

# N95 Mask Alternative from HVAC Filters

March 27<sup>th</sup>, 2020

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## Disclaimer Statement:

The mask constructed in this procedure could be considered for possible use in certain activities while N95 masks are unavailable. If approved N95 masks are available, use those approved N95 masks first.

While these masks may provide some level of particulate matter filtration that offers some measure of protection, but no guarantee, representation, or warranty is made relating to meeting or exceeding the performance standards of an N95 PPE mask certified by the National Institute for Occupational Safety and Health (“NIOSH”) or approved by the Federal Drug Administration. Any use of this type of mask is at the user’s own risk.

These masks are NOT rated, NOT sterile, and NOT for sale.

## 1. Background:

In settings where certified personal protective equipment (PPE) is unavailable for use, non-elective medical procedures and care must still be administered, leaving healthcare workers in the difficult position of extending PPE use far beyond its intended duration of use and possibly placing themselves and their patients at elevated risk of exposure to various types of infectious pathogens. These situations should be avoided at all costs, but extenuating circumstances such as economic instability or a sudden unforeseen influx of patients into the healthcare system may leave practitioners with little choice. Epidemic or pandemic conditions such as the 2019-2020 COVID-19 disease outbreak have placed many medical systems in danger of such a precarious position as of the time of this document's authorship.

In such situations, where the manufacturing and supply-chain are unable to provide necessary PPE, alternatives of varying, unproven effectiveness are often turned to in efforts to mitigate risk and provide the best possible safety to all parties. Many of these alternatives take the form of locally sourced do-it-yourself, or DIY, PPE that are manufactured by individuals or groups in their homes or places of work. To aid in these DIY efforts, this work lays out a rationale and method for improving the effectiveness of DIY respiratory masks often worn when caring for patients with infectious conditions. The goal is to create DIY masks that achieve the closest possible performance to the N95 masks commonly worn by healthcare professionals which filter out 95% of 0.3-micron aerosolized particles that can carry viruses or bacteria in the air.

To design a DIY mask with N95-like performance, both the mask's filtering performance and ability to fit the face of the wearer must be achieved. While the filtering performance is primarily a property of the material selection, fit testing is dependent on user facial geometry and proper testing according to OSHA standards ([https://www.osha.gov/video/respiratory\\_protection/fittesting.html](https://www.osha.gov/video/respiratory_protection/fittesting.html)). If either fit or filtering fail, the mask will not provide the type of performance necessary to mitigate the risk of transmitting infectious contaminants. Additionally, both mask fit and filtering performance must be achieved using materials that are accessible and safe to the users. Therefore, it is important to weigh the balance between mask performance, cost, and ease of assembly in creating a DIY N95 mask alternate.



**Figure 1:** The final version of the N95 Mask Alternative prototype in use

## 2. Theory

### Types of Commonly Available Filter Materials

When making an N-95 facemask alternative, the filtering material must be chosen to provide at least 95% removal of 0.3-micron particles. However, many of the materials often found in DIY respiratory masks have unknown characteristics. To ensure that a minimum standard of N95-like functionality is preserved, it is desirable to find a source of filter material that is commonly available which has been performance rated using commonly accepted standards. A reliable material that satisfies both criteria is the polyester substrate in household heating, ventilation, and air-conditioning (HVAC) filters, which can be bought at many hardware and home-supply stores. In the United States, these filters are typically rated on the MERV scale, which is based on ASHRAE Standard 52.2. For more information of MERV ratings, a reliable overview can be found at [www.nafahq.org](http://www.nafahq.org) under “Publications” → “Understanding MERV”. While MERV ratings will be used for this document, the same rationale can be applied to alternative HVAC filter rating systems including ISO Standard 16890 so long as performance has been reliably clarified.

### Calculation of Filtering Efficiency for Various Materials and Layers

To achieve the necessary filtering performance for an N95 alternative, multiple layers of HVAC filter material must be stacked to achieve the desired effect. For filters providing only a MERV rating number, it was determined that to optimize for N95-like performance, MERV 13 rated filters necessitate using 4 layers to approximate the performance of an N95 mask, MERV 14 and MERV 15 materials need 2 layers, and MERV 16 materials need only a single layer. High-efficiency-particulate-air (HEPA) filters can be assumed to be equivalent to MERV 16 ratings and need only a single layer to approximate 95% efficiency. These results are summarized in Table 1 below.

