New Frontiers in Materials for Global Development: From Health to Energy and the Environment

Wole Soboyejo
Department of Mechanical and Aerospace Engineering &
The Princeton Institute of Science and Technology of Materials (PRISM)
Princeton University
Princeton, New Jersey, USA
and
Department of Materials Science and Engineering
African University of Science and Technology (AUST)
Abuja, Nigeria

Research Supported by NSF, NIH and World Bank

The Pan-African AIST Flower Model

Burkina Faso
Center for water and environmental engineering

Nigeria
AIST campus in Abuja

Tanzania
AIST campus in Arusha

Nigeria
Center for offshore petroleum engineering (G2i)

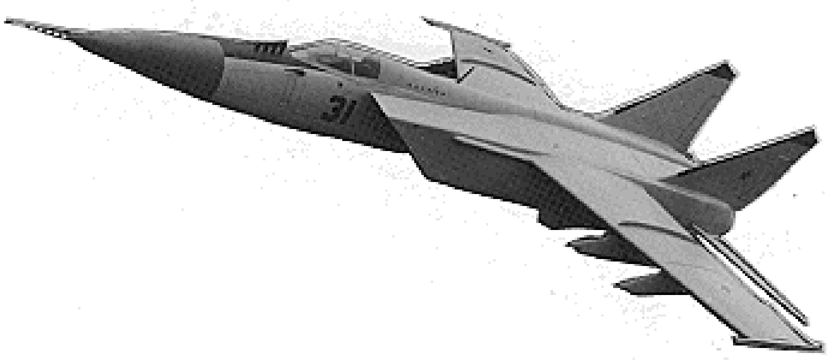
South Africa
Center for applied mathematics (partnering with the existing African Institute for Mathematical Sciences)

Materials – A Major Driver

- Science and technology are the major engines of development
- Materials have always been a major driver in technological change…
  - Alloys
  - Semiconductors
  - Polymers
  - …

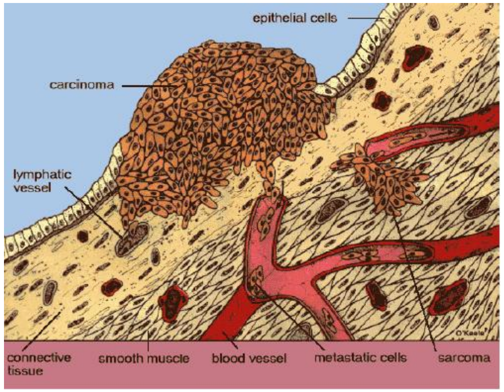
Hard materials

Soft materials



Examples of Strategy for Systems-Based Interdisciplinary Approach to Research

- Advanced Materials (Bio and Nano)
  - Targeting of disease
  - Alternative energy
- Societal Development
  - Affordable infrastructure e.g. recycling of agricultural/industrial waste
  - Value addition to people, minerals and natural products



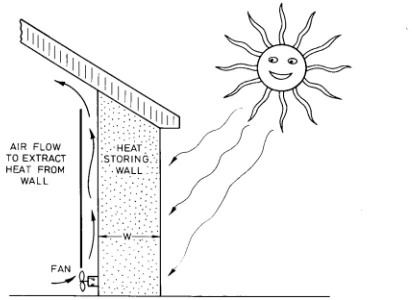
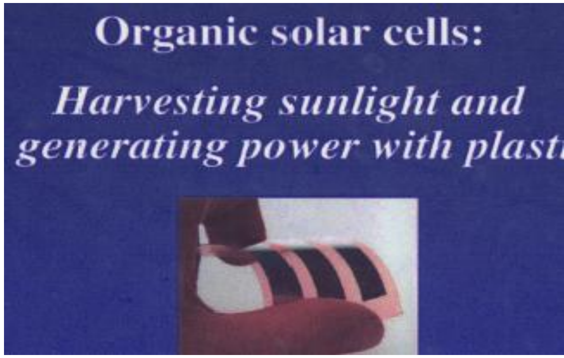


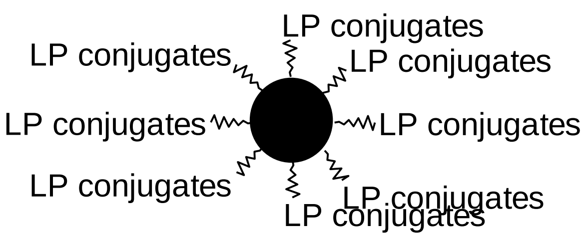
FIG. 6.32 A heat-storing wall. The sun shines on the outside during the day; heat is extracted from the inside at night. The heat diffusion time through the wall must be about 12 hours.

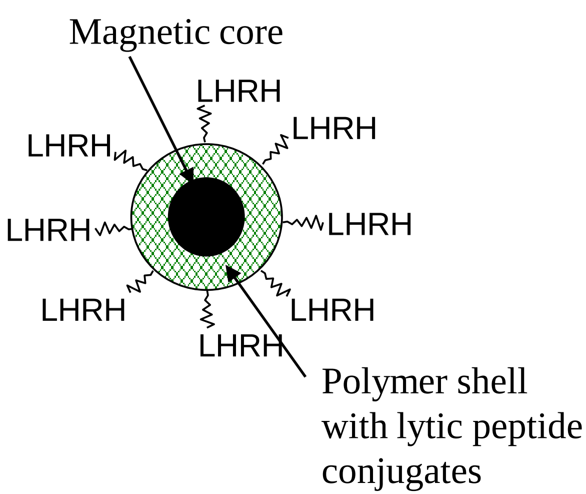


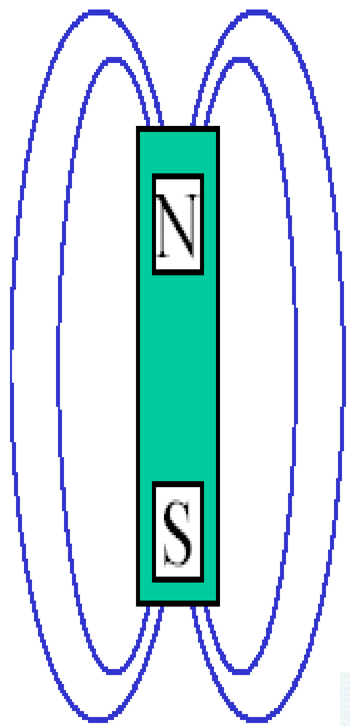
CAMD

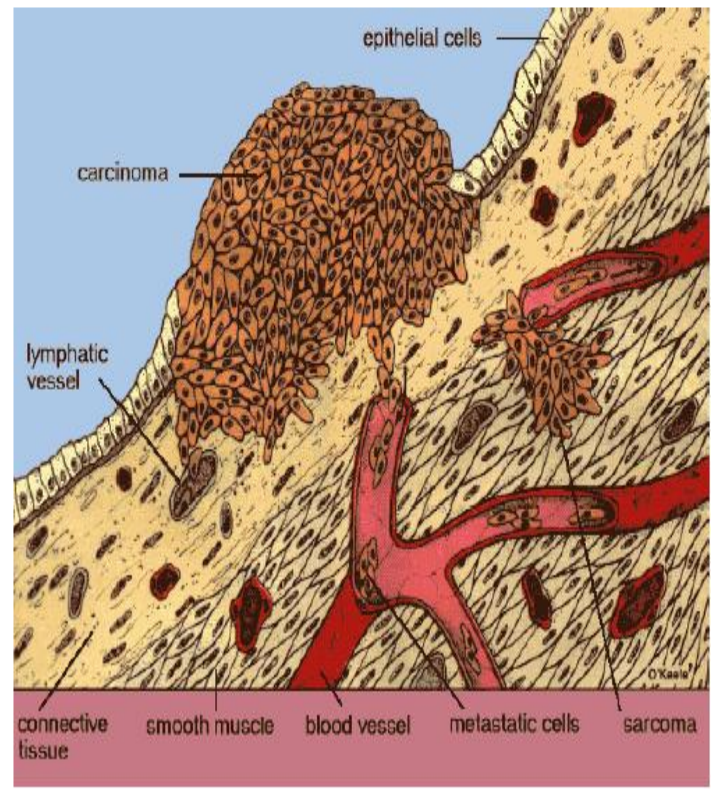
Nanotechnology Approach to Early Breast Cancer Detection and Treatment!

A novel use of magnetic fields and magnetic particles to deliver therapeutic drugs at the desired time in the correct dosage to the correct site in the human body.



