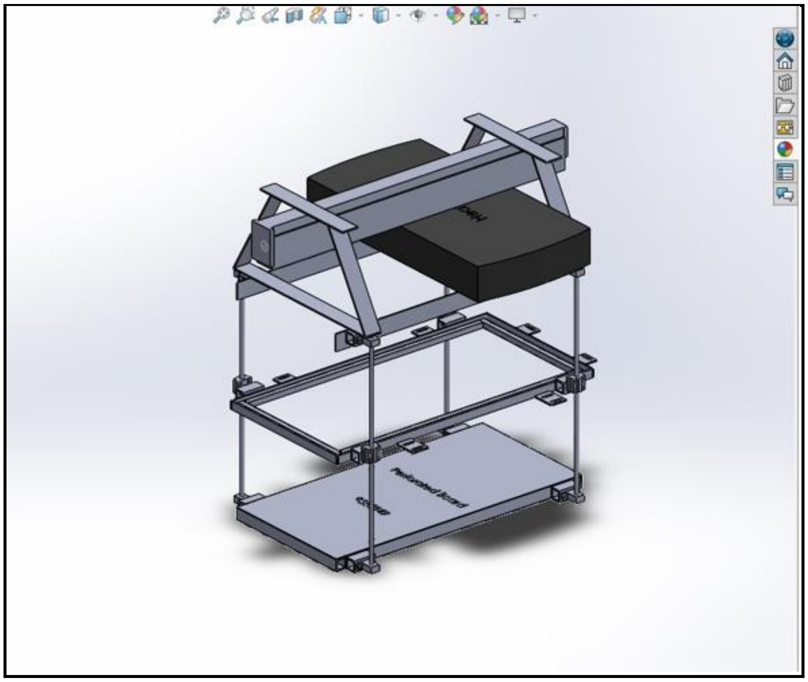

Figure 6: First "A-Frame" SOLIDWORKS Assembly Model

We later added the bolted connections that we believed would connect the spacers to the guide rods, and these were kept in the final assembly. A closer view of these connections are shown beside the final model later in Figure 7. Without having an exact CAD model of the ball bearing slides, we had to model our own. However, we did not account for the fact that the throughole on the outside of the slide would be smaller than the threaded hole on the front. When actually assembling the physical thermoformer, we ended up running into problems and had to use different sized bolts to hold the slides to the spacers connected to the middle frame. We learned that we should never assume anything, and instead measure everything when creating a CAD model of a part. The ball bearing slide showing the inaccurately modeled throughole is shown below.

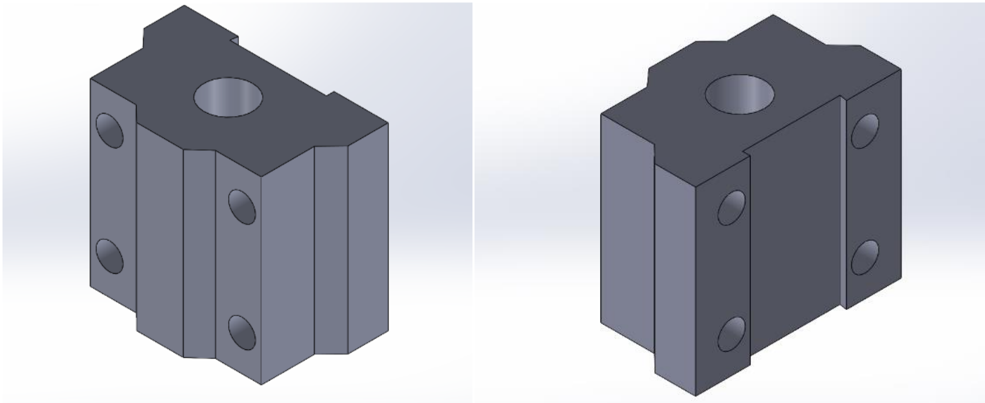

Figure 7: Our model of the ball bearing slide for the linear guide rod.

The larger, more detailed components of the assembly were more generally modeled, such as the heating fan, just to know that we left enough clearance for it to fit within the top frame assembly. This also proved to be a flaw in our CAD design, because we did not account for the correct sized bolts that would be used. All of our modeled parts and sub-assemblies came together to form the final assembly shown in Figure 8 below, which we used to construct our physical thermoformer prototype.

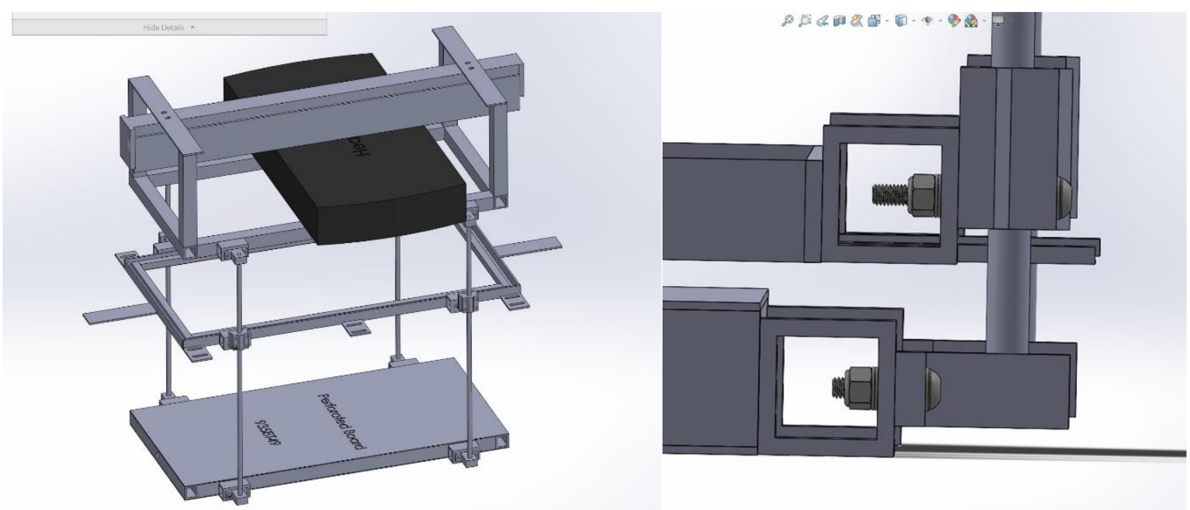

Figure 8: Final Thermoformer Assembly and Bolted Connections.

4. Assembly:

Physically assembling the thermoformer was predominantly done later in the semester near the conclusion of the project. Numerous iterations of part ordering, small errors in part properties, delayed completion of a comprehensive SOLIDWORKS model, and numerous hours of welding required by Professor Garner largely contributed to this delayed assembly.

The first order of business was assembling the three necessary frames for the thermoformer, but before that could be done, many of the pieces needed to be cut or milled. The spacers that attach to each frame needed to be milled as slots to allow for some tolerance since welding isn't necessarily a precise art. A picture of the milling process for these pieces is shown in Figure 9. Additionally, the cross beams on the top frame which connect to the linear actuator needed to be cut into segments using a band saw.

Figure 9: Milling process.

After all the ordered pieces were modified as necessary, the welding process could begin. Professor Garner possessed the steel that composed most of the frame and was welded to the necessary 1 ft. by 2 ft. dimensions at each level. Four steel pillars were then welded to the top frame, which were welded to the eight-inch flat steel bar. Lastly, the milled pieces were welded to each level of the frame to allow for spacing between the linear guide rods and the frame.

In order to connect the heat lamp to the linear actuator, some modifications were necessary to the original product, shown in Figure 10. The mounting point that was originally connected to the heat lamp needed to be removed. After the bracket was broken off, the lamp was disassembled to access the back panel for drilling. Four holes were drilled through the posterior metal sheet and the lamp was then mounted to the red and black trolley of the linear actuator, shown in Figure 11.

Figure 10: Original Ceiling Heater

After the heat lamp and linear actuator assembly was complete, both items were connected to the top frame. In this connection, the group ran into tolerancing issues as the bolts ordered were too long to fit into the slots for the linear actuator. To compensate for the fit, shims were added to ensure a tight connection. Then, the pressure clamps were attached to the sliding frame. There

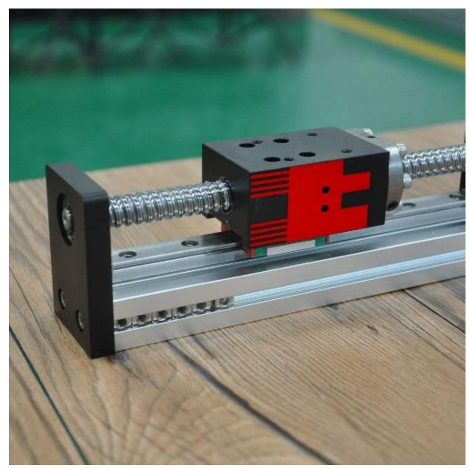

Figure 11: Linear actuator.

were six total connections, and each was adjusted to ensure pressure was placed on the compressing frame for the plastic.