**Table 1: Typical Layers of Filter Needed per MERV Rating**

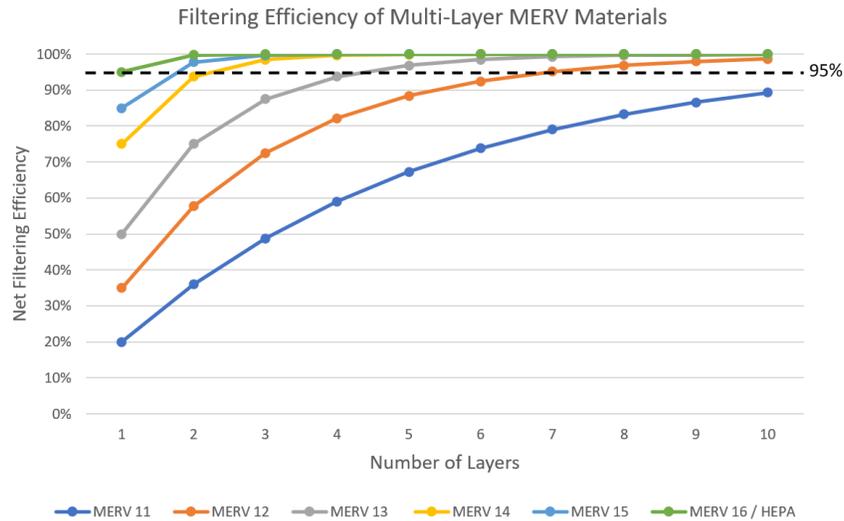
MERV Rating	Filter Layers Needed
13	4
14, 15	2
16	1

If, however, the precise efficiency of a filter is known, it is possible to calculate the minimum number of layers needed to achieve 95% efficient filtering performance beyond the prescription of Table 1. The equation giving the expected relationship between the number of layers and the overall filter efficiency is given by

$$\mathbf{Net\ Efficiency = 1 - (1 - E)^n}, \quad \text{Equation 1}$$

where  $E$  is the filtering efficiency for 0.3-micron particles and  $n$  is the number of layers. This equation assumes that the filtering performance of a material is compounded as it stacks, with the expected proportion of contaminants being removed after each successive layer. In this equation, a 100% efficient filter is considered to have an efficiency value of 1, and a 0% efficient filter has a value of zero. To use this equation, plug in the given material's efficiency for  $E$  and the number of layers for  $n$  to yield the overall percent efficiency. For example, MERV 13 filters are rated to be at least 50% efficient for 0.3-micron particles, so substituting 0.5 for  $E$  and increasing values for  $n$  shows that the performance improves as we

increase the number of layers. Figure 2 illustrates this efficiency/layer relationship given by Equation 1 for various materials with minimum MERV ratings.

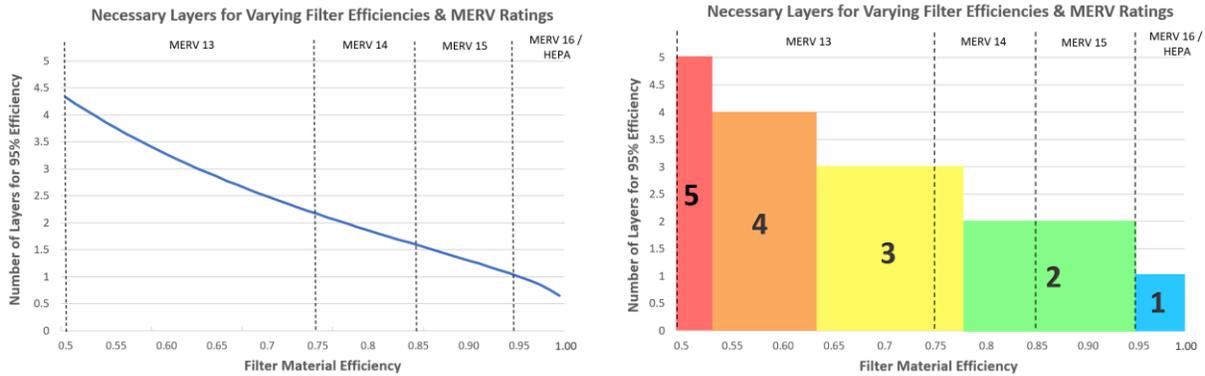


**Figure 2:** Net filtering efficiencies of materials with minimal performance for each MERV rating, shown for stacks of varying layers. The black dashed line at 95% efficiency indicates N95-like performance.