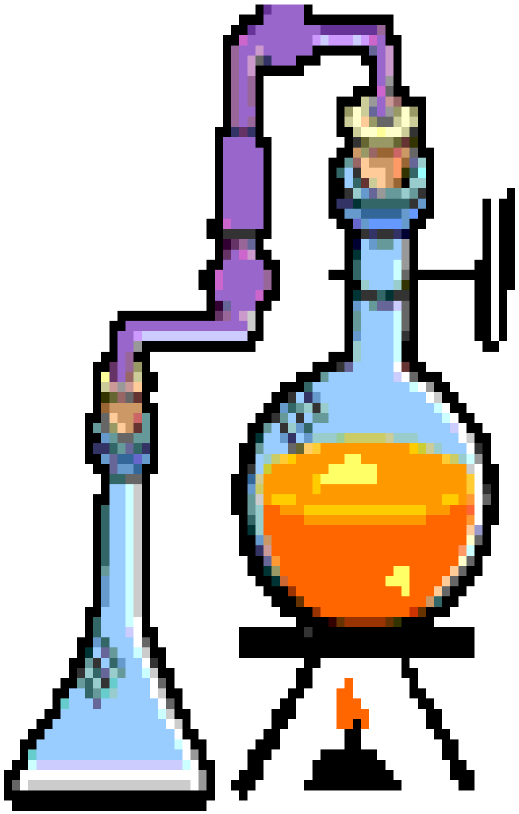






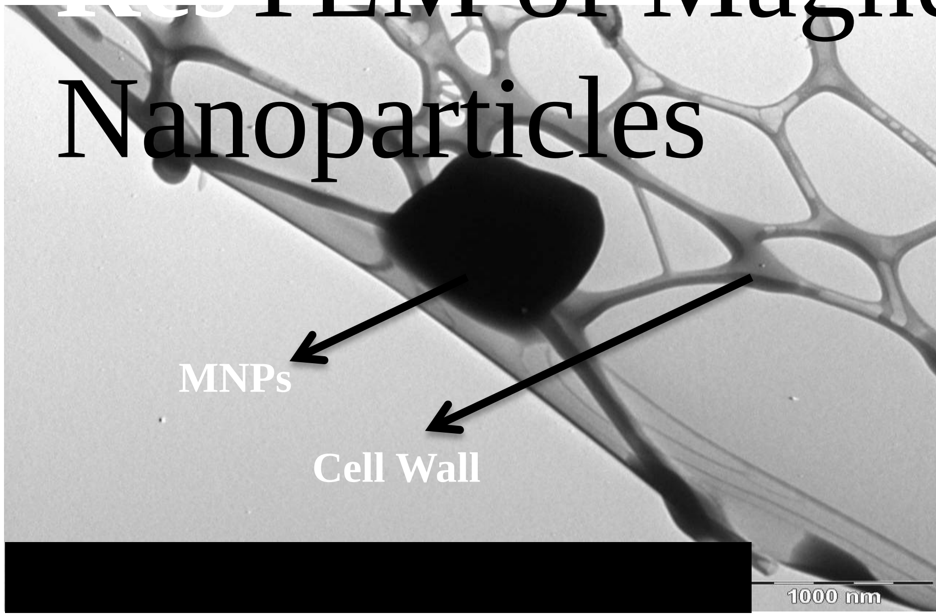
CAMD

Wet Chemical Synthesis and Bio-Synthesis of Nanoparticles

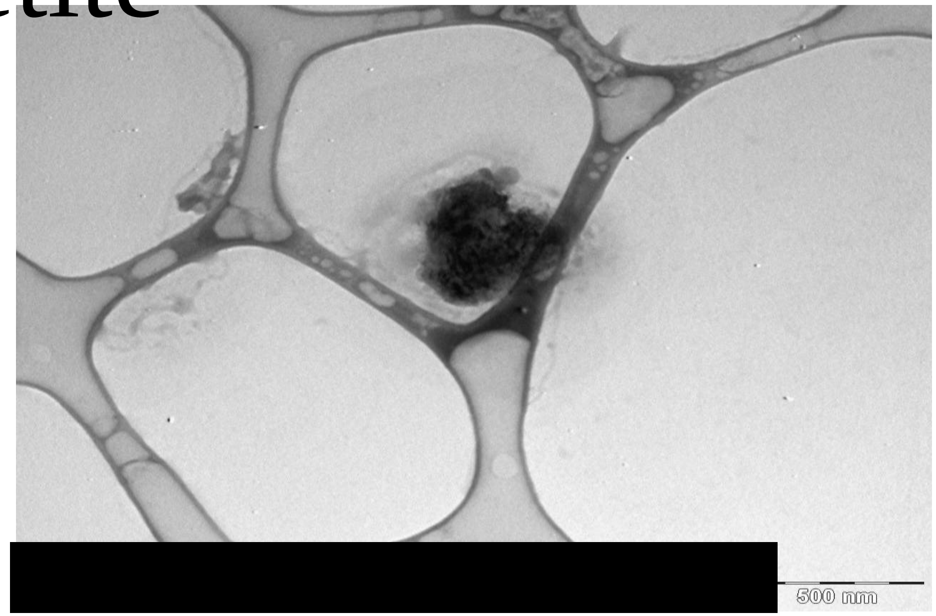


- Metallic, polymeric and metal-polymer Nano-particles using bottom-up approaches
- Biosynthesis with Magneto-spurillum
- Novel Micro reactor technology for scale-up and controlled synthesis
- Synchrotron radiation based X-ray absorption Spectroscopic characterization
- Capability to attach bio-molecules

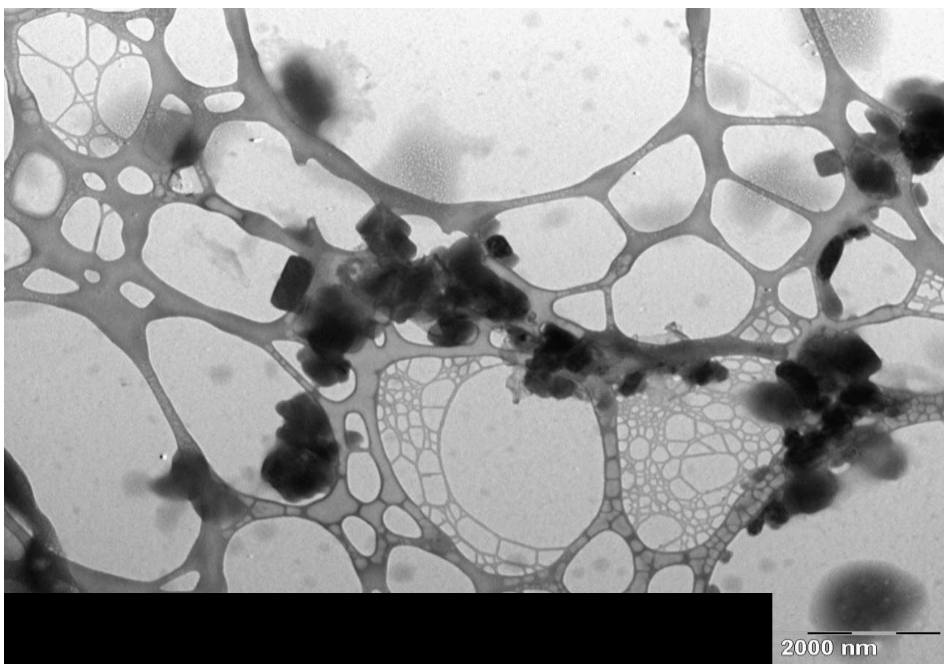
TEM of Magnetite Nanoparticles



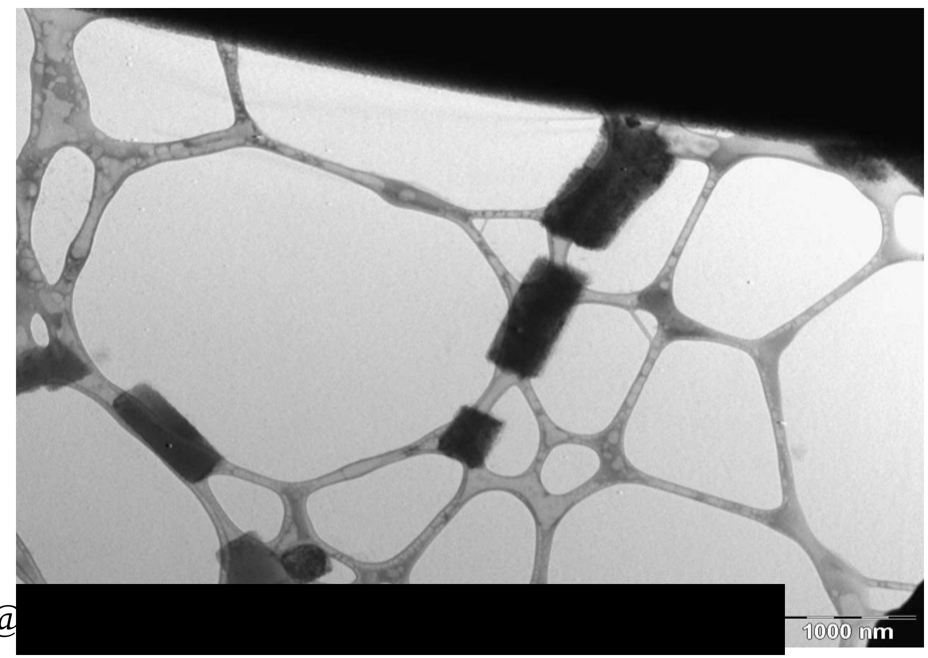
[redacted]



[redacted]



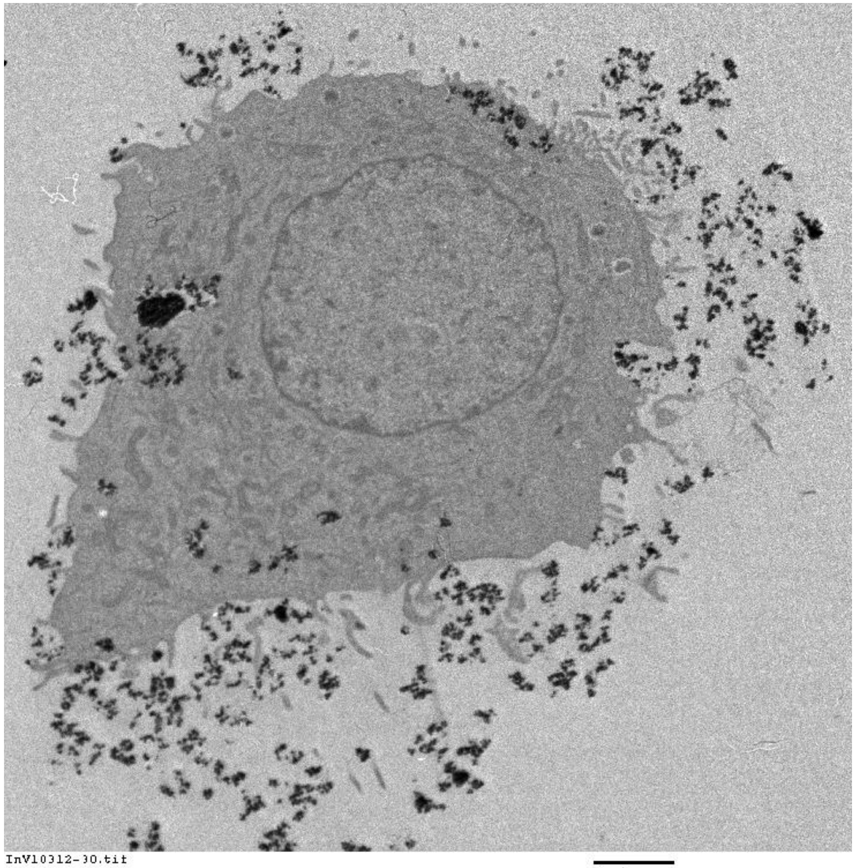
[redacted]



[redacted]

LHRH-SPION Uptake - 37 C for 3 Hours

- MNPs-LHRH, 37 C, 3 Hr
- Note endocytosis process by which particles enter cell
- Engulfed particles carried within the cell
- Excreted or egested within 30 days
- Modeling of transport across membranes and ligand-receptor interactions