All frames were then connected to their respective mounting agents in the linear guide rod kit, shown to the right in Figure 12. The top and bottom frames were attached to the end positions of the linear guide rods, and the sliding frame was connected to the ball bearing sliders. The guide rods had to be adjusted a number of times to ensure a relatively smooth vertical movement of the sliding frame. Additionally, the imprecise nature of welding left the linear guide rods slightly off perpendicular to the ground, so shims were required on some guide rods to prevent a smooth movement of the sliding frame.

Figure 12: Linear Guide Rods

Once the main structure of the thermoformer was completed, the soldered circuit board, created by Professor Garner, was connected to an acrylic sheet. A 3D printed part was designed to clamp onto the stepper motor, and the acrylic sheet was then mounted to the 3D part. The measurement of the stepper motor to create said part was done with a pair of calipers, as shown in Figure 13, and the model was deliberately oversized to ensure a loose fit for ease of removal should any electronics need to be repaired or modified.

Once the electronics were in place, magnetic bearings were created to hold the top frame and the

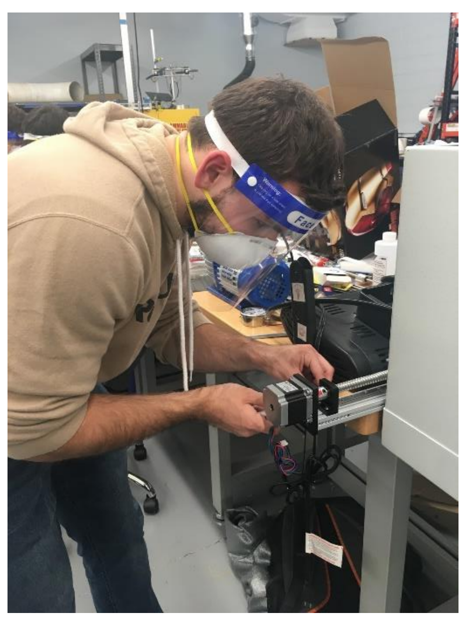

Figure 13: Stepper motor case measurement.

sliding frame together during heating. The magnets used were quite strong, and made removal difficult by a single individual. Another modification was that the caps of the clamps for the compressing frame were removed, as the depth of the clamp was too great and could not lock into position in order to hold the compressing frame.

The largest issue encountered during assembly was that of the bottom frame's seal for the vacuum. The metal sheet ordered that was meant to be welded to the bottom of the bottom frame was stainless steel, which was incompatible to weld with the rest of the non-stainless steel. In turn, an improved approach using duct tape as a sealant for the bottom frame was instituted, as shown in Figure 14. Furthermore, the sliding frame and the bottom frame did not compress as uniformly as intended, and left gaps between the silicon lining and the sliding frame as a result. To compensate for this discrepancy, further use of duct tape was implemented to attempt to fill in the smaller gaps around the two frames.

Figure 14: Completed thermoformer after seal modifications.

5. Mechatronics for Thermoformer:

The vacuum thermoformer constructed is a mechatronic system including mechanical, electrical, and computer science elements. The primary mechatronic system in the thermoformer consists of the single axis linear slide controlled by a stepper motor, an Arduino Nano microcontroller, and a DRV8825 Stepper Motor Driver. The circuit diagram for the system can be seen below in Figure 15.

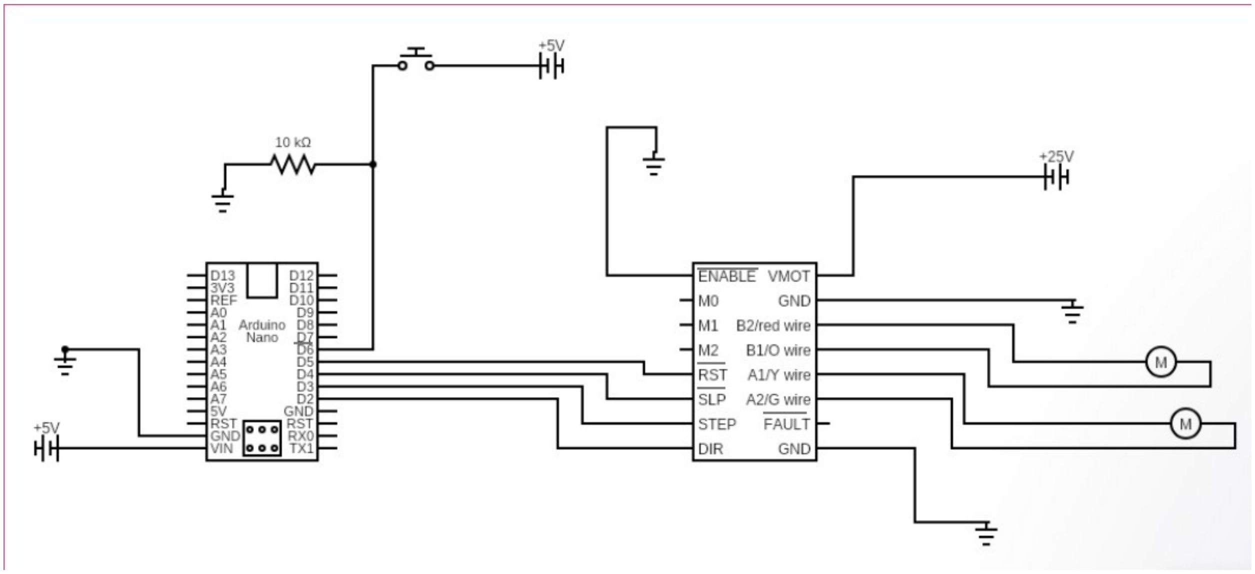

Figure 15: Circuit diagram for the thermoformer.

The stepper motor requires a power supply of 25 volts and 1.5 amps, a power that cannot be delivered by a standard microcontroller. To solve this problem, a stepper motor driver was used. This stepper driver, shown in Figure 16, is capable of taking a control signal from a microcontroller and using that signal to control a circuit of much higher current and voltage. This can be seen in the figure below, with the stepper driver on the right and the microcontroller on the left. The motor is connected to the A1, A2, B1, and B2 pins, while the external 25-volt power supply is connected to the VMOT pin of the stepper driver. The RST, SLP, STEP, and DIR pins represent the control aspect of the system. The DIR pin will set the direction of motion of the slide to either be forward or backward depending on whether a HIGH or LOW signal was sent, while the STEP pin instructs the motor to step when HIGH and do nothing while LOW. In order to provide smooth motion, the STEP pin is sent alternating

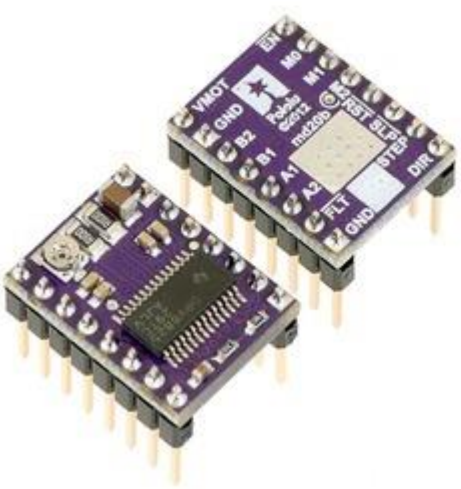

Figure 16: Stepper driver.

HIGH and LOW pulses. The speed of the slide can be varied by altering the amount of time that the microcontroller waits between high and low pulses. The direction of these pins was controlled using the Arduino Nano. A limit switch was also implemented on one end of the linear slide so that the thermoformer would not hit the end of the slide. This was done using a simple button with a 10kΩ pull down resistor and a pin of the Arduino Nano. A completed picture of the circuit board is shown in Figure 17.

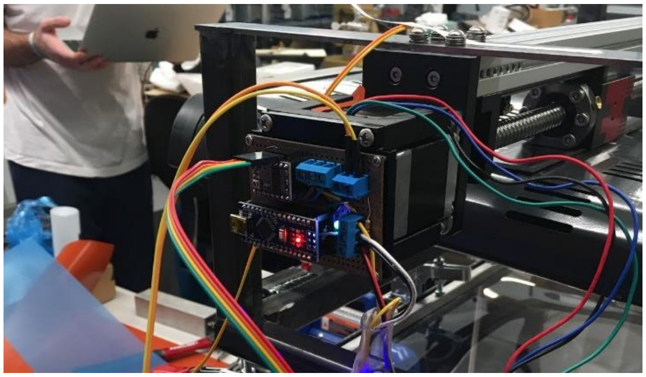

Figure 17: Completed and soldered circuit board.

