Modern Meadow Process:

Step 1: Engineer Epithelial Cells -- Test Tube

* In:
  + 1 mL solution with 1,000 epithelial cells
  + 3000 sets of DNA base pairs which code for the specific pattern of collagen desired
    - 1,500 recycled
    - 1,500 fresh
  + 3000 restriction enzymes specific to the base pairs and the section of DNA to which the base pairs should be added
    - 1,000 recycled
    - 2,000 fresh
* Out:
  + 1 mL solution with 1,000 engineered epithelial cells
  + 3,000 restriction enzymes
    - Recycle half back into the next batch of engineered epithelial cells
    - Purge the other half
  + 2,000 sets of DNA base pairs
    - Recycle half back into the next batch of engineered epithelial cells
    - Purge the other half

Step 2: Scale Up -- Petri Dish, or similarly-sized container

* In:
  + 1 mL solution with 1,000 engineered epithelial cells
  + 0.1 microL Nutrients (oxygen, agarose, antibiotics, water)
    - Assuming the volume of an average epithelial cell is 2 \* 10^-6 microL (<http://kirschner.med.harvard.edu/files/bionumbers/fundamentalBioNumbersHandout.pdf>)
    - The number of cells will grow by 24,000
    - 24,000\*2\*10^-6 = 0.048 microL of nutrients needed to create new cells.
    - Input 0.1 microL to ensure that there is enough!
      * 0.026 microL from recycle
      * 0.074 microL fresh
  + 0.01 microL Additives (growth factors, minerals, fiber, fatty acids, amino acids)
    - See work above.
    - Assume 10% of volume requires additives.
    - 0.048 \* 0.10 = 0.0048 microL of additives needed to create new cells.
    - Input 0.01 microL to ensure that there is enough!
      * 0.0026 microL from recycle
      * 0.0074 microL fresh
* Out:
  + 25,000 engineered epithelial cells
  + 0.052 microL Nutrients (oxygen, agarose, antibiotics, water)
    - Recycle half back to next batch
    - Purge the other half
  + 0.0052 microL Additives (growth factors, minerals, fiber, fatty acids, amino acids)
    - Recycle half back to next batch
    - Purge the other half

Step 3: Scale Up -- Dinner Plate sized plate/container

* In:
  + 25,000 engineered epithelial cells
  + 20 microL Nutrients (oxygen, agarose, antibiotics, water)
    - See assumptions above
    - 4975000\*2\*10^-6 = 9.95 microL of nutrients required to create new cells
    - Input 20 microL of additives to ensure that there is enough
      * 5.025 microL from recycle
      * 14.975 microL fresh
  + 2 microL Additives (growth factors, minerals, fiber, fatty acids, amino acids)
    - See assumptions above
    - 0.995 microL of additives required to create new cells
    - Input 2 microL to ensure that there is enough!
      * 0.5025 microL from recycle
      * 1.4975 microL fresh
* Out:
  + 5,000,000 engineered epithelial cells
  + 10.05 microL Nutrients (oxygen, agarose, antibiotics, water)
    - Recycle half to next batch
    - Purge the other half
  + 1.005 microL Additives (growth factors, minerals, fiber, fatty acids, amino acids)
    - Recycle half to the next batch
    - Purge the other half

Step 4: Bioprinter

* In:
  + 5,000,000 engineered epithelial cells
* Out:
  + 5,000,000 engineered epithelial cells

Step 5: Substrate Scaffold (3 ft x 6 ft)

* In:
  + 5,000,000 engineered epithelial cells
  + 400 L Nutrients (oxygen, agarose, antibiotics, water)
    - See logic and assumptions above
    - (100,000,000,000,000-5,000,000) \* 2\*10^-6 = 199,999,990 microL = 199.999990 L
    - Input 400L to ensure enough
      * 100L from recycle
      * 300L fresh
  + 40 L Additives
    - 19.9999990 L required
    - Input 40L to ensure enough
      * 10L from recycle
      * 30L fresh
* Out:
  + Single layer of collagen
    - 3 ft x 6 ft x 1 inch
    - 100,000,000,000,000 cells
  + 200 L Nutrients
    - Recycle half to next batch
    - Purge the other half
  + 20 L Additives
    - Recycle half to next batch
    - Purge the other half

Step 6: Wash collagen

* In:
  + Single layer of collagen
    - 3 ft x 6 ft x 1 inch
  + 60 L Cold Water
    - Volume of collagen = 3\*6\*1/12 = 1.5 cubic feet = 42.4753 L
    - Use 60 L of water
  + 5 L Soap
    - Ratio of soap should be 1:12

60 \* 1/12 = 5 L of soap

* Out:
  + Clean layer of collagen
    - 3 ft x 6 ft x 1 inch
  + 65 L dirty water