By choosing a value of 0.95 (95%) as the overall desired filtering efficiency and rearranging Equation 1 to solve for  $n$ , a form of the equation is found that can be used to directly calculate the number of layers needed to achieve N95-like filtering performance for 0.3-micron particles (Equation 2). This equation is especially useful if the filtering efficiency for 0.3-micron particles is known beyond the specificity implied in the MERV rating, and can be given by

$$n = \frac{\log(.05)}{\log(1-E)}, \quad \text{Equation 2}$$

where a logarithm of any base can be used, so long as it is consistently implemented. As an example of how to use Equation 2: if a MERV 13 filter is specified to have a filtering efficiency of 64% for 0.3-micron particles, substituting 0.64 for  $E$  yields an output of 2.98 for  $n$ , indicating that use of 3 layers will achieve a net efficiency above 95%. The given value for  $n$  should be rounded up to the nearest whole number to indicate the minimum number of layers needed to guarantee N95-like performance. The continuous and stepwise characteristics of Equation 2 are shown graphically in Figure 3.



**Figure 3:** The number of layers necessary to achieve 95% filtering efficiency for 0.3-micron particles, shown continuously (*left*) and stepwise assuming that whole layers are to be used (*right*). Filter efficiencies given by MERV and HEPA ratings are shown at the spaces between the vertical dashed lines.

From the results of Equation 2, it can be shown that for the majority of MERV 13 filters, use of 4 layers will give above 95% filtering efficiency, however it is possible to use only 3 layers for filters rated to be at least 64% efficient. Likewise, the majority of MERV 14 filters will give 95% efficiency with only two layers, but the actual transition doesn't happen until efficiency eclipses 78%. All MERV 15 filters should use 2 layers, and all MERV 16 and HEPA filters may use only a single layer to achieve above 95% performance.

### 3. Materials & Methods

Numerous iterations of DIY mask geometries and manufacturing techniques were experimented with before the current design prototype was decided upon. An overview of the procedure used to create the prototype DIY N95-Alternative mask is recorded here. Prior to mask assembly, materials were procured as described in Table 2: Bill of Materials. In mask preparation, heavy duty scissors/shears, needle-nose pliers, a ruler or tape measure, disinfecting solution, rubber gloves, and a personal face mask were all used in addition to the mask materials. When making masks in a batch of at least ten, it was found that an average assembly time of approximately 10 minutes per mask was necessary.

**Table 2: Bill of Materials**

Part Description	Recommended Part	Amount Needed	Estimated Cost
Filter Material	HVAC Filter: MERV 13+	1 / 5-10 masks	\$20 / each
Polyester Sheer Fabric	Sheer Drapery or Curtain	1 / ~10 masks	\$10 / each
Malleable Wire or Thin Sheet Metal	17-gauge aluminum fence wire; galvanized roof flashing	5" strip / mask	\$25 / ¼ mile spool
Stapler & Staples	Heavy Duty Office Stapler	~25 staples / mask	\$10
Strap Band	Elastic; 5 wt. "bulky" yarn; or Cotton Butcher's / Cooking Twine	6 ft. / mask	\$8 / spool
Packaging Bag	Plastic Slow-Cooker or Oven Bags	1 / 5-10 masks	\$2 / each
<b>Estimated Total:</b>			<b>~\$5 / mask</b>

To begin mask preparation, a flat, clean work surface was disinfected using CDC recommended practices: <https://www.cdc.gov/coronavirus/2019-ncov/prepare/cleaning-disinfection.html>. All hands were washed prior to preparation, and clean pairs of rubber gloves and facemasks were donned to prevent any assembled masks from being accidentally contaminated. For general assembly procedures in situations where masks are unavailable, measures may be taken to ensure cleanliness including using a cloth bandana to begin, to be replaced by the first mask once assembled.

### Creating Nose-piece

Five inches of malleable wire, flashing material, or pipe-cleaner were cut from a spool using needle-nose pliers. Both ends were brought together, and the metal was bent in half around a finger to create a V-shape at approximately 60 degrees with gentle curvature at the point.