Because an Arduino Nano was used as the microcontroller for the system, the programming language used was Arduino, which is based on C/C++. Stepper motors are controlled only by high and low pulses, consequently, when they are powered on, they have no way of knowing the orientation at which they are starting. Because of this a homing algorithm (setup()) initializes when the thermoformer is first powered on. This homing sequence sends the linear slide in the direction of the limit switch until it reaches the switch, then continues with the rest of the program. After the homing sequence has been completed, the standard motion of the thermoformer begins. The linear slide is directed away from the limit switch by an experimentally determined number of steps, then changes direction and returns until the limit switch is reached again. Additionally, the speed is reduced near the edges to more evenly heat the surface of the plastic. This feature allows for the plastic to retain its dipped shape to prevent cooled areas of the plastic from affecting the formation of the final mold.

stepper_motor_v2 | Arduino 1.8

stepper_motor_v2

```
int fast = 1000;
int slow = 5000;

int dir_pin = 2;
int step_pin = 3;
int sleep_pin = 4;
int reset_pin = 5;
int switch_pin = 6;
int count = 0;


void setup() {
  // put your setup code here, to run once:
  digitalWrite(sleep_pin, HIGH);
  digitalWrite(reset_pin, HIGH);
  Serial.begin(9600);
  for (int i = 0; i < 6000; i++) {
    if (digitalRead(switch_pin) == LOW){
     digitalWrite(dir_pin, HIGH);
     count = 0;
     break;
   }
   digitalWrite(step_pin, LOW);
   delayMicroseconds(slow);
   digitalWrite(step_pin, HIGH);
   delayMicroseconds(slow);
   count = count+1;

  }
}
void loop() {
  // put your main code here, to run repeatedly:
  for (int i = 0; i < 1000; i++){
    digitalWrite(step_pin, LOW);
    delayMicroseconds(slow);
    digitalWrite(step_pin, HIGH);
    delayMicroseconds(slow);
    count = count + 1;
    Serial.println(count);
  }
  for (int i = 0; i < 2900; i++){
    digitalWrite(step_pin, LOW);
    delayMicroseconds(fast);
    digitalWrite(step_pin, HIGH);
    delayMicroseconds(fast);
    count = count + 1;
    Serial.println(count);
  }
  for (int i = 0; i < 1000; i++){
    digitalWrite(step_pin, LOW);
    delayMicroseconds(slow);
    digitalWrite(step_pin, HIGH);
    delayMicroseconds(slow);
    count = count + 1;
    Serial.println(count);
  }
  digitalWrite(dir_pin,LOW);
  for (int i = 0; i < 1000; i++){
    digitalWrite(step_pin, LOW);
    delayMicroseconds(slow);
    digitalWrite(step_pin, HIGH);
    delayMicroseconds(slow);
    count = count + 1;
    Serial.println(count);
  }
  for (int i = 0; i < 3900; i++) {
    if (digitalRead(switch_pin) == LOW){
      digitalWrite(dir_pin, HIGH);
      count = 0;
      break;
    }

    digitalWrite(step_pin, LOW);
    delayMicroseconds(fast);
    digitalWrite(step_pin, HIGH);
    delayMicroseconds(fast);
    count = count + 1;
    Serial.println(count);
  }
  for (int i = 0; i< 2000; i++){
    if (digitalRead(switch_pin) == LOW){
      digitalWrite(dir_pin, HIGH);
      count = 0;
      break;
    }
    digitalWrite(step_pin, LOW);
    delayMicroseconds(slow);
    digitalWrite(step_pin, HIGH);
    delayMicroseconds(slow);
    count = count + 1;
    Serial.println(count);
  }
}
```

Figure 18: Completed stepper motor code.

6. Future Improvements:

Knowing everything we know now; we would have gone about designing and creating our thermoformer very differently. Nevertheless, we completed a working prototype that has the potential to be built upon in the future. Firstly, we would have put together a better way to keep the sliding frame connected to the top frame when not in use. The last-minute idea to hold it together with magnets glued to wooden blocks worked for our purposes but could be improved to make it feel like a more finished design. Initially, we had planned this out in CAD by placing ten holes around the bottom surface of the top frame. The magnets we had bought would be screwed into these holes, hanging down about an inch to latch on to the racking frame below. However, we realized this would be infeasible due to the strength of each 100 lbf magnet. The twisting action of the wooden handle allowed for easier removal of the racking frame from the top frame. However, we leave it to any student in the future to devise a more elegant solution to this. The original design and the physical wooden handle connected to the magnets is shown in Figure 19 below.

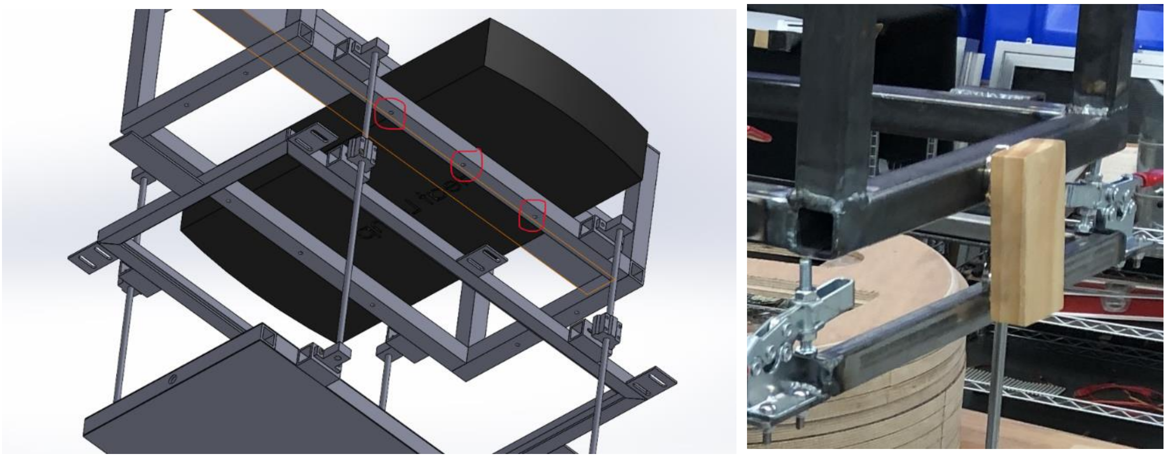

Figure 191: Original placement of locking magnets in the CAD Model vs wooden block design.

Many features could be added to our thermoformer prototype beyond this. One thing we wanted to do, but ran out of time, was to seamlessly switch power between the vacuum pump and the heating lamp because of the huge amount of power they draw from an electrical socket. To test our prototype, we initially cut power to the heat lamp before turning on the vacuum and lowering the racking frame, which was a clumsy process to continue doing. This could be resolved with a solid state relay connected between the two power sources. When one switch or button is pressed, power could automatically be shifted from the lamp to the pump, avoiding any large current draws and electrical surges. The relay was also initially designed to be connected to a Hall Effect sensor, which would be tripped by breaking the magnetic lock holding the racking frame to the top frame and allow for the solid state relay to divert the power as explained before.

Many features could be added regarding electronics and microcontrollers, such as temperature and vacuum pressure sensing. However, the most critical area to fix and improve upon would be the vacuum suction. As we mentioned before, we were unable to create a perfect vacuum seal between the racking frame, silicone gasket, and the perforated board at the bottom. From our CAD model we did not envision we would run into problems with this, as everything was modeled completely flat. However, imperfections in the physical assembly and tiny angles between the welded pieces resulted in small gaps that allowed air to escape, preventing the pressure to drop. If we had allowed for more time for testing and prototyping, we would have been able to resolve these problems and provide a better solution. Before moving on to any other features, this is the most important problem to fix.

7. Using the Thermoformer for a PAPR Design:

With our functional thermoformer we were able to create custom shaped plastic molds shown in Figure 20. After completing the seal on the vacuum chamber, we would have created three different molds and secured them using bolted connections. As the thermoformer is not capable of handling objects more than a few inches tall because the plastic would stretch and break, the mask would have to be divided into segments which would then be brought together and sealed. The rigid shell would then have been cut to allow for the 3D printed fan bay to be inserted. After the mask and fan complex was assembled, we would have integrated the electronics, filters, and head strap, thus completing our original idea: The Clean-19. The battery pack and the circuit board were projected to rest above the user's head, while the NIOSH filters would clamp onto the holsters designed on the outside of the fan bay. This first iteration would likely have problems in functionality, and

Figure 20: The face shield portion of our Iron Man helmet PAPR created from thermoformed plastic.

would have to be Bitrex testing to ensure a proper seal. Additionally, the timings for the duty cycles of the fans for PWM would likely need to be adjusted in order to reach the appropriate internal pressure of the mask.

8. Conclusion:

The project was a great learning experience for the design and fabrication of a complex system. Though the group fell short of the intended goal to create a functioning dual filtration system, the development of a functional thermoformer was an exceptional engineering process.