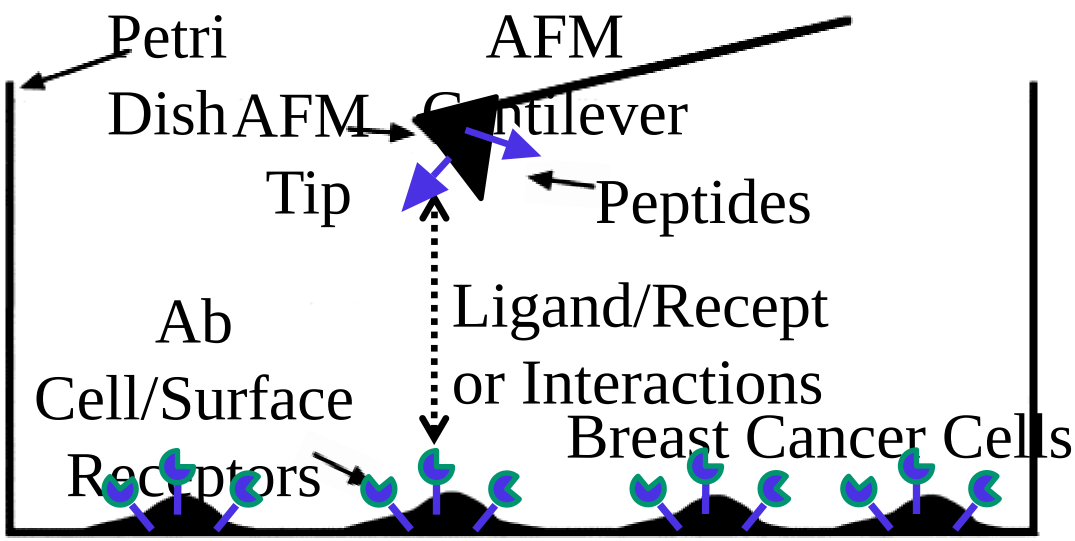


InV10312-30.tif
In Vitro

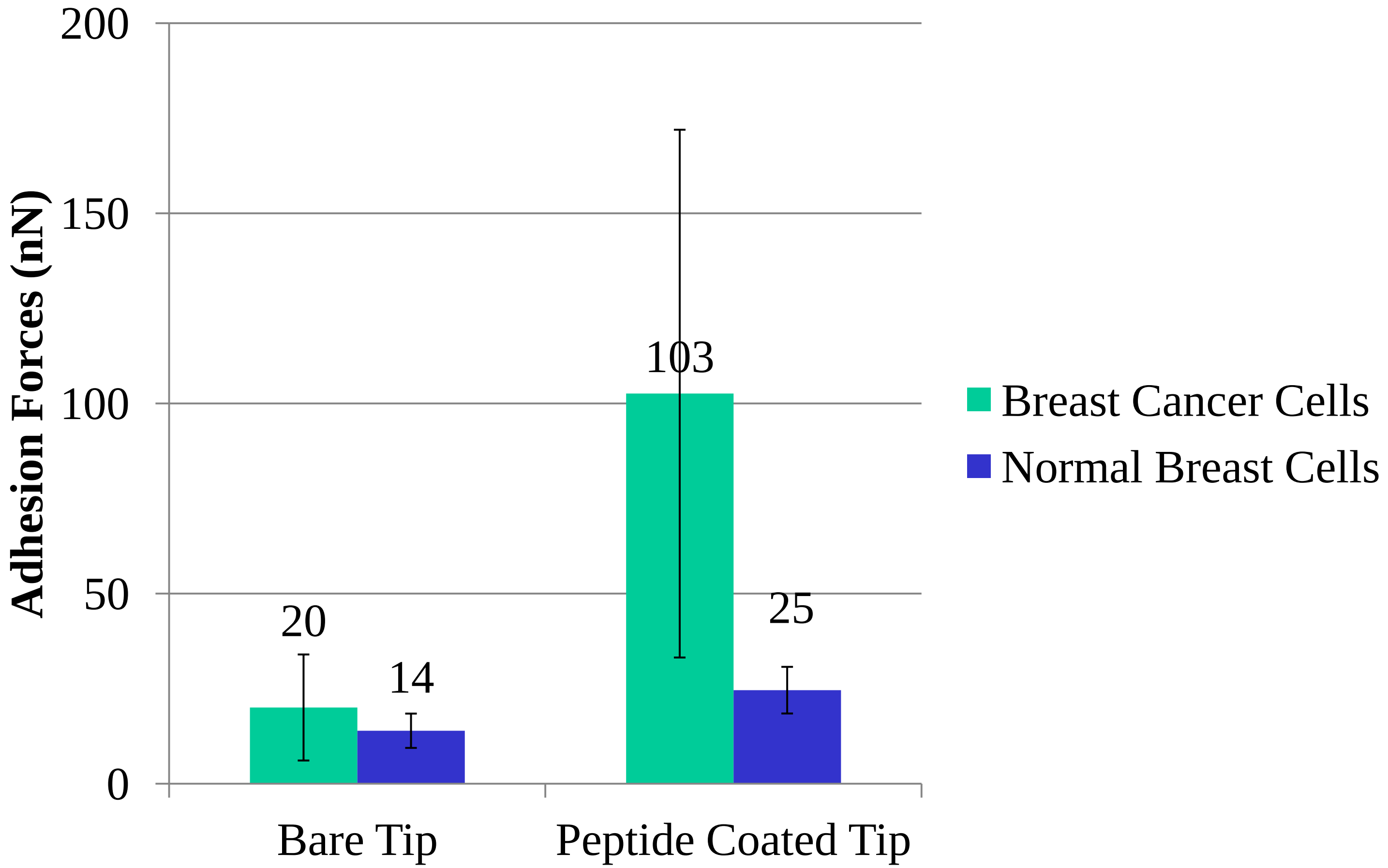
2 microns

AFM Peptide Adhesion Studies

- AFM Tip (VeecoProbes) dip coated in LHRH peptide
- SEM used to verify success of coating
- AFM contact mode used to obtain force vs. deflection curves to quantity adhesion forces
  – Peptide vs. MDA-MB-231 and Hs578Bst
  – Bare tip vs. MDA-MB-231 and Hs578Bst