**Figure 4:** Final shape of malleable metal nose-piece to be created.

### Preparation of Filter Material

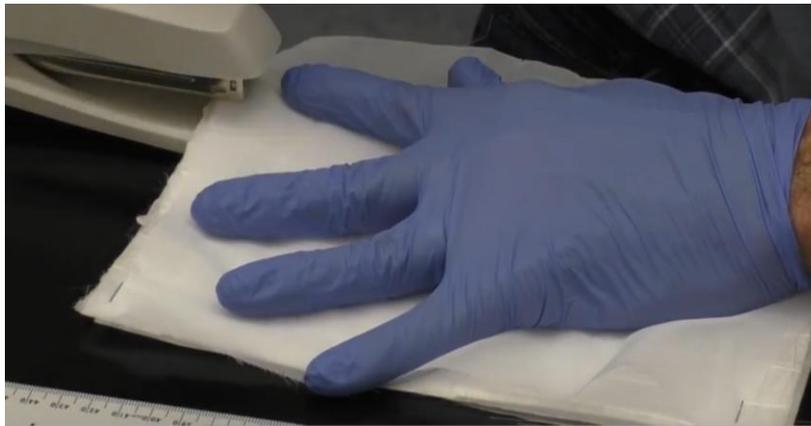
An HVAC filter was broken down by snipping wire backing from the filter material along the inside edges of the cardboard frame on both sides. Then scissors were used to cut the filter material out alongside the inside edge of the cardboard frame. Priority was given to maximizing the amount of filter material harvested from each air filter and minimizing any defects induced in the material as a result of separating the wire backing from the filter substrate. The filter material was pressed flat onto a clean work surface, then cut to the appropriate number of 9" x 6" rectangular sheets according to the number of layers prescribed in Table 1, depending on the rating of the filter material. When cutting the rectangular sheets, it is preferable that the folded pleats in the material run parallel with the 9" length of the rectangle.

MERV	( $\mu\text{m}$ ) PSE (%)	0.30-1.0	1.0-3.0	3.0-10	Airflow Rate (CFM) Débit d'air ( $\text{p}^3/\text{min}$ )	590	885	1180	1475	2000*	*Max Rated Airflow
13	62	87	95	Initial Resistance (IWC) Résistance initiale (IWC)	0.07	0.13	0.18	0.25	0.38		*Débit d'air nominal max

**Figure 5:** Label from frame of an HVAC filter. Note the MERV rating is listed at 13, and it is rated to filter at least 62% of 0.3 -1.0-micron particles (red box).

### Creating Filter Stack

From the sheer fabric, two rectangles of material were cut out for each mask, one measuring 9" x 6" and one measuring 9" x 8". It is necessary to cover the polyester HVAC filter material with layers of durable sheer fabric to prevent the HVAC fabric from fraying. A stack of filter materials was created by placing the larger sheer sheet on the work surface, followed by the layers of HVAC filter material, followed by the smaller sheer sheet. The stack was aligned so that all layers share a common long edge and two corners, leaving a single 2" wide strip of sheer material from the base layer exposed. The layers were stapled together at the four corners of the 9" x 6" sheet, with staples running parallel to the short edge of the rectangles. Care was taken to ensure that all corners align as well as possible.



**Figure 6:** Correct placement of corner staples holding all layers together.

### Mask Shaping

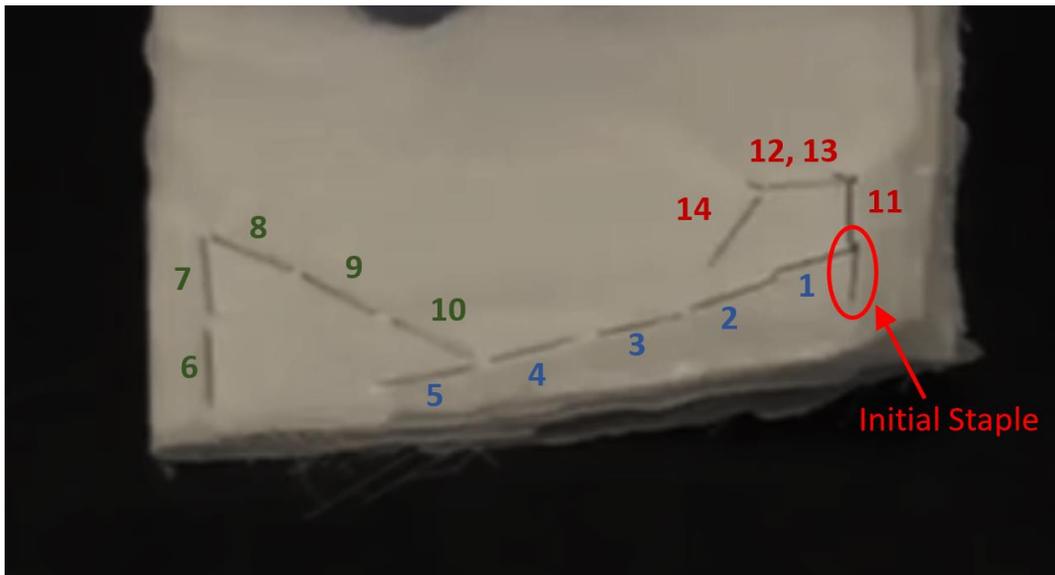
The stapled stack was folded in half to form a nearly square shape, with the larger sheer layer on the inside of the fold. Next, the corner to begin stapling was identified as the corner of the folded sheets at the open end of the fold, away from the protruding sheer fabric. At this corner, there exist two staples nearly touching each other as a result of the initial fold.