The team learned a few valuable lessons that will guide engineering efforts in the future. First, extensive design in the planning stages of the project, especially that in SOLIDWORKS, provides a large payoff later in the process. A completely refined SOLIDWORKS model would have prohibited many of the problems that the team encountered during the design process. For example, the SOLIDWORKS model did not possess dimensions for the clamps. In the model, the team assumed the clamps were too complicated to model as well as mostly unnecessary since they were not projected to interfere with the rest of the assembly. However, the clamps prevented the sliding frame from pushing against the top frame in a flush manner, leading to an improvised approach for the magnet locking system.

Additionally, the team recognized that most engineering processes are simpler in theory than in application. For example, the assembly of the thermoformer, once welded, was projected to happen relatively quickly but did not account for issues in bolt sizes, tolerancing for the linear guide rods, and disassembly of some components. Furthermore, ensuring the proper parts are ordered further exacerbated this problem, and more careful analysis and planning for material orders could have prevented a number of problems in the final product.

Lastly, and perhaps most importantly, is that the engineering process sometimes requires a shift in methodology, which was evident from the team's work on the pressure sensor for the mask system. Transitioning to a different problem-solving method is often the most beneficial step to success if the current method is not on track to succeed.

The project will hopefully benefit future lab generations in their endeavors. With minor modifications to the seal of the vacuum in the bottom frame, the thermoformers should be functional for future use. In terms of the project, the original intention to 3D print the mold of the mask was likely not the most useful engineering approach. For a prototype or a piece of art the 3D printing approach would have been successful. However, thinking like engineers, the thermoformer allows for a more permanent and faster solution for the production of mask shells in the future.

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Factors that Influence the Implementation of Renewable Energy Technologies in India

An STS Research Paper Submitted to the
Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements of the Degree
Bachelor of Science, School of Engineering

Jacob St. Martin
Fall 2020

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

Signature _______________________________________ Date __________
Jacob St. Martin
Approved _______________________________________ Date __________
Richard Jacques, Department of Engineering and Society

Introduction:

The rise in temperature associated with climate change is accompanied by a rise in global average sea level, a shift to more extreme weather patterns, a loss in biodiversity, and a significant danger to coastal communities (Heltberg et al., 2008). Over the last few decades, awareness of climate change and its significance has increased, as has the adoption of renewable energy systems. However, fossil fuels still overwhelmingly dominate energy generation despite significant advances in technology. The Paris Agreement is an international effort to combat climate change. One of the goals of the Paris Agreement is to keep the increase in global temperature below 2 degrees Celsius (*What Is the Paris Agreement? | UNFCCC*, n.d.). Meeting this goal would not only require major developed nations to transition off fossil fuel sources but would require developing countries to electrify using renewable sources as well. Developing countries often face additional challenges related to the implementation of renewable energy sources. In 2000 only 59% of India's population had access to electricity, while in 2018 over 95% of the population had access (Access to electricity (% of population) - India | Data n.d.). As seen in the Figure 1, the primary energy source sustaining this electrification has been coal. Despite widespread availability of renewable energy resources in India and the falling costs of renewable energy, it was not implemented on a large scale during the electrification of India. This suggests that there are forces other than cost and availability that influence the adoption of renewable energy in developing nations. If the goals of the Paris Agreement are to be fulfilled it is crucial that these other forces are understood. These forces are investigated using the socio-technical frameworks of actor network theory, technological momentum, and the SPEED framework (Socio-Political Evaluation of Energy Deployment) in a case study of the electrification of India.

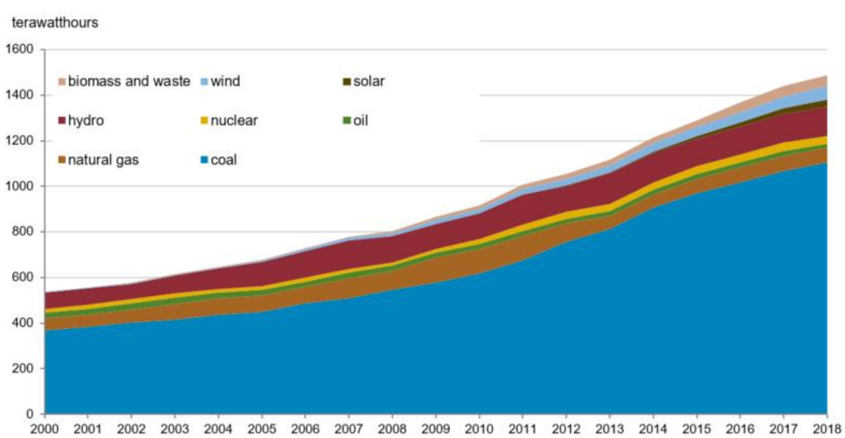

Figure 12: India's Energy Distribution (International - U.S. Energy Information Administration (EIA) n.d.)

Sociotechnical Frameworks:

The implementation of renewable energy technologies is a complex global socio-technical problem with many influential factors. One framework for analyzing these factors is the Socio-Political Evaluation of Energy Deployment (SPEED) (Stephens et al., 2008). As show in Figure 2, the SPEED framework includes a comprehensive list of factors that may influence the implementation of renewable energy systems. This framework draws from other broader socio-technical theories. The two main frameworks used are the actor network theory and technological momentum. Actor Network Theory (ANT) is a socio-technical theory in which everything can be represented as a network that is constantly being influenced by a vast and interconnected web of actors that contribute to the network (Cressman 2009). Technological momentum is a framework that describes the interplay between technology and society as existing on a spectrum, with a technologies location on that spectrum being time dependent. Thomas Hughes, the creator of the framework, identified young technological systems as being more driven by society, where older systems tend to be more driving of society (Hughes 1994). These two ideas are represented within the SPEED framework, specifically using actor-network language, and presenting it in a manner that is consistent with technological momentum (Stephens et al., 2008).

Alone none of these frameworks paint complete pictures. Actor network theory is a helpful framework because it allows for a limitless number of factors and emphasizes the interconnected nature of those actors (Cressman 2009). A network can be as complex as the socio-technical system demands. However, actor-network theory is lacking in its description of

	Area	Considerations	Actors and Institutions
Technical	Technical	• Resource availability within state • Associated resource availability (e.g. water, land) • Transmission considerations • Energy demand patterns • Existing electric infrastructure • Demographic profiles (electric demand growth or decline) • Research base	State energy office, geologicsurvey, natural resources department, oil and gas office, public utilities commission, statistical/ demographic office, electric power companies, transmission organizations, research institutions, technical experts
Socio-political	Institutional	• Restructured or regulated electricity market • Balance of investor-owned utilities, municipalities and co-ops generating electricity • Dispatch policy (state level and regional level) • Technology transfer mechanisms • Institutional experience (state institutions, historic industrial activities, industry development plans) • State energy producer or importer	Governor, legislature, state employees, power company employees, non-profits, business community, energy office, transmission organization, muni, co-op and IOU's active in state, energy and environmental non-profits, Chamber of Commerce
	Regulatory and legal	• State-specific energy and environmental regulations (air, water, waste, climate) • Renewable portfolio standard • Siting policies • Other state policies (tax credit, liability limit, financial arrangements) • Insurance requirements • Property ownership regimes • Liability considerations • Transmission issues	Governor, legislature, state environmental office, energy office, county and city commissioners and boards, insurance commission, public utilities commission, courts, lobbyists, industry, environmental, energy, and consumer non-profits
	Political	• Overarching energy policy goals • Natural coalitions to support/oppose technology • Power relationships among political constituents concerned with energy system • Political saliency of environment/energy/climate • Competing political priorities	Governor, legislature, lobbyists, State Democrat and Republican parties, third parties
	Economic	• Cost of electricity, industry cost structure • Whether state is an energy importer or exporter • Rural and urban economic development • Benefits, costs and risk to local residents • Employment considerations • Entrepreneurial climate • Tax incentives and other budget priorities • Ease of market entry • Ownership patterns • Important businesses and industries within state	Public utilities Commissions, Chamber of Commerce, consumer protection groups, Departments of Economic Development, energy intensive industries within state, businesses, farmers, other stakeholder groups
	Social	• Perception of technology/industry by key actors • Public trust and past relations with industry • Perceived fairness of risks and benefits • "Not in my Backyard" (NIMBY)—other opposition • Historical land use • Impact on social groups and relationships	Citizens, official government bodies at state, county and city levels, non-profits and citizen groups, business community, agricultural interests

Figure 2: Influential Factors in the Speed Framework (Stephens, Wilson, and Peterson 2008)

the relationship between actors and the network. In a real socio-technical system actors not only influence the network but influence each other and the network then acts on the actors. This feedback loop adds complexity to the system that actor-network theory does not account for. Technological momentum integrates feedback, describing how the maturation and development of a technology influences how that technology continues to develop and how it interacts with society (Hughes 1994). However, the technological framework only analyzes the relationship between technology and society and does not account for the influence of other factors on the system. The unification of actor-network theory and technological momentum applied to the SPEED framework allows for a specific and wholistic analysis of renewable energy systems.