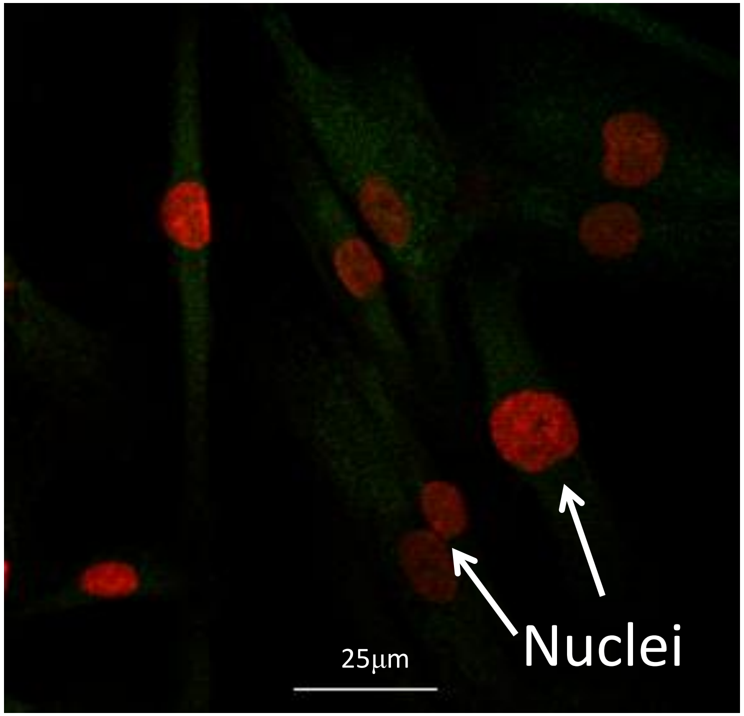


Comparisons with Prior Results: Adhesion with LHRH Peptide

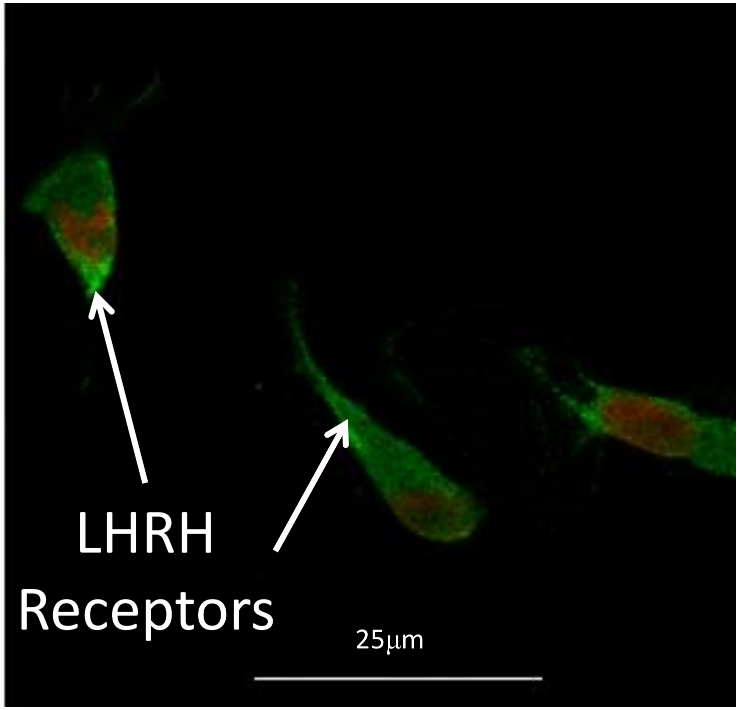


Confocal Staining for LHRH Receptors

Normal Breast Cells
Hs578Bst

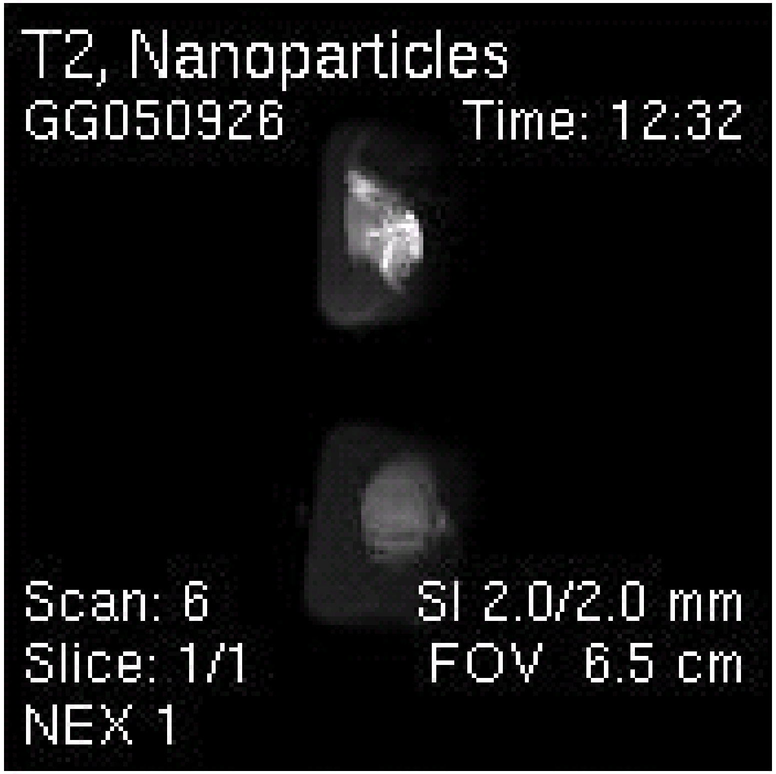


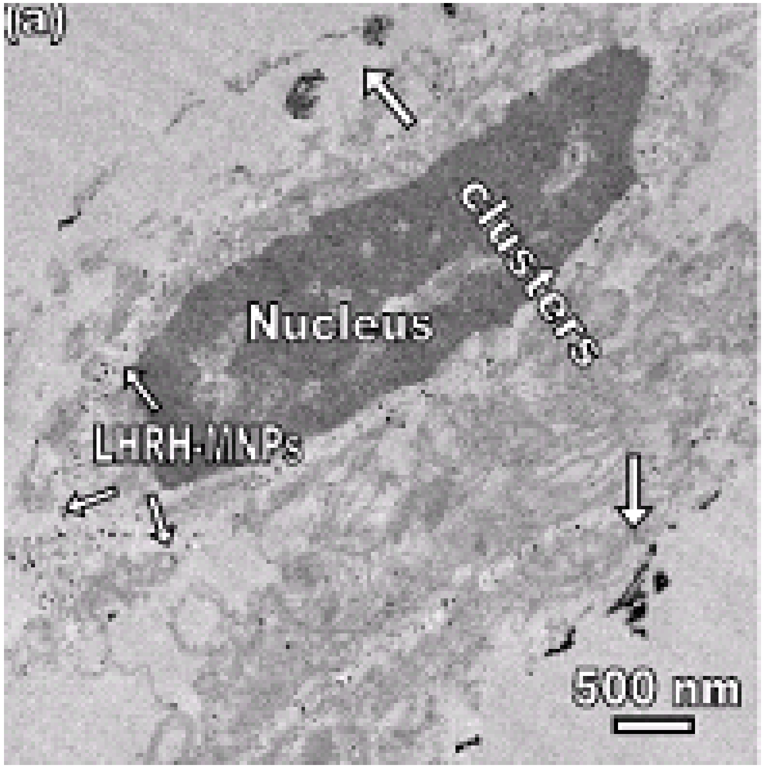
Breast Cancer Cells
MDA-MB-231



LHRH Receptors: *green*, Nuceli: *red*

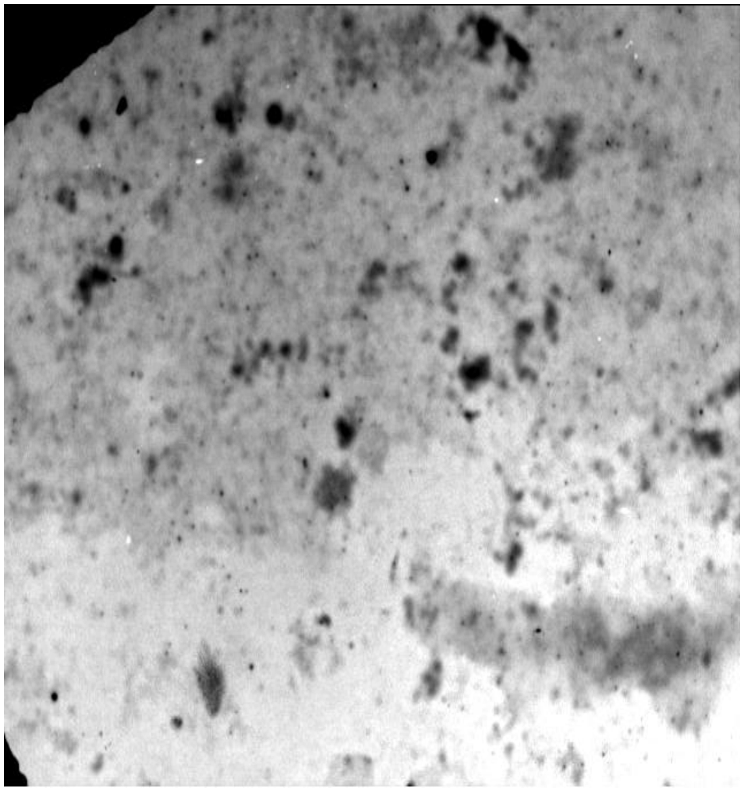
T2 MRI Images of Tumors – Contrast Due to LHRH-MNPs