**Figure 7:** Identification of corner staple (red circle) indicating the starting place for edge binding.

The edge of the folded stack was stapled together to form the pattern depicted in Figure 8, according to the following steps. All staples for this portion should go through all layers in the folded stack.

- First, place 5 staples in a line beginning at the central edge of the corner staple previously identified and sloping towards the edge of the stack (Staples 1-5).
- Next, place two adjacent staples along the folded edge, beginning near the open edge of the stack (Staples 6-7). Then, from interior edge of the Staple 7, place three adjacent staples (Staples 8-10) in a straight-line angling toward the gap between Staples 4 & 5.
- Returning to the corner with the initial staple, place Staple 11 in line with that initial staple, with one end near the outer end of Staple 1.
- Perpendicular to Staple 11, place Staples 12 and 13 in the same location, but from opposite sides of the stack. Place Staple 12 at a right-angle to the inner edge of Staple 11, pointing into the center of the stack. Flip stack over, and place Staple 13 in the same position.
- Returning to the original side of the stack, place Staple 14 at an angle between Staple 12 and Staple 2.



**Figure 8:** Order & placement of staples to bind edge of folded stack together. All staples should go through the full stack of material. Note the initial staple circled in red is the same as in Fig. 7.

### Connecting Nose-piece to Mask

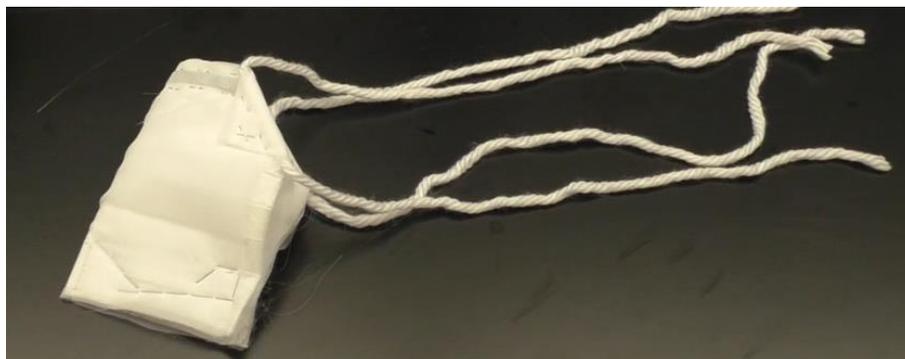
The first step in this process was to invert the protrusion of sheer material so that it folds around the stacked layers and lays flat against the outside of the folded stack. A row of 3-4 staples was created along the edge just folded over on each side, near to the edge. These staples should go through a single half of the stack, stapled from inside of the fold to the outside the fold so that the flat side of the staple rests on the inside of the fold. The bent metal nose-piece was slid under the flap of sheer material so that the closed pinch of the wire rests over the fold of the stack. The metal was pushed all the way to the edge of the stack, between the layers of sheer material, so that it came to rest against the rows of staples placed in the previous step. Finally, a new row of staples was placed parallel to the previous rows, but on the other side of the nose-piece so that the metal was fully captured near the edge of the folded stack.



**Figure 9:** Metal nose-piece (circled in red) captured between layers of sheer material using parallel rows of staples along edge of filter stack.

### Strap Attachment

If elastic bands were used, they were first tied in a closed loop approximately 13" long when laid against a ruler. The exact process and lengths of elastic band material were found to be variant on the type of material used. Thus, customization at this stage of the process was necessary, depending on the available materials. If yarn or twine were used as static bands, two 36" lengths of were cut per mask. The center of one piece of band was placed in the free corner of the filter stack. Then the corner of the stack was folded back so that it enclosed both the wire and the band material. Three staples were placed through the folded over corner to hold in place, one parallel to each edge of the folded over triangular shape. This process was repeated for the other side of the mask to form symmetric bands attached to each side of the mask.