Economic:

As climate change becomes a greater concern among world leaders, there is a growing push toward renewable energy sources. The adoption of renewable energy sources in the United States and many other developed countries has been slow. The slow integration of renewable energy sources is often attributed to inadequate technology and high cost. However, as technical capabilities have lowered the cost of renewable energy systems to competitive levels, as seen in Figure 3, one must ask why these systems have not been more widely adopted. The lack of renewable energy system implementation suggests that there are other factors that influence the use of these technologies other than cost and technological capabilities.

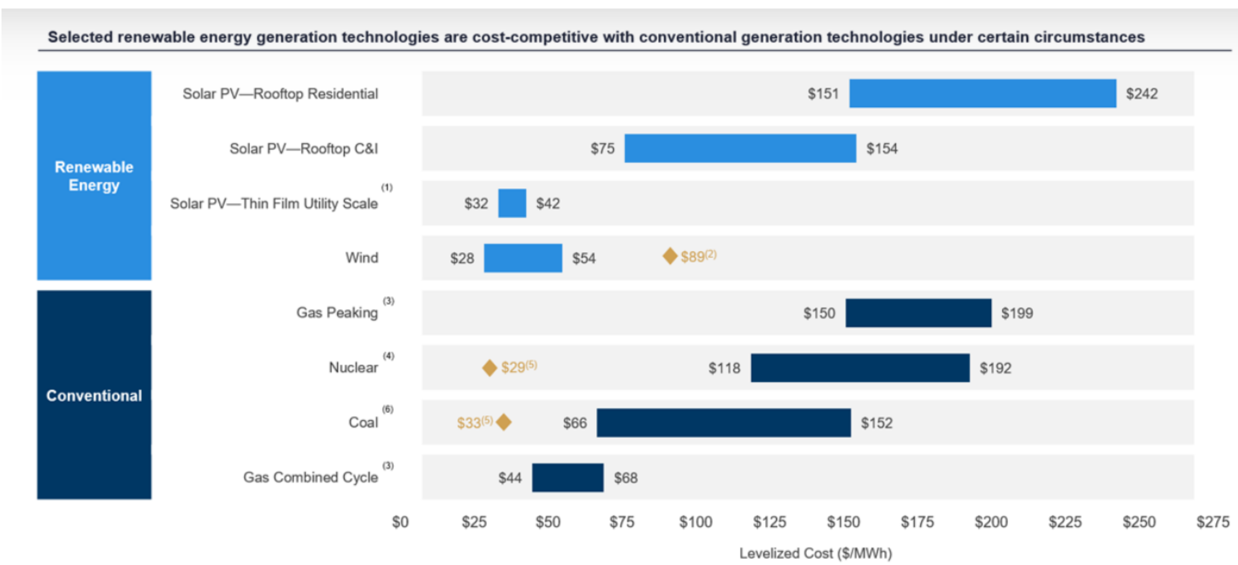

Figure 33: Energy System LCOE (Levelized Cost of Energy and Levelized Cost of Storage 2019 n.d.)

Developing nations, such as India, face the same technical and financial issues that developed nations do, but with additional challenges. In these countries the priority is often to provide electricity to the entire population as cheaply and quickly as possible. However, if the Paris Agreement goal of limiting global temperature increase by less than 2 degrees Celsius is to be reached, developing nations must find an alternate pathway to electrification (*What Is the Paris Agreement? | UNFCCC*, n.d.). As seen in Figure 4, the potential for renewable energy use in India is very high. Figure 3 shows that renewable energy is now cost competitive with fossil fuel sources. Renewable energy sources are now more cost effective and are clearly widely available in India. However, current levelized cost of energy may not be an appropriate indicator for India's development, as the LCOE of renewable energy technologies have been dramatically reduced over the last decade. The figure below shows that during the time period that India was electrifying renewable energy sources may not have been as cost effective as they now are. The

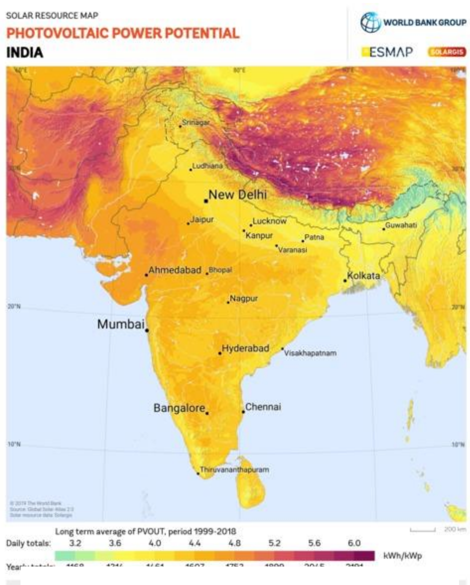

Figure 4a: Solar Energy Potential in India (Solar resource maps of India n.d.)

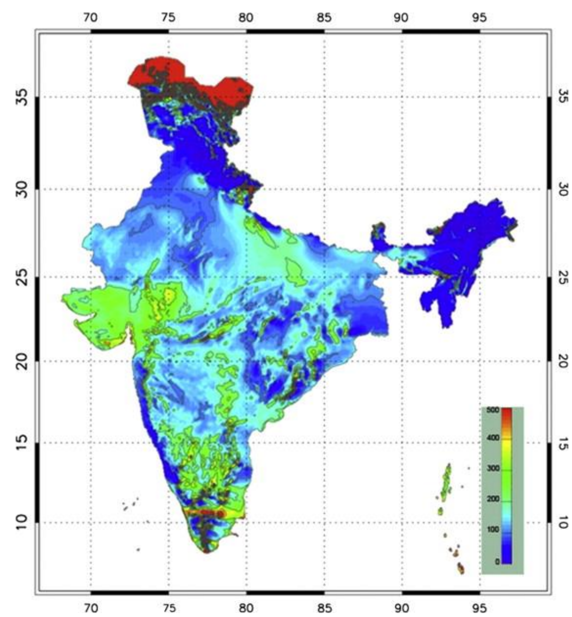

Figure 4b: Wind Energy Potential in India (Khare, Nema, and Baredar 2013)

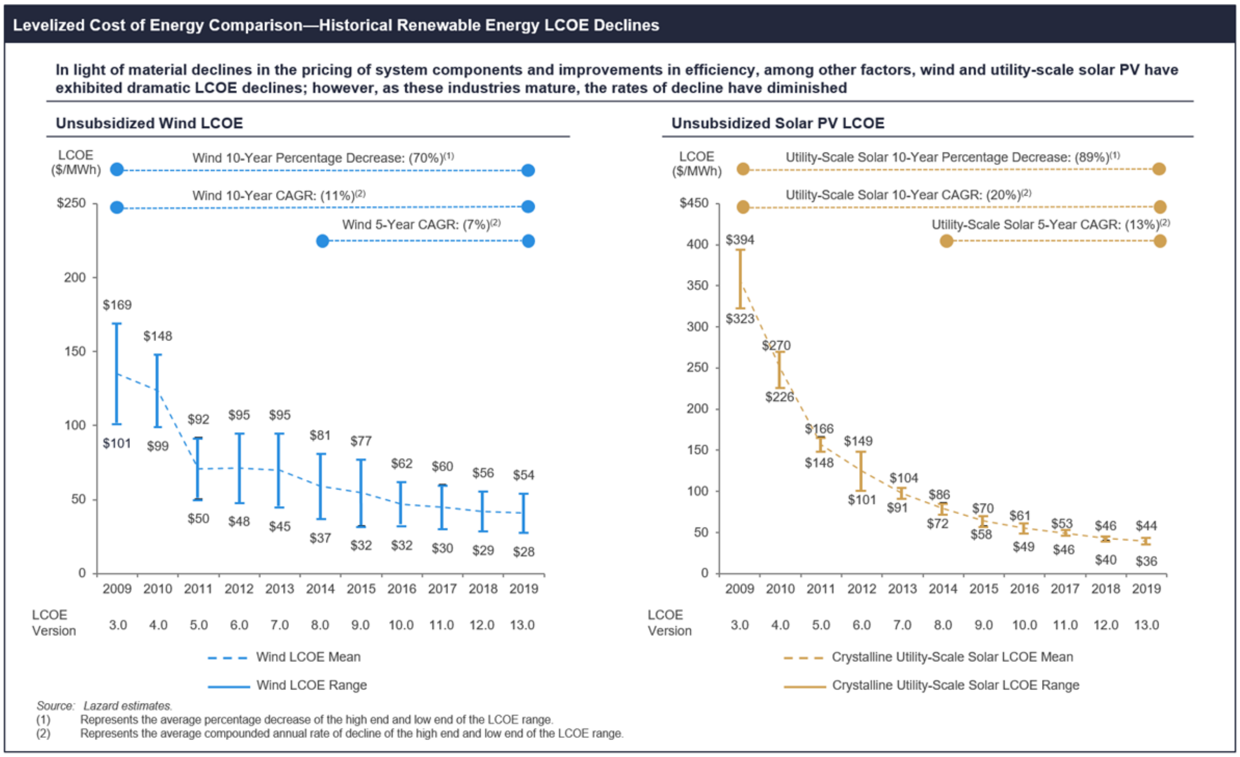

Figure 5: LCOE vs. Time (Levelized Cost of Energy and Levelized Cost of Storage 2019 n.d.)

price of wind energy could have potentially been competitive with fossil fuel sources, but until 2011 utility scale solar would not have been economically viable for India.