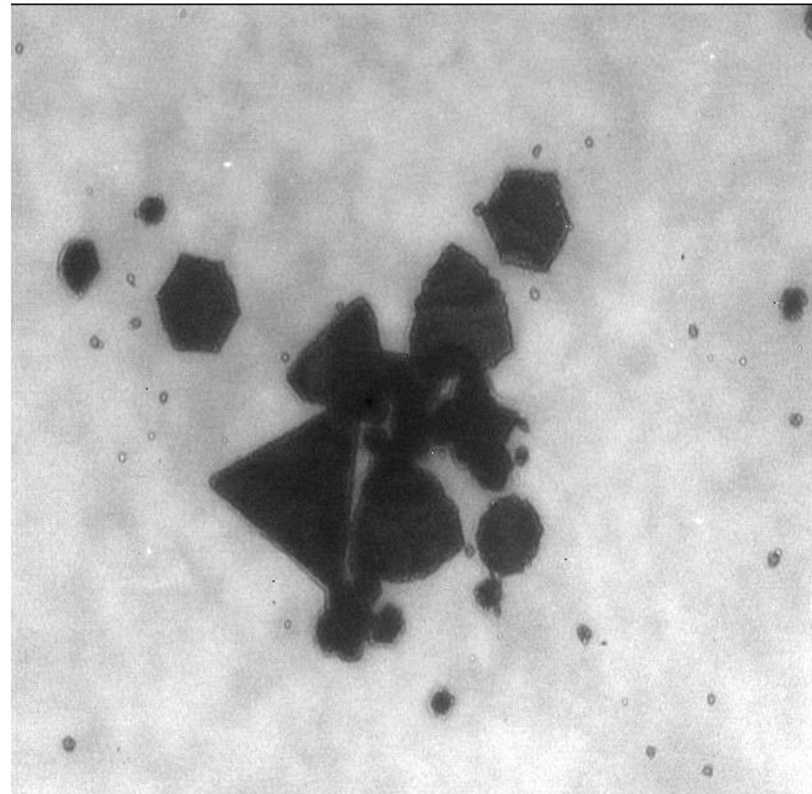


TEM of Au NPs in *Serratia Marcescens*

pH 3

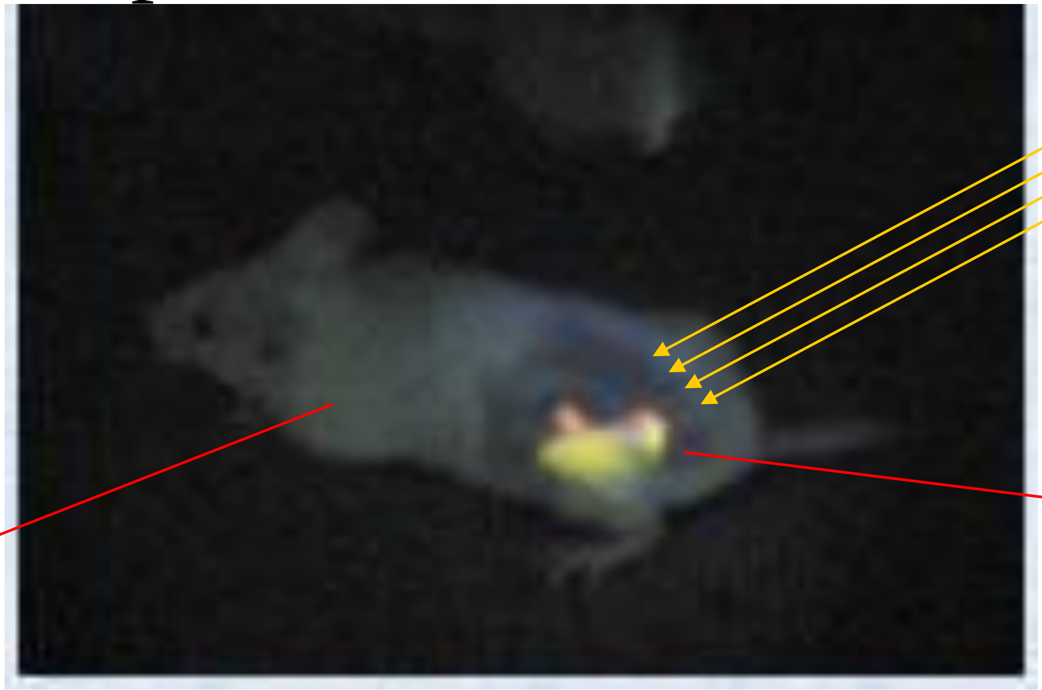


pH 4



Gold Nanoparticle Research Strategy

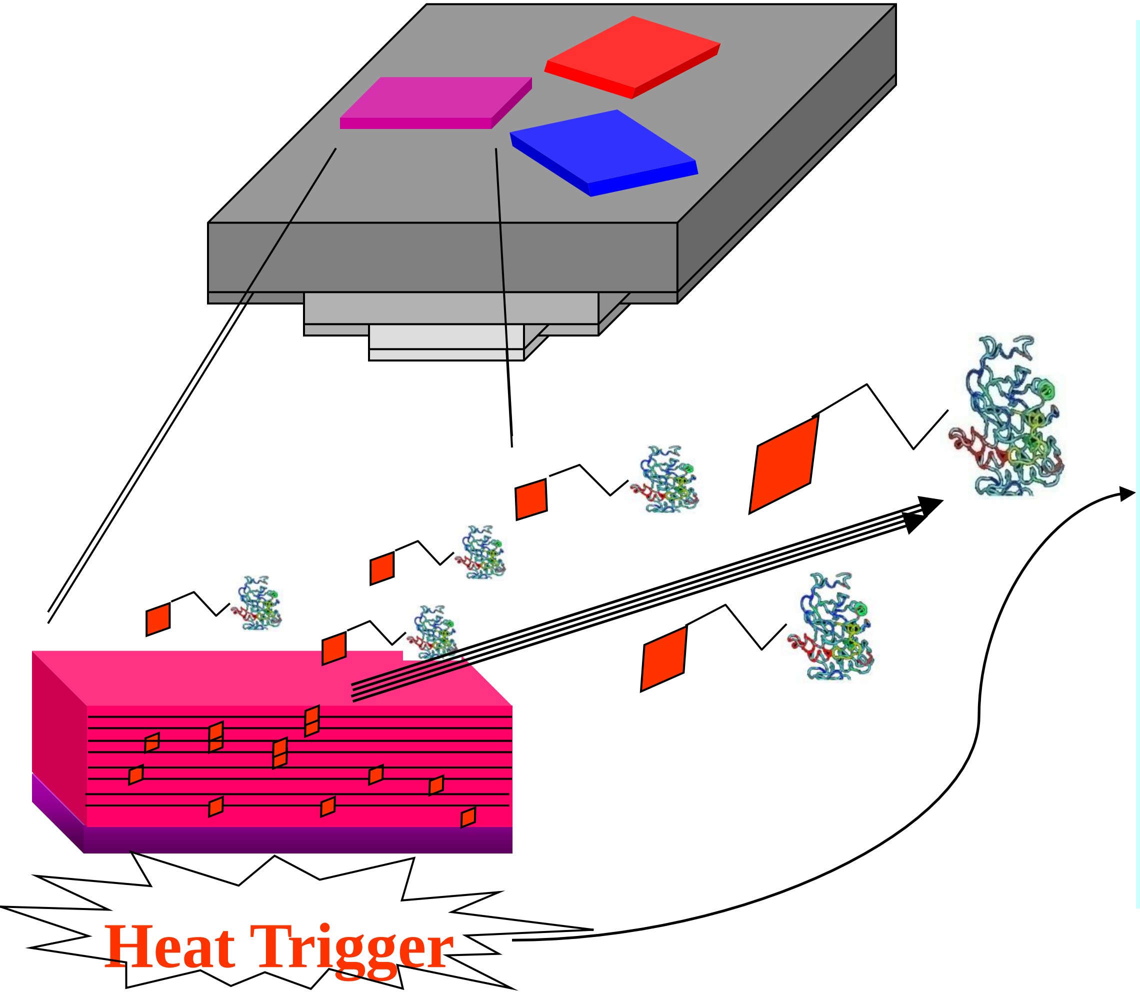
Photosensitizer:
Porphyrin



Laser
Beam

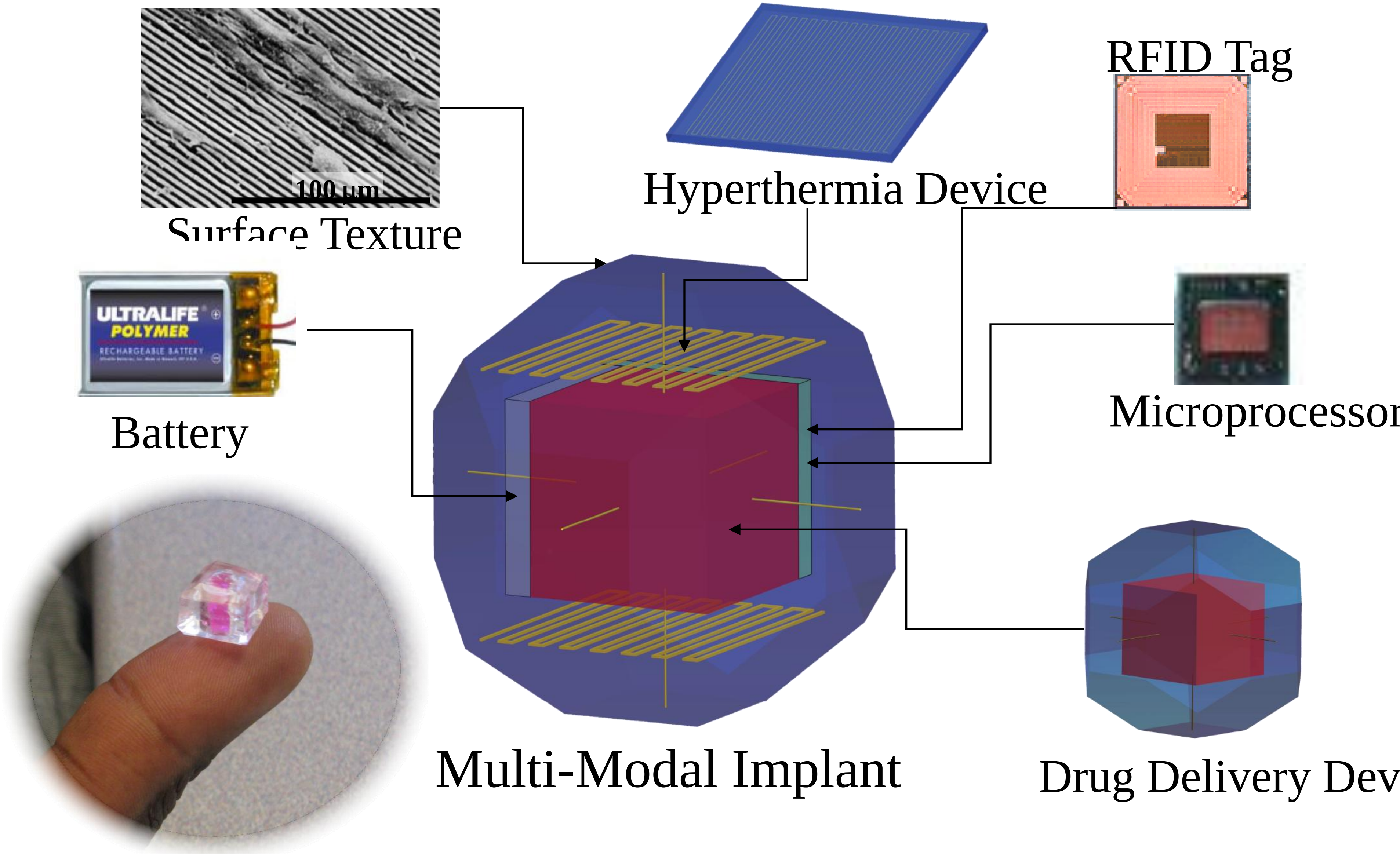
Au NP directly injected

Drug Delivery by Resistive Heating



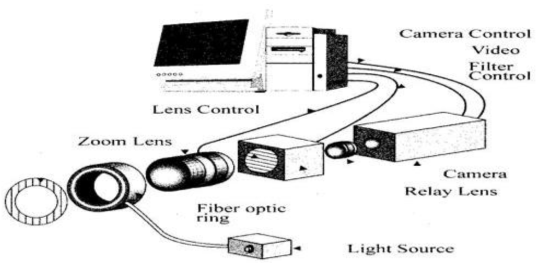
- Hydrogels sit on metallic plates
- Current running through plates heat plates
- Temperature controlled by current
- Current controlled by open/closed switch programming

Hyperthermia + Drug Delivery



Cervical Cancer Imaging

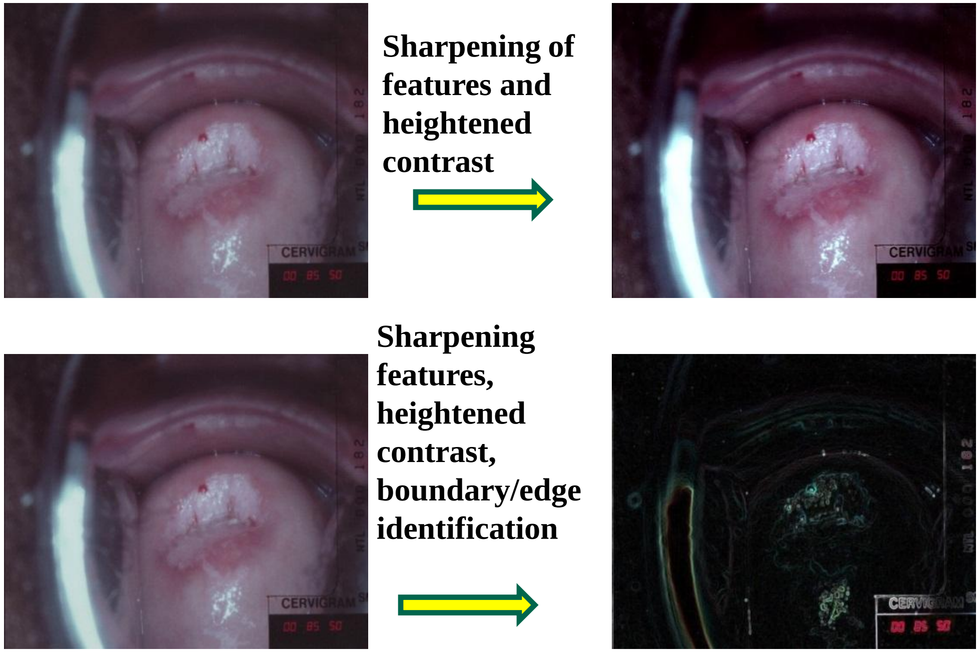
- **Second most commonly occurring cancer in women of all ages world wide**
- **Cervical intraepithelial neoplasia precedes invasive cervical cancer**
- **Common procedure: Pap smear followed by colposcopy if abnormal**



.

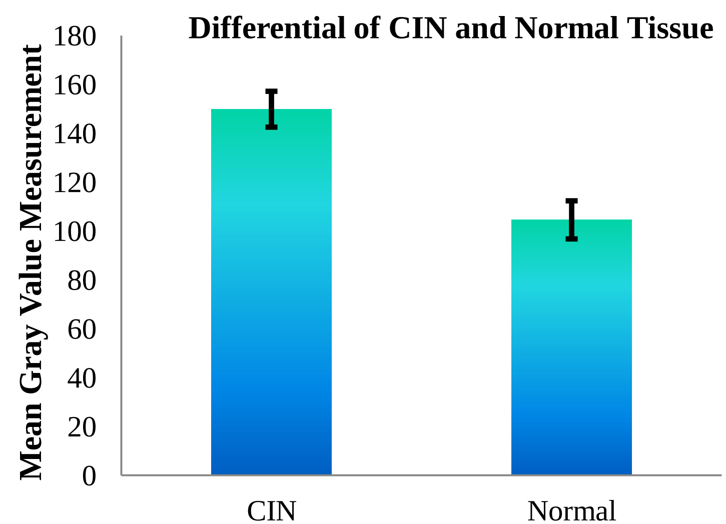
Strategy for Cervical Cancer Imaging Regions

Sample Cervical Cancer Image Processing



Positive AAT, high grade SIL anterior (CIN II)

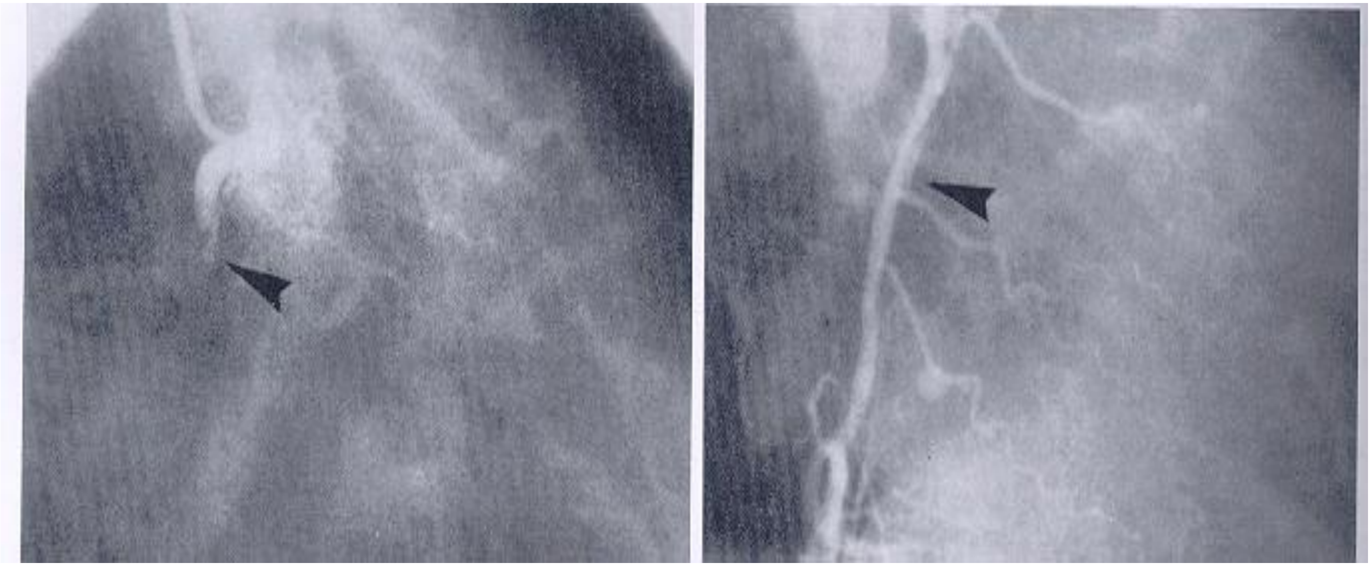
Sample Image Analysis Results



- Field test results suggest that digital camera and cell phone images can be used to image cervical and oral cancers (500 clinical cases studied in Janmur City in India)
- Can combine with hypothermia or hyperthermia treatment techniques