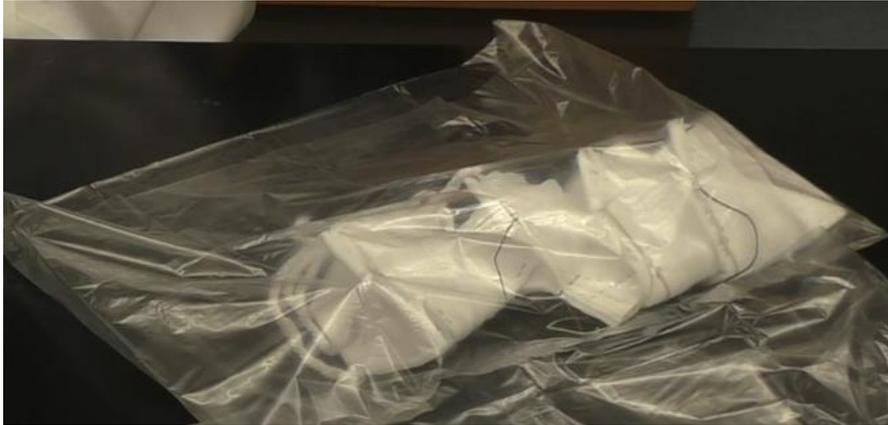
**Figure 10:** Completed mask prototype

### Packaging & Heat Treatment

In cases where the masks were intended to be used by those other than the makers, a method to package and heat-treat the masks to minimize possible contaminants was desired. The procedure found to be optimal for these masks was to place the completed masks inside a plastic cooking bag, ensuring that some space was left so that bag could later be sealed. The filled open bag was placed inside an oven pre-

Devices are NOT rated, NOT sterile, NOT for sale, and should be inspected before use.

heated to 200 Fahrenheit (95 Celsius) for 20 minutes, leaving the bag open while in the oven. After 20 minutes, the bag was removed from the oven, closed, and sealed using packaging tape while still hot. The package was labeled with a package label similar to that shown in Figure 12, stating that the masks are N95 Alternatives and are not rated, sterile, or for sale. To encourage transparency and tracking, the filtering materials used, number of layers, and place and date of assembly were identified. After placing the label on the exterior of the bag containing the masks, a secondary bag was placed around all contents to further seal and protect them from damage.



**Figure 11:** Completed masks placed inside oven bag prior to being heat-treated

### **N95-Style Alternative Mask**

The masks herein could be considered for possible use in certain activities while N95 masks are unavailable. If approved N95 masks are available, use those approved N95 masks first.

While these masks may provide some level of particulate matter filtration that offers some measure of protection, no guarantee, representation, or warranty is made relating to meeting or exceeding the performance standards of an N95 PPE mask certified by the National Institute for Occupational Safety and Health (“NIOSH”) or approved by the Federal Drug Administration. Any use of this type of mask is at the user’s own risk

This type of mask is NOT NIOSH certified, NOT FDA approved, NOT tested to NIOSH or FDA standards, NOT sterile, and NOT for sale

Filter Material: MERV 13 Layers: 4

Place of assembly: College Station

Date: 3/27/2020

**Figure 12:** Sample label to be placed on each bag of packaged masks.

#### 4. Results

The prototype mask was put through in-house qualitative fit testing, which was incorporated into the iterative mask developmental process. Over thirty prototype designs were created and vetted en route to the current prototype design. After the prototype was able to pass the in-house qualitative fit test, a professional quantitative fit test was performed with the same parameters as commercial N95 masks for use in a Biosafety-Level-3 laboratory environment. The prototype DIY mask outperformed other commonly available DIY mask designs made using the available information, including several 3D printed varieties, but it did not fully meet professional OSHA fit-testing standards required for approved N95 masks.

In summary, a low-cost, easily assembled N95-like mask was produced using materials easily found in most home-supply or hardware stores. The total estimated cost of the prototype mask is less than \$5/mask, and it could be assembled in approximately 10 minutes/mask. Its materials are rated to achieve 95% filtering efficiency for 0.3-micron particles which commonly carry viral pathogens. In its current state, it is believed that this prototype may present a viable stopgap measure when rated N95 masks are unavailable, and it is strongly believed to outperform most other DIY masks currently available in light of PPE shortages in the healthcare space.