In an interview with Leonardo DiCaprio for the documentary *Before the Flood*, Sunita Narain said, "Coal is cheap. Whether you like it or not, coal is cheap. You have to think about this from this point of view. If you created this problem in the past, we will create it in the future." (Stevens, 2016). In the same interview, she stated that India is the 3rd or 4th largest coal reservoir in the world.

This brings to light an interesting ethical dilemma; should the major developed nations expect, or even impose regulations on developing nations so that they follow a more sustainable path to electrification than was followed before? It seems that Sunita Narain has a good point. If major countries like the United States cannot generate a sustainable model for low carbon electrification, should developing nations be expected to electrify using renewable energy technologies? In order for developing nations to sustainably electrify, there must be a global effort to provide a path for these nations to follow.

Political:

Now that renewable energy technologies are economically viable, implementation is heavily reliant on politics. The SPEED framework emphasizes that there are three main components to renewable energy policy: legal, regulatory, and institutional (Stephens et al., 2008). The legal component examines current and proposed laws that may either help or hinder the implementation of renewable energy technologies. Regulatory analysis highlights the influence coalitions, interest groups, key individuals, and the legislation process on policy formation. Institutional analysis includes broad policy goals, executive orders, press releases, etc.

(Stephens et al., 2008). This framework pulls largely from the actor network theory. All of these factors influence the renewable energy network to varying degrees and are constantly shifting.

Thus far India's energy policy has largely been focused on providing cheap energy to its citizens. Until recent years coal was the primary energy source used in this electrification, but as cost of renewable energy technologies has become competitive with fossil fuel sources, India has installed a significant capacity from renewable energy sources, totaling 74 gigawatts by the end of 2018 (Kumar. J & Majid, 2020). This puts India among the world's leaders in installed renewable energy capacity. Additionally, India has set the goal of achieving a capacity of 225 gigawatts by 2022 (Kumar. J & Majid, 2020). While this is an admirable goal, India's energy consumption is projected to increase by over 50% from 2018 to 2022. If India meets its goals for installed renewable capacity, the overall share of renewable energy in India's installed capacity will be greater, but there will still be an increase in the quantity of fossil fuels used. In a review of India's energy policy the international energy agency (IEA) stated that one of India's primary goals should be the movement from government allocated energy supplies to allocation by market pricing (*India 2020 - Energy Policy Review*, n.d.). This would allow for market competition which should lower cost of energy generation, reduce the burden carried by the government, and free up government funds to incentivize renewable energy developments. Additionally, the IEA encourages the establishment of a permanent energy policy co-ordination in India's central government (*India 2020 - Energy Policy Review*, n.d., p. 20). The formation of a strong political framework for renewable energy development will be crucial for India's journey to reducing emissions through renewable energy.

Social:

The perception of energy systems by a society is extremely influential. While there have not been specific case studies analyzing these social impacts of renewable energy in India, global trends have been observed. One of these trends is the Not In My Backyard (NIMBY) hypothesis. This hypothesis states that residents may be generally in favor of a certain energy development but would prefer it to be somewhere else, and may even oppose it if it is in close proximity to their residence (Devine-Wright, n.d.). This theory is typically used in reference to nuclear energy. People are generally in favor of nuclear energy as an option but do not want the power plant near them. However, there seems to be little to no evidence that the not in my backyard theory applies to renewable energy technologies like wind and solar. In fact, with technologies like wind and solar there tends to be greater support from locals. This discrepancy is best explained by the social perception of solar and wind as opposed to nuclear energy.

The SPEED framework states that, "Research indicates that the news media plays an important role in developing the public's perceptions of science and technology because media links the technical assessments of experts to the psychological assessments of laypersons." (Stephens et al., 2008). Given the relatively recent development of renewable energy systems, this link between science, media, and common people is incredibly important. This is supported by the application of technological momentum. Technological momentum states that less mature technical systems are more easily influenced by social factors than more developed technical systems. Thus, the portrayal of renewable energy in media and the response of common people to that media has the potentially to drastically impact the implementation of renewable energy technology. The positive portrayal of renewable energy in media most likely accounts for the willingness for people to live in close proximity to renewable energy developments but not nuclear plants.

Additionally, the internet social media gives people not directly involved with renewable energy a greater influence on media, public perception, and even policy related to renewable energy. It is becoming more common for celebrities or other social influencers to use their social media following or social statues as a platform for encouraging social change. Leonardo DiCaprio is an excellent example of this. He has used his social influence to advocate for the implementation of renewable energy using social media, the aforementioned documentary, funding research, and even speaking at the UN General Assembly on the day that the Paris Agreement was signed (Stevens, 2016). The internet and social media allow for people to become actors in the renewable energy network who previously would have had no platform to get involved. If renewable energy technologies are going to be widely adopted, it will likely require a social movement in addition to the political and economic developments.

Conclusion:

The application of the SPEED framework, actor-network theory, and technological momentum allow for in depth analysis of the socio-technical systems that influence the implementation of renewable energy systems. If India is going to transition to more sustainable energy systems, it will require mastery of the social, political, economic, and technical factors that influence the network of renewable energy. This will likely require global participation and the leadership of the major developed nations of the world. For instance, if the United States could lead the charge to carbon neutrality and provide a pathway for developing nations, it may be possible to mitigate global carbon emissions before global warming reaches devastating levels. Hopefully, understanding the socio-technical system of renewable energy will enable the world to move toward a more sustainable future.

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Powered Air-Purifying Youth Respirator for Protecting and Uniting Students (PAPYRPUS)
(Technical Paper)

Forces that Influence the Adoption of Renewable Energy Technologies in India
(STS Paper)

A Thesis Prospectus Submitted to the

Faculty of the School of Engineering and Applied Science
Department of Mechanical Engineering
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements of the Degree
Bachelor of Science, School of Engineering

Jacob St. Martin
Spring 2021

Technical Project Team Members
Noah Rempfer
Dale Midkiff
Jack Herrmann
Ryan Gibiser

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

Signature ____ Date __________
Jacob St. Martin
Approved ____ Date __________
Bryn Seabrook, Department of Engineering and Society
Approved ____ Date __________
Gavin Garner, Department of Mechanical Engineering

Introduction:

Over the last few decades, the world has faced significant challenges that are complex in nature. Two such challenges are the coronavirus pandemic and global climate change. The STS research paper outlined below will address the forces that influence the adoption of renewable energy in India, while the technical project proposed will involve the development of a Powered Air Purifying Respirator (PAPR) for children for use during the coronavirus pandemic and other future pandemics.

Worldwide there have been over 64 million cases of corona virus and almost 1.5 million deaths, with almost 14 million of the cases and 270,000 deaths from the United States alone (coronavirus statistics - Google Search n.d.). Prior to the start of the coronavirus pandemic it was rare, if not unheard of, to see someone wearing a mask in the United States outside of a hospital. Now it is normal, and even required by law in many states, for a person to put on a mask any

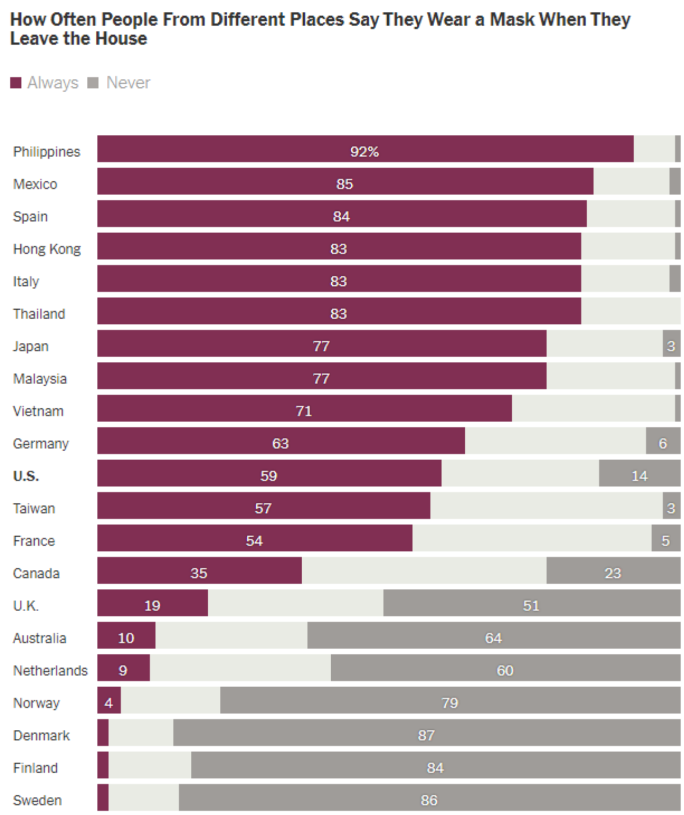

Figure 4: Percent of people who claim to wear a mask by country.