Background and Introduction

Cardiovascular Disease (CVD):

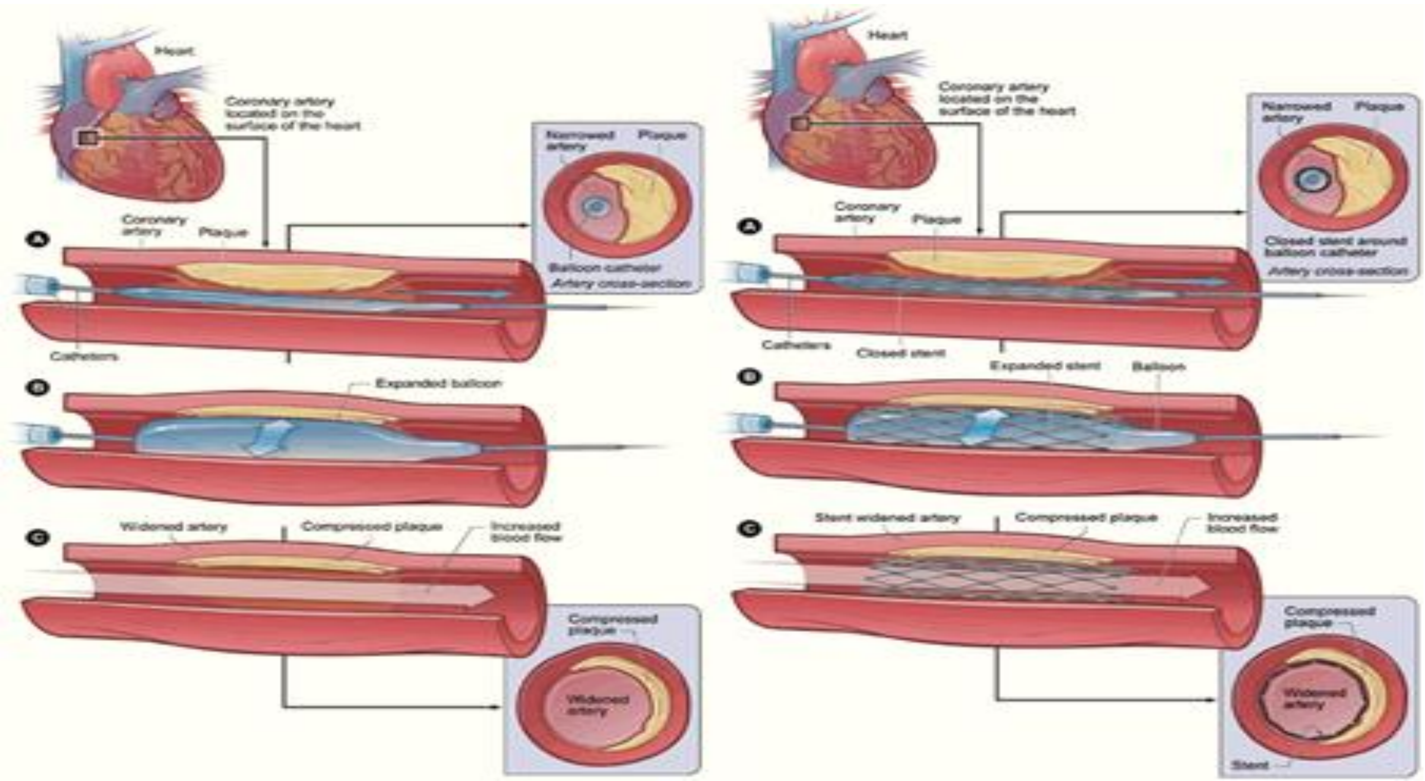


[redacted]

Recanalization of Right Coronary Artery with Chronic Total Occlusion

Drug Eluting Stents (DES)

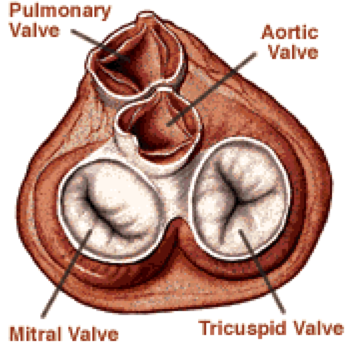
- Operating Process of Drug Eluting Stent

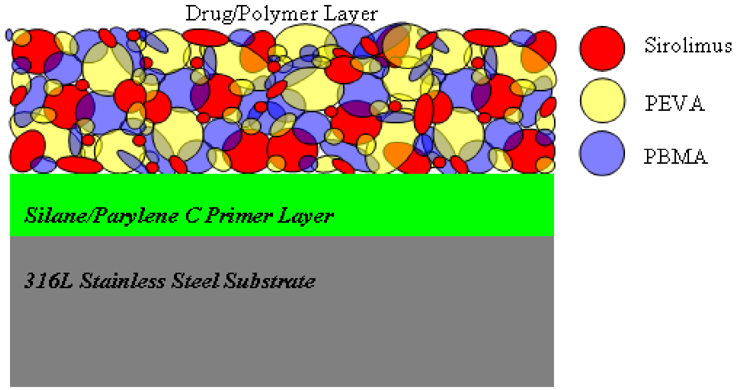


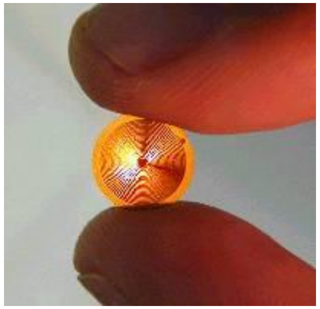
From Wikipedia

Summary of Approach to Cardiovascular Disease

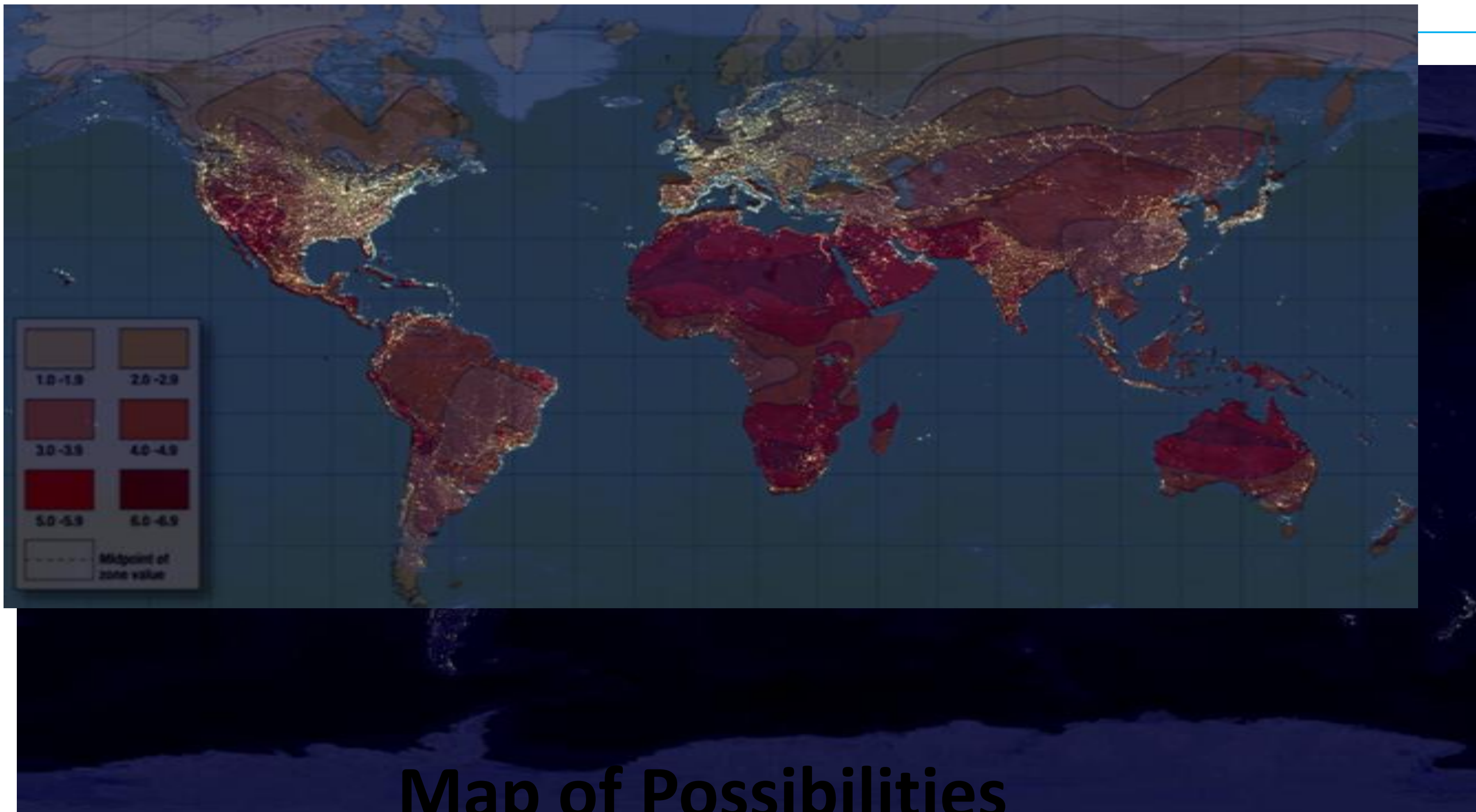
- Linking imaging and diagnostic tools with mobile phones and tele-medicine
- Stent designs and drug delivery concepts being explored
- Potential to integrate implantable sensors
- Could significantly affect global life expectancy







