The Pump Master
Duke University
EGR190/WERC 2011

Presented by:
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Daniel Moss, Maria Nayfa, Andrew Wood
Task 7: Clean Energy Water Disinfection for Small, Remote, Rural Communities

Our project must:

- Harness clean energy (non-fossil based)
- Be easy to implement, maintain and operate
- Be portable
- Be cost-effective
- Apply to third-world and rural settings
- Have potential for real-life application
Additional Design Considerations

- Usable by majority of the community
- Easily adapted to different situations
  - Desalination or other water treatments
  - Available construction materials
  - Ability to manufacture versus purchase parts
- Simple design based on concepts that are intuitive or widely recognized
Available Energy Technologies

Potential Energy Sources

- Hydropower
- Wind power
- Biomass
- Solar photovoltaic
- Mechanical (human powered)
Available Treatment Technologies

Chemical Disinfection Methods
- Chlorine
- Iodine
- Hydrogen peroxide
- Ozone

Physical Disinfection Methods
- Ultraviolet (UV) Exposure
- Ceramic filters
- Granular media
- Membrane filtration
- Boiling
- Solar disinfection
Technologies were evaluated with a weighted matrix considering:
- Efficacy
- Cost
- Ease of implementation and maintenance
- Portability

Final decision: human powered stepping mechanism that operates two piston pumps, forcing water through a membrane
<table>
<thead>
<tr>
<th>Weighting (5 - most important)</th>
<th>Efficacy</th>
<th>Cost (Initial and O&amp;M)</th>
<th>Ease of Implementation/ Maintenance</th>
<th>Portability</th>
<th>TOTAL</th>
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<tr>
<td>Treatment Methods (S cost)</td>
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http://www.youtube.com/watch?v=AsSXa60DtAY
Process-Flow: Human powered filtration

Removing bacterial contaminants from water
  Contaminated water drawn into inflow pipe
  Contaminated water pumped through membrane
  Clean water discharged via outflow pipe
  Clean water discharged into storage

via: Human Power
  via: "Upstroke" of lever
  via: "Downstroke" of lever
  via: "Downstroke" of lever
Concept: Mechanical System (Levers and Pulley Mechanism)
Lever Design

- Calculated ratio of a to b using the minimum and maximum pressure for the filters and the minimum and maximum body weights the system is designed for.

- Final dimensions:
  - Length: 6’10”
  - Applied weight (a): 6’
  - Pump (b): 6’7”
Pulley Design

- Length of cable specified to optimize pump stroke length while minimizing step size
- Ensures continual up-down motion
- Depends on frame construction – trial and error to achieve correct length
Concept: Pumping System
Simple Piston Pump

- Possible to manufacture a simple piston pump from steel or plastic, or whatever materials are locally available.
- Design pressure 30-100 psi (fails at 150 psi)
- $P = \frac{F}{A}$, where $A = \pi r^2$
Designing the Pump

**Pump Attachment**

- Elevates pumping system so that levers remain close to ground
- Utilizes eye-hooks to allow for pivoting
MUST remove bacteria

Options:
- micro-
- ultra-
- nano-
- reverse osmosis

Ultrafiltration has “absolute bacteria and virus removal from surface waters”* with less pre-treatment and lower pressures than nanofiltration or RO

Choosing a Membrane

- Membrane selected: AMI Membranes, Polyethersulfone Ultrafiltration Membrane Model No. M-U4040PES
- Maximum flow rate of 20 GPM, able to meet 3000 GPD requirement
- ~10,000 MWCO (.01 micron pore size)
Market Product

- Mechanical System: levers and pulley
- Pump: simple piston pump
- Membrane: large ultrafiltration membrane (max flowrate: 20 GPM)
Bench-Scale Product

- Mechanical System: levers and pulley
- Pump: Reed HTP300 hydrostatic pump
- Membrane: small ultrafiltration membrane (max flowrate: 2 GPM)
Testing and Evaluation: Bench-Scale Product