time they are outside of their house. The data shown in Figure 1 is the result of a survey conducted in June 2020 showing the percentage of people that claim to wear a mask when they leave their house, by country (Katz, Sanger-Katz, and Quealy 2020). This data shows that as of June a significant portion of the global population were wearing masks, and these numbers have likely risen since. The widespread use of masks is one of the many significant changes that the coronavirus pandemic has forced upon the world. The requirement for masks in nearly all environments has brought forth new challenges. Employees, college students, and children are sometimes required to wear masks for entire days. Wearing a mask for long periods of time is difficult for anyone, but children tend to fidget more than adults and may not be as conscious of how much they are touching their face or removing their masks. While research shows that children are less likely to exhibit serious symptoms of covid-19, this poses a significant threat for educational staff as schools begin to open (Lee et al. 2020). To encourage this reopening, the proposed capstone project will focus on the development of a Powered Air Purifying Respirator (PAPR) for children.

Much like the threats of the coronavirus pandemic, the threats of climate change extend far beyond the surface level. The rise in temperature associated with climate change is accompanied by a rise in global average sea level, a shift to more extreme weather patterns, a loss in biodiversity, and a significant danger to coastal communities (Heltberg et al. 2008). Over the last few decades awareness of climate change and its significance has increased, as has the adoption of renewable energy systems. However, fossil fuels still overwhelmingly dominate energy generation despite significant advances in technology. The question that must be answered is, why?

When reviewing renewable energy, the focus is often on the technological or economic aspects of the renewable energy system. The social and political aspects of these technologies are rarely investigated past the surface level of a public forum where people can voice complaints (Polatidis and Haralambopoulos 2007). There is a vast collection of material detailing the economic and technological feasibility of renewable energy sources. According to a 2015 article by Steve Capanna of energy.gov, “when the social cost of carbon is taken into account, renewable generation is economically viable in many parts of the country.” (Capanna n.d.) .

While renewable energy technologies may be economically viable in some areas of the United States, the implementation of these technologies in countries that are still developing poses unique challenges. One example of the energy development of a developing country is India. In 2000 only 59% of India's population had access to electricity, while in 2018 over 95% of the population had access (Access to electricity (% of population) - India | Data n.d.). As seen in Figure 1, the 2020 distribution of India's energy generation largely favors fossil fuel sources, particularly coal.

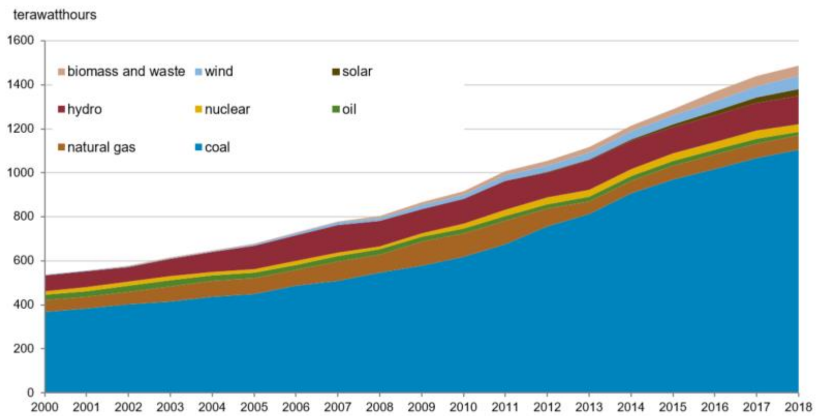

Figure 5: India's Energy Distribution (International - U.S. Energy Information Administration (EIA) n.d.)

For this proposed STS research project, the effects of social, political, economic, and technical forces on India's electrification will be investigated using the STS frameworks of technological momentum, actor network theory, and the SPEED framework.

PAPYRPUS:

Schooling of children during the covid-19 pandemic has been incredibly challenging. Elementary, middle, and high schools have taken a wide range of measures to protect both children and staff, but the problem is far from being solved. In order to adequately protect teachers and students, N95 masks should be used and properly fitted, for every student and teacher. However, this type of mask tends to be uncomfortable, and getting children to wear them for extended periods of time without fidgeting with it or taking it off seems highly unlikely. Another technology that rivals the N95 in its protective capability is the PAPR. A PAPR works by using a fan system to blow air through a HEPA filter and into an enclosed mask or helmet. A PAPR is not sealed, which allows this air to flow out but is still protective because the mask has a pressure slightly higher than that of the atmosphere (Powered Air Purifying Respirator (PAPR) - Minnesota Dept. of Health n.d.). Given that PAPRs are not dependent on the fit of the mask, they can be significantly better at protecting the wearer. The Occupational Safety and Health Administration (OSHA) has created an Assigned Protection Factor (APF) that assesses the level of protection of each type of PPE with regards to protective capability and leakage potential. N-95 masks have an APF of around 10, standard respirators have an APF of roughly 50, and PAPRs can have an APF ranging from 25 to 1,000 depending on the design (Cichowicz, Coffey, and Fries 2020). The two biggest drawbacks of standard PAPRs are that they are incredibly expensive and are not aesthetically pleasing, as seen in Figure 2. Of the PAPRs that are certified by the National Institute for Occupational Safety and Health (NOISH) and meet the Center for Disease Control (CDC) criteria, nearly every unit costs near or well over $1,000 (Approved Air-Purified Respirators Meeting CDC Criteria for Ebola | NPPTL | NIOSH | CDC 2020). Due to this price and the design of current PAPRs, most people would not consider PAPRs a viable alternative to masks.

Figure 6: NIOSH Certified PAPR (3MTM VersafloTM Easy Clean PAPR Kit TR-300N+ ECK 1 EA/Case n.d.)

This capstone research project seeks to develop a low cost PAPR designed specifically for children to use. The intent of this project is to provide a safer, low cost, and reasonable way of protecting both students and teachers in the school system during the covid-19 pandemic. In order to meet these design goals, the PAPR will be constructed primarily by using 3D printers and a plastic vacuum former that the team is designing and building. One significant difference between this design and traditional PAPR designs is that this designed to filter the exhaust as well as the intake. As the covid-19 virus is spread through aerosolized particles, blowing unfiltered exhaust from the PAPR could result in the spread of the virus if the wearer is contaminated. Additionally, the team will be exploring the use of sensors to save battery and implement safety measures. To make the design more visually pleasing, the team has decided to fashion the helmet in the shape of an iron man mask with a clear face shield material so that the full face of the wearer can be visible. In order to test the efficacy of the system developed a bitter spray will be used that can be tasted by the wearer if aerosolized particles make it through the PAPR.

Social, Political, Economic, and Technical Factors of Renewable Energy in India:

As climate change becomes a greater concern among world leaders, there is a growing push toward renewable energy sources. The adoption of renewable energy sources in the United States and many other developed countries has been slow. The slow integration of renewable

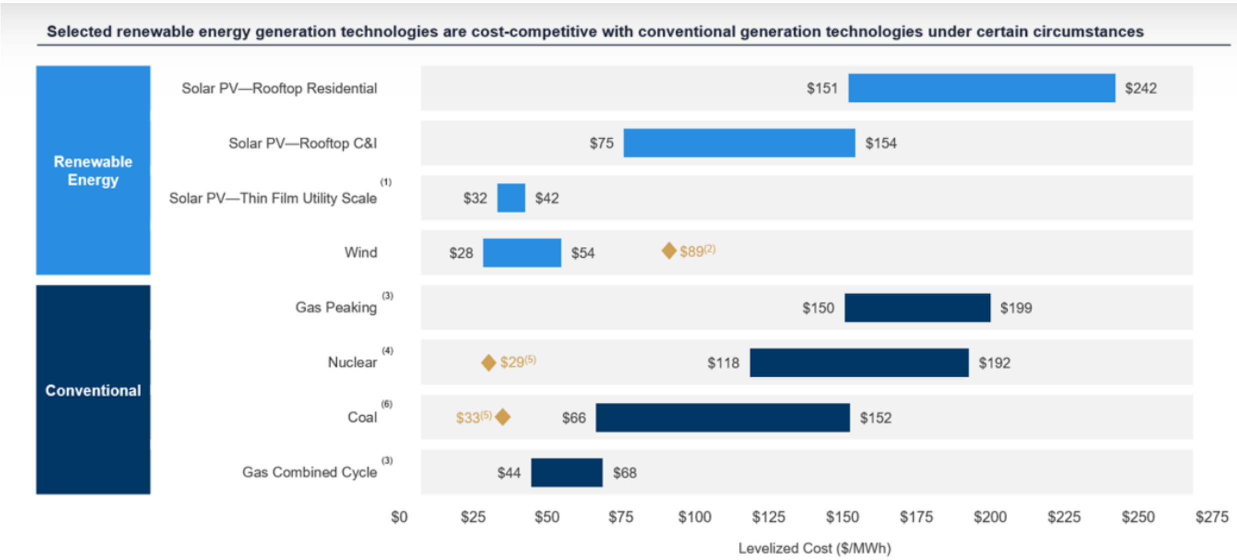

Figure 7: Energy System LCOE (Levelized Cost of Energy and Levelized Cost of Storage 2019 n.d.)

energy sources is often attributed to inadequate technology and high cost. However, as technical capabilities have lowered the cost of renewable energy systems to competitive levels, as seen in Figure 4, one must ask why these systems have not been more widely adopted. The lack of renewable energy system adoption suggests that there are other factors that influence the use of these technologies other than cost and technological capabilities.