Step 7: Layer Compressing

* In:
  + Desired number of layers of collagen
    - Assuming 19 other layers
    - 3 ft x 6 ft x 1.6 ft
* Out:
  + Plurality of layers of collagen
    - 20 layers fused together
    - 3 ft x 6 ft x 1.67 ft

Step 7: Drying

* In:
  + Plurality of layers of collagen
    - 20 layers fused together
    - 3 ft x 6 ft x 1.67 ft
    - Temperature: 20 C
  + Dry, hot air
    - 1.62 kg water / kg protein in collagen
    - <http://www.i-sis.org.uk/Collagenwaterstructurerevealed.php>
    - ρ(org) = 1000 [(12 + 1(H:C) + 16(O:C)]/[7.0 + 5.0(H:C) + 4.15(O:C)]
    - <https://www.ncbi.nlm.nih.gov/pubmed/22145565>
    - C2H5NOC5H9NOC5H10NO2 is molecular formula
      * C = 2+5+5 = 12
      * H = 5+9+10 = 24
      * N = 1+1+1 = 3
      * O = 1+1+2 = 4
        + H:C = 24/12 = 2
        + O:C = 4 / 12 = 0.3333
    - <http://www.slideshare.net/nashton/collagen-5444601>
    - Density = 1000\*((12+2+16\*0.3333)/(7+5\*2+4.15\*0.3333)) = 1051.6561 kg/m^3
    - Volume = 3\*6\*1.67 = 30.06 \* 0.0283168 = 0.851203 \* 1051.6561 = 895.172827 kg collagen
    - 895.172827 = w + p
    - W = 1.62p
    - 895.172827 = 1.62p + p = 2.62p
    - P = 895.172827 / 2.62 = 341.669018 kg protein
    - W = 341.669018 \* 1.62 = 553.503809 kg water = 553.5 L water to remove = 30.716083 mol water to remove
    - Assume 18 m^3/min STP dry air in
      * 1.00 atm \* 1.01 bar/atm \* 18 m^3 = n \* 8.314 (bar \* m^3 / mol \* K) \* 273 K
      * N = 8.314 \* 273 / (1.01 \* 18) = 124.8472 mol air
      * Mass air = 124.8472 mol \* 29 g / mol \* 1 kg / 1000 g = 3.6206 kg air / min
    - Dry Bulb Temperature: 100 C, no moisture content
    - <http://nvlpubs.nist.gov/nistpubs/jres/55/jresv55n4p191_A1b.pdf>
    - Heat capacity of collagen: 1.790752 kJ / g \* C
    - 1790.752 kJ/kg\*C
    - 1790.752 \* 341.669018 = 611844.477322 kJ/C
    - Air loses 4 kJ /kg dry air in process
    - 4 \* 3.6206 = 14.4824 kJ / min
    - 0.028 kg water leaves per minute
    - 553.503809 / 0.028 = 19,767.993179 minutes of drying
    - 19,767.993179 \* 14.4824 = 286,287.984416 kJ added to collagen
    - 286,287.984416 / 611844.477322 = 0.46791 degrees C
* Out:
  + Dry collagen layer
    - 341.669018 kg protein
    - 341.669018 / 1051.6561 = 0.324887 m^3
    - 0.324887 \* 1000 = 324.887 L
    - Temperature: 20.46791 C
  + Hot, saturated air
    - 30 degrees C
    - 100% saturated
    - 28 kg water / kg air
    - 100 kJ / kg dry air

Step 8: Tanning Process

* In:
  + Dry collagen layer
  + 400 L Chromium (III) sulfate
    - 324.887 L required to tan the entire piece
    - Add 400 L to be sure
      * 37.56 L from recycle
      * 362.44 L fresh
  + 400 L Additives (coloring, odor)
    - 324.887 L required to add to entire thing
    - Add 400 L to be sure
      * 37.56 L from recycle
      * 362.44 L fresh
  + 400 L Preservatives (calcium propionate, sodium nitrate, sulfites)
    - 324.887 L required to add to entire thing
    - Add 400 L to be sure
      * 37.56 L from recycle
      * 362.44 L fresh
* Out:
  + Tanned leather piece
  + 75.113 L Chromium (III) sulfate
    - Recycle half to next batch
    - Purge other half
  + 75.113 L Additives (coloring, odor)
    - Recycle half to next batch
    - Purge other half
  + 75.113 L Preservatives (calcium propionate, sodium nitrate, sulfites)
    - Recycle half to next batch
    - Purge other half

Step 9: Waxing

* In:
  + Tanned Hide
  + Wax
    - Surface area of tanned hide about 3ft x 6 ft = 18 ft^2 = 1.67 m^2.
    - Height of hide = 0.324887 / 1.67 = 0.194543 m
    - Assume layer of wax = 1/4 height on each side of the hide ==> 1/2 height total
    - 1.67 \* 0.194543 \* 1/2 = 0.162443 m^3 of wax
    - 0.162443 \* 1000 = 162.443 L of wax needed
* Out:
  + Finished product