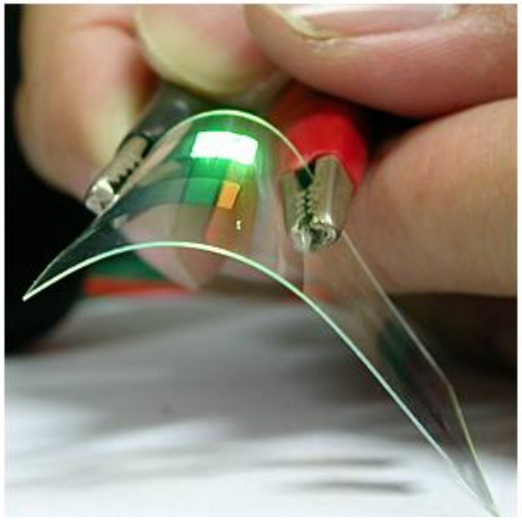
Motivating Solar Energy



Map of Possibilities

Map of the World at Night

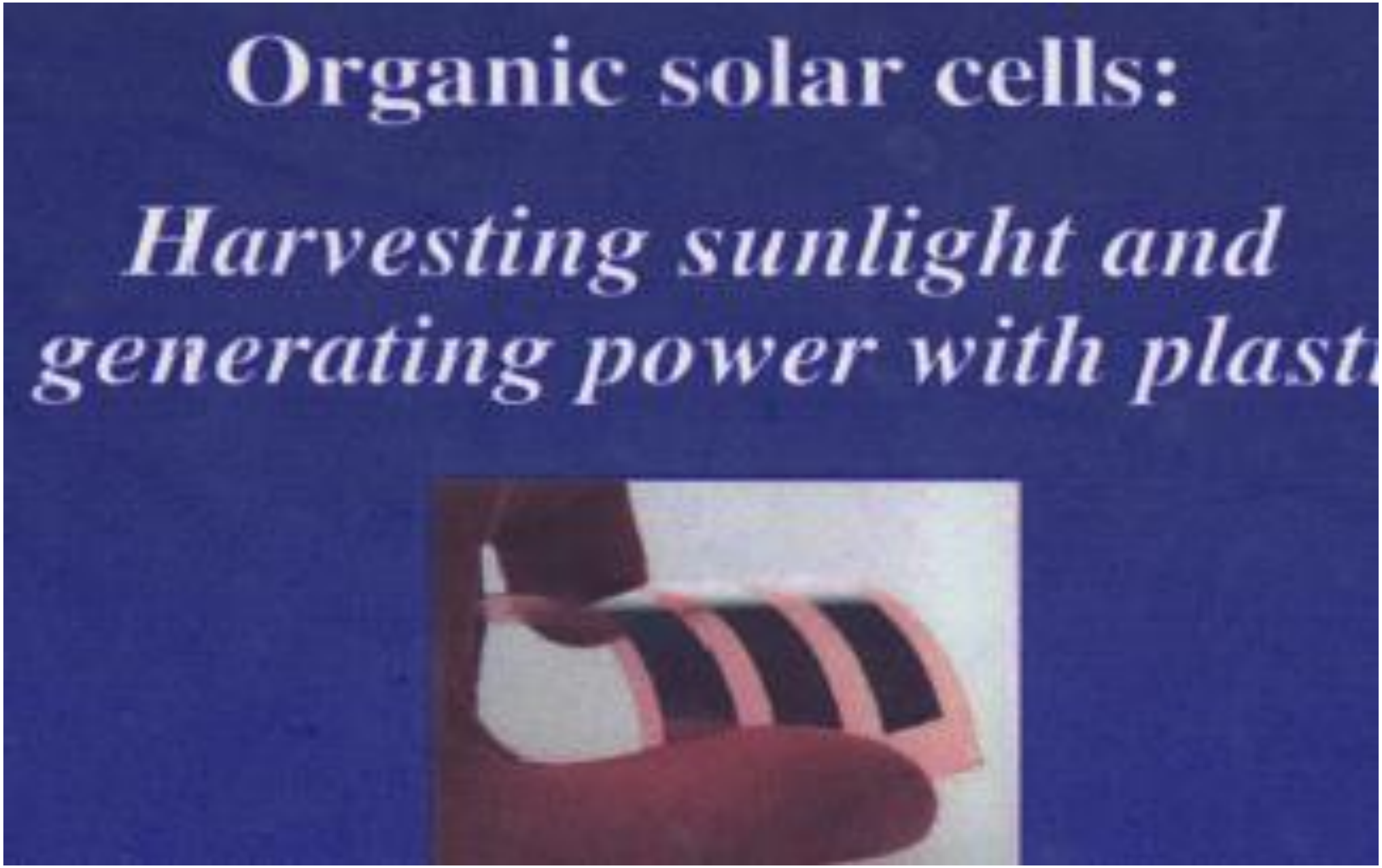
BACKGROUND AND INTRODUCTION



Satellite view of the world at night

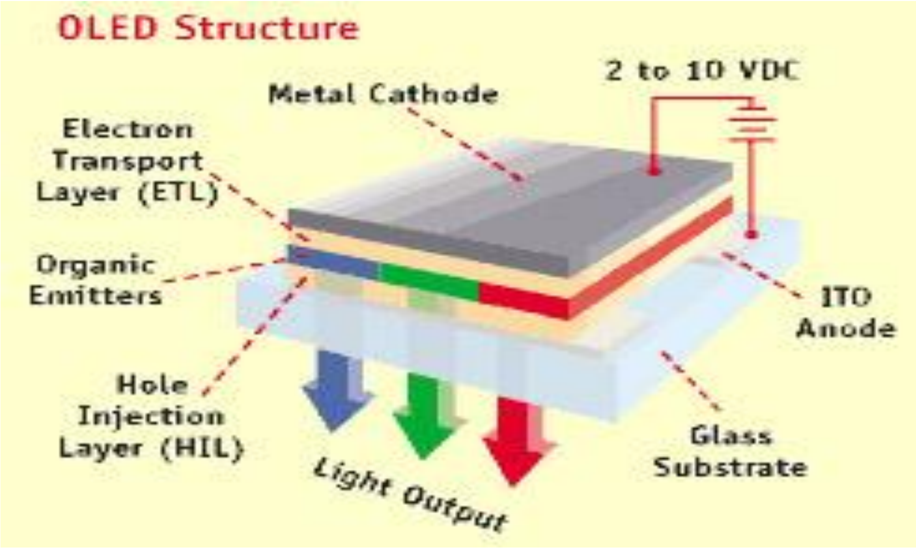
Source: C. Mayhew & R. Simmon (NASA/GSFC), NOAA/ NGDC, DMSP Digital Archive

Flexible Devices



Introduction to OLEDS

- OLED = Organic Light Emitting Device

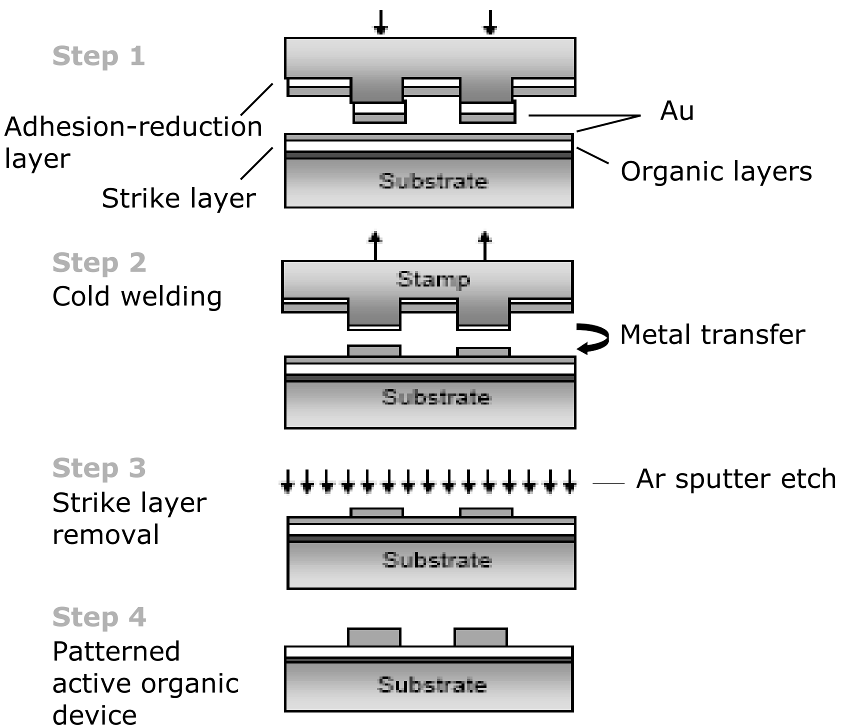


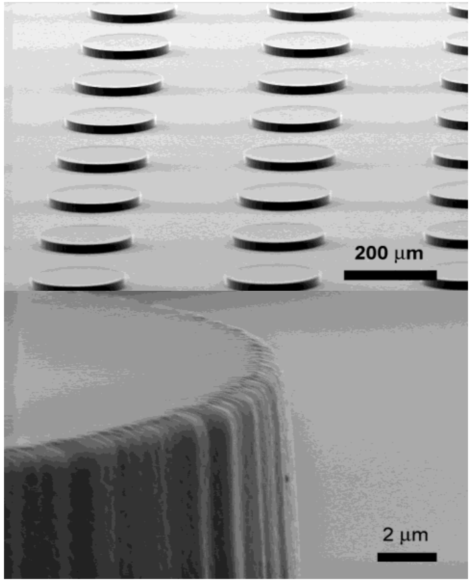
- The advantages of OLEDs:
  - Large viewing angle
  - Increased brightness and contrast
  - Low power consumption
  - …

http://www.kodak.com/

Cold Welding for OLED Fabrication

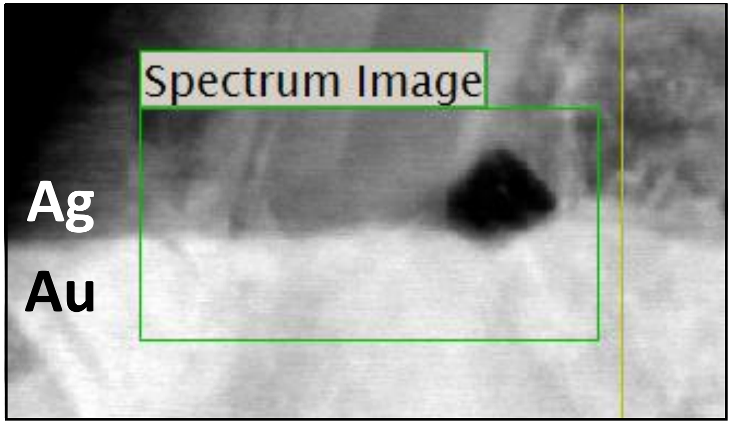
- Patterning of the OLED electrodes is difficult by photolithography since the organic material degrades in conventional solvents or high temperature
- Nano- and micro-patterning can be realized by inducing cold-welding between a metal coating on the stamp and the metal layer on the organic film

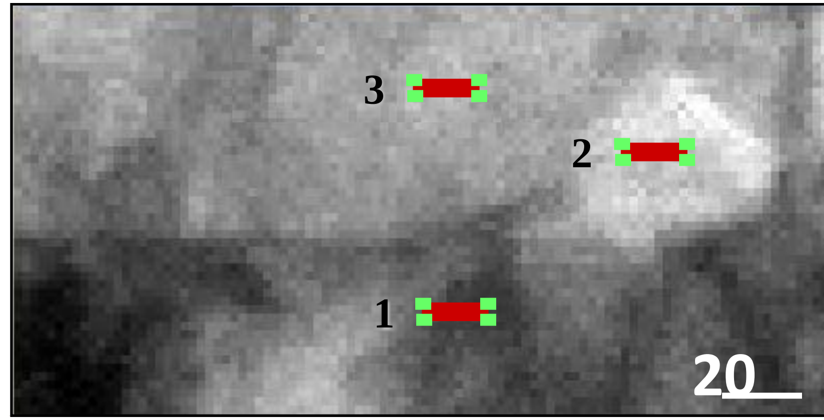


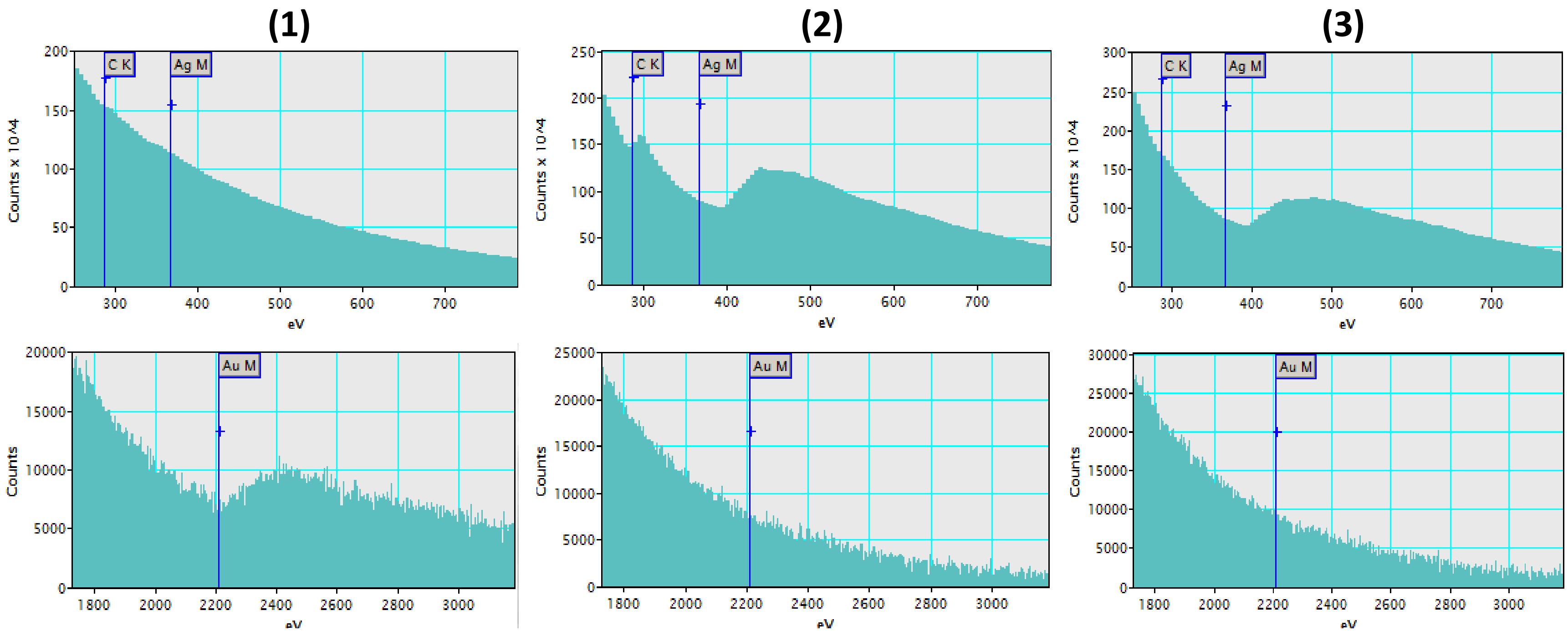


--- Kim, Forrest, *Adv. Mater*. (2003)

Electron Energy Loss Spectra of Au-Ag Interface

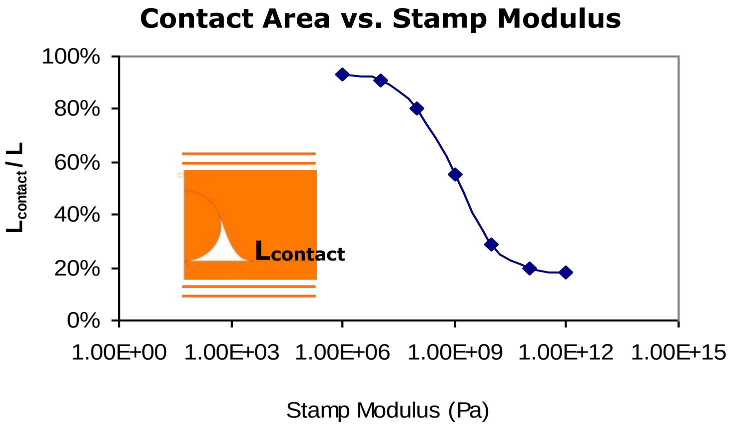


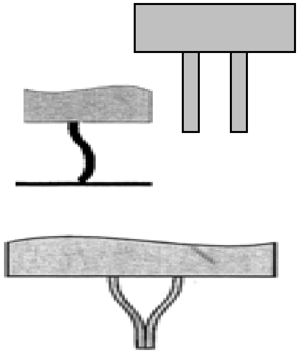




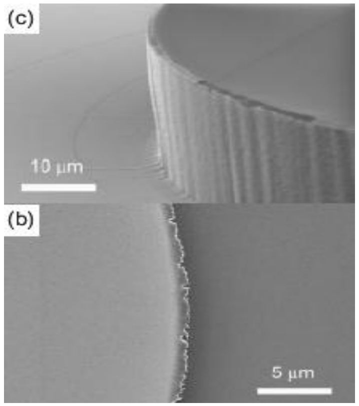
Comparison of EELS collected from various locations across the Au-Ag cold-welded interface. It shows there is a clear increase in both carbon and Ag peaks in position 2.

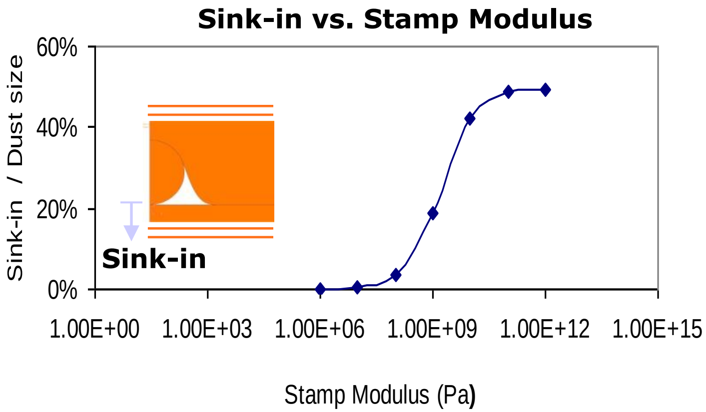
Stamp Modulus Design





---C. Hui, et al. (2002)

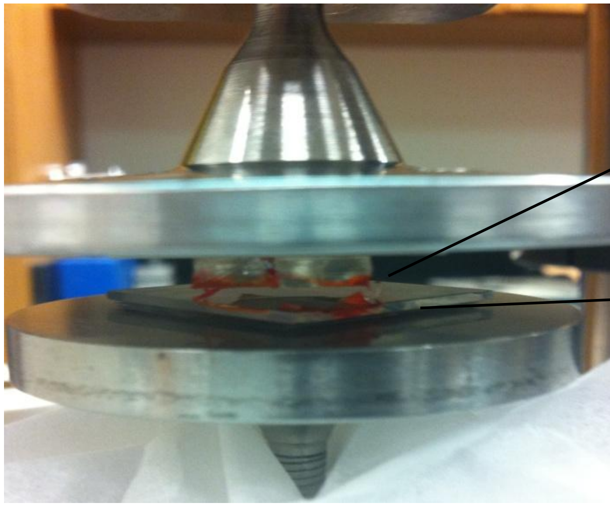




---400KN, 1µm dust

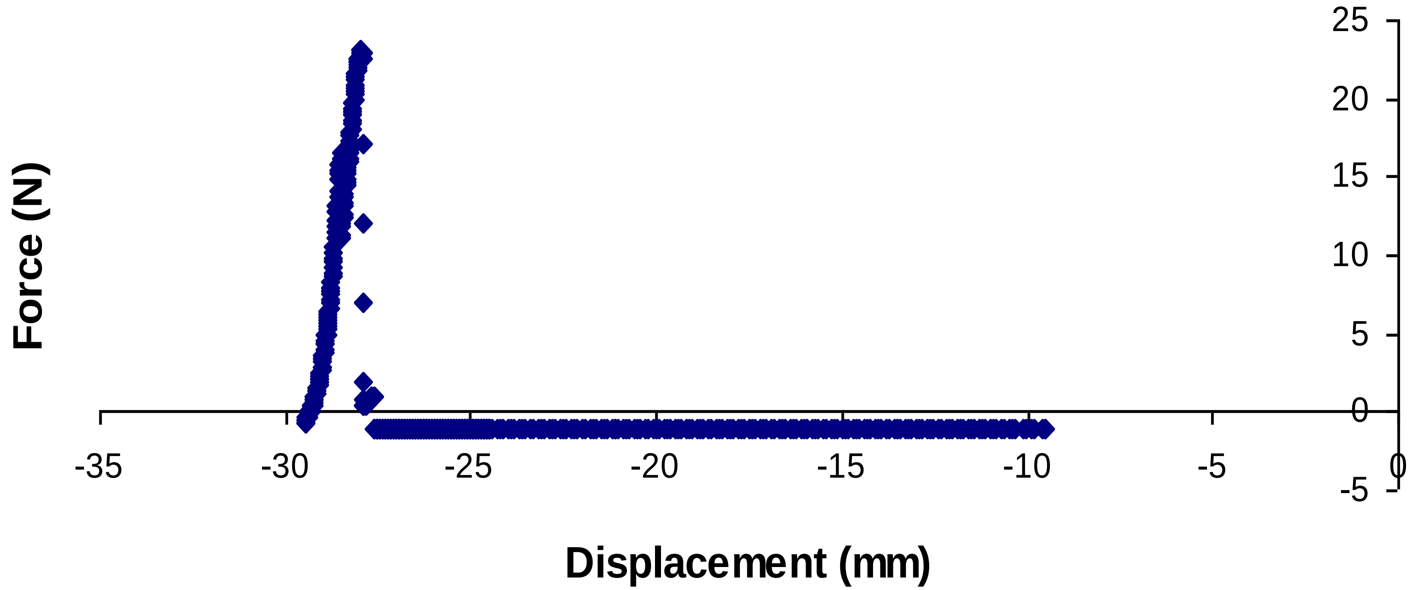
- Advantages of soft stamps: flexibility & low damage
- Disadvantages of soft stamps:
  - Dimensional instability problems
  - Stamp edge rounding
- Trade-off in design:
  - Low modulus vs. high modulus stamp

Adhesion test for pre-laminated sample