- Functional pumps
  - Hand-tested, achieved >300 PSI with upper body strength
- Operational mechanical system
  - Tested with variety of team members
- Off the shelf membrane
  - Rated for absolute bacterial removal
  - Flow rate achieved at WERC: ~0.167 GPM
  - Flow rate <2 GPM, so pressure <150 PSI
    - Boundaries: (30-150 PSI) and (0 GPM, 2 GPM)
    - Linear interpolation: for 0.167 GPM, operating at 40 PSI
Additional Testing and Evaluation: Market Product

- Functional pumps
  - Would need to ensure proper seal - test independent of mechanical system

- Operational mechanical system
  - Test with a verity of team members (done)

- Off the shelf membrane
  - Similar calculations using the larger membrane
  - Boundary conditions: (30-150 PSI), (0-20 GPM), (60-290 lbs)
  - Design conditions: (30-100 PSI), (0-11.67 GPM), (60-180 lbs)
Potential Design Improvements

- Pre-treatment
  - Granular media to remove large particles and prevent membrane fouling
- Post-treatment
  - Chlorination to prevent bacteria regrowth
- Pressure checks
  - Pressure gauges in-line to monitor pressure in front of membrane
- Periodic water sampling
  - Plating to test for bacteria in treated water
- Pulley system materials
  - Use steel cable and low friction pulleys
## Economic Analysis:
### Market Product Estimated Cost

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit Cost</th>
<th>Quantity</th>
<th>Total Cost</th>
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<tbody>
<tr>
<td>Membrane Housing</td>
<td>$50</td>
<td>1</td>
<td>$50</td>
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<tr>
<td>Membrane</td>
<td>$240</td>
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<tr>
<td>Manufactured Pump System</td>
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<td>Frame Materials</td>
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<tr>
<td>Piping Materials</td>
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<td>Testing Equipment</td>
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<tr>
<td>Installation</td>
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<tr>
<td>Total Initial Capital</td>
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<td>Maintenance (Annual Filter Replacement, Pump Maintenance, and Miscellaneous Cost)</td>
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<td>$12/hr</td>
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<tr>
<td>Annual O &amp; M</td>
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<td>Expected Lifetime in Years</td>
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<td>Annual Lifetime Cost</td>
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<td>Annual Water Cost</td>
<td>3000 G/d</td>
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<td>$0.001/G</td>
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## Economic Analysis: Bench-Scale Product Cost

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit Cost</th>
<th>Quantity</th>
<th>Total Cost</th>
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<tbody>
<tr>
<td>Membrane Housing</td>
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<tr>
<td>Membrane</td>
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<td>Testing Equipment</td>
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<td>Aesthetics</td>
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<tr>
<td><strong>Total Initial Capital</strong></td>
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<td><strong>$695</strong></td>
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Economic Analysis: Market Entry and Product Distribution

- Set up as a non-profit corporation
- Partner with international organizations for deployment
  - Microfinance
  - Focus on local ties
  - Ex: The Water Project
- Assess and construct on site
- Roll-out Plan
  - 3rd World Countries
  - Disaster Zones
    - current example: Haiti
Public Involvement and Education

- Educate community about project: purpose and benefits
  - Seminars targeted to specific demographics within a community
- Community input
  - How to adapt the design for the community
  - Financial plans
  - Long-term partnership
Safety

- Concerns: minor physical injury during construction, maintenance and operation
  - Addressed by proper training on use and maintenance of the system
  - Appropriate security measures and safety mechanisms
- Health benefits from disinfected water outweigh any potential negatives
Environmental Considerations

- Marine and terrestrial habitat
  - Minimal disturbance
- Byproducts of the Pump Master
  - Concentrate
    - Use as fertilizer
      - Long Term Storage Treatment
      - Heat Treatment
    - Pit Disposal
Recent events have necessitated a system that is:
- Simple
- Affordable
- Adaptable
- Easy to maintain
- Portable

The Pump Master IS this system!
Special thanks to:
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