Developing nations, such as India, face the same technical and financial issues that developed nations do, but with additional challenges. In these countries the first priority is often to provide electricity to the entire population as cheaply and quickly as possible. However, if the

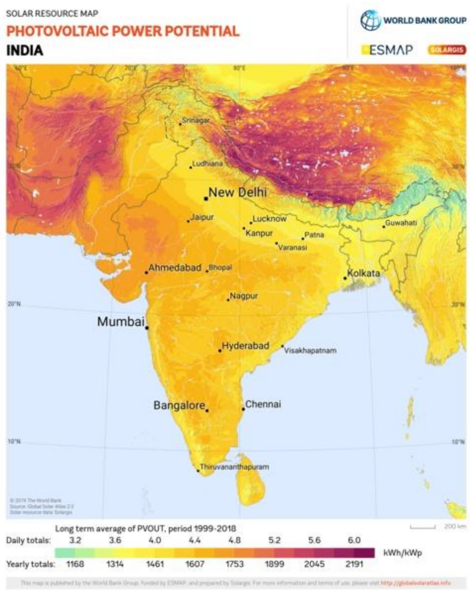

Figure 5a: Solar Energy Potential in India (Solar resource maps of India n.d.)

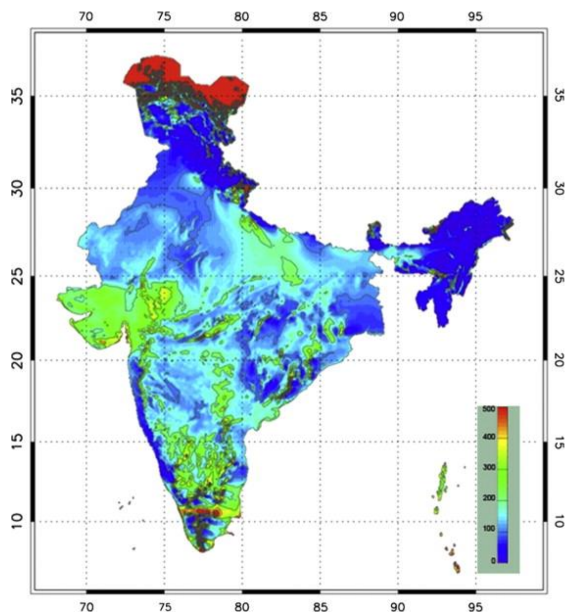

Figure 5b: Wind Energy Potential in India (Khare, Nema, and Baredar 2013)

Paris Agreement goal of limiting global temperature increase by less than 2 degrees celcius is to be reached, developing nations must find an alternate pathway to electrification (What is the Paris Agreement? | UNFCCC n.d.). As seen in Figure 5, the potential for renewable energy use in India is very high. Figure 3 shows that renewable energy is now cost competititve with fossil fuel sources. Renewable energy sources are now cost effective and are clearly widely available in India, therefor there must be other forces that can account for the lack of renewable energy integration in India. Understanding these factors will be the key to more responsible future electrification.

One framework for analyzing these factors is the Socio-Political Evalutaion of Energy Deployment (SPEED) (Stephens, Wilson, and Peterson 2008). As show in Figure 6, the SPEED

	Area	Considerations	Actors and Institutions
Technical	Technical	• Resource availability within state • Associated resource availability (e.g. water, land) • Transmission considerations • Energy demand patterns • Existing electric infrastructure • Demographic profiles (electric demand growth or decline) • Research base	State energy office, geologicsurvey, natural resources department, oil and gas office, public utilities commission, statistical/ demographic office, electric power companies, transmission organizations, research institutions, technical experts
Socio-political	Institutional	• Restructured or regulated electricity market • Balance of investor-owned utilities, municipalities and co-ops generating electricity • Dispatch policy (state level and regional level) • Technology transfer mechanisms • Institutional experience (state institutions, historic industrial activities, industry development plans) • State energy producer or importer	Governor, legislature, state employees, power company employees, non-profits, business community, energy office, transmission organization, muni, co-op and IOU's active in state, energy and environmental non-profits, Chamber of Commerce
	Regulatory and legal	• State-specific energy and environmental regulations (air, water, waste, climate) • Renewable portfolio standard • Siting policies • Other state policies (tax credit, liability limit, financial arrangements) • Insurance requirements • Property ownership regimes • Liability considerations • Transmission issues	Governor, legislature, state environmental office, energy office, county and city commissioners and boards, insurance commission, public utilities commission, courts, lobbyists, industry, environmental, energy, and consumer non-profits
	Political	• Overarching energy policy goals • Natural coalitions to support/oppose technology • Power relationships among political constituents concerned with energy system • Political saliency of environment/energy/climate • Competing political priorities	Governor, legislature, lobbyists, State Democrat and Republican parties, third parties
	Economic	• Cost of electricity, industry cost structure • Whether state is an energy importer or exporter • Rural and urban economic development • Benefits, costs and risk to local residents • Employment considerations • Entrepreneurial climate • Tax incentives and other budget priorities • Ease of market entry • Ownership patterns • Important businesses and industries within state	Public utilities Commissions, Chamber of Commerce, consumer protection groups, Departments of Economic Development, energy intensive industries within state, businesses, farmers, other stakeholder groups
	Social	• Perception of technology/industry by key actors • Public trust and past relations with industry • Perceived fairness of risks and benefits • "Not in my Backyard" (NIMBY)—other opposition • Historical land use • Impact on social groups and relationships	Citizens, official government bodies at state, county and city levels, non-profits and citizen groups, business community, agricultural interests

Figure 6: Influential Factors in the Speed Framework (Stephens, Wilson, and Peterson 2008)

framwork includes a comprehensive list of factors that may influence the implementation of renewable energy systems. This framework draws from other socio-technical concepts that will also be used for the analysis of the specific renewable energy systems. The two main frameworks used are the actor network theory and technological momentum. Actor Network Theory (ANT) is a socio-technical theory in which everything can be represented as a network that is constantly being influenced by a vast and interconnected web of actors that contribute to the network

(Cressman 2009). Technological momentum is a framework that describes the interplay between technology and society as existing on a spectrum, with a technologies location on that spectrum being time dependant. Thomas Hughes, the creator of the framework, identified young technological systems as being more driven by society, where older systems tend to be more driving of society (Hughes 1994). These two ideas are represented within the SPEED framework, specifically using actor-network language, and presenting it in a manner that is consistent with technological momentum (Stephens, Wilson, and Peterson 2008). These frameworks will be applied in a study of the electrification of India to determine what factors are the most influential for developing nations.

Research Question and Methods:

The STS research question being answered is, what social, political, economic, and technical factors have influenced the electrification of India, specifically with relation to the adoption of renewable energy. The primary research methods that will be used to investigate this relationship are documentary research, discourse analysis, and policy analysis. Most of the data will be collected through journal articles and reviews, but some other sources may be applicable such as documentaries. Often the focus of research relating to renewable energy is on the technical aspects. In order find information more relevant to the other factors of renewable energy adoption discussed, the keywords “social”, “political”, “economic”, and so on will be paired with renewable energy to target sources that incorporate these factors. Additionally, “India” will be included in some of these searches to get information more relevant to India specifically. Research will also be conducted on mnre.gov.in, the Indian government’s website for new and renewable energy. The information on this website is divided by energy source, and thus different renewable sources will be investigated individually.

Conclusion:

The covid-19 pandemic and climate change are two significant global threats that must be dealt with in order to preserve the quality of life for ourselves, our fellow citizens of the world, and of future generations. If successful PAPYRPUS could allow for the reopening of schools in a safer and more normal capacity. The investigation of the factors impacting renewable energy adoption in India will identify the key forces inhibiting the current growth of renewable energy technologies in developing nations. The knowledge of these factors will help developing countries, as well as developed nations, electrify in a more responsible manner. By engaging these research questions, hopefully these global issues will be slightly less daunting to tackle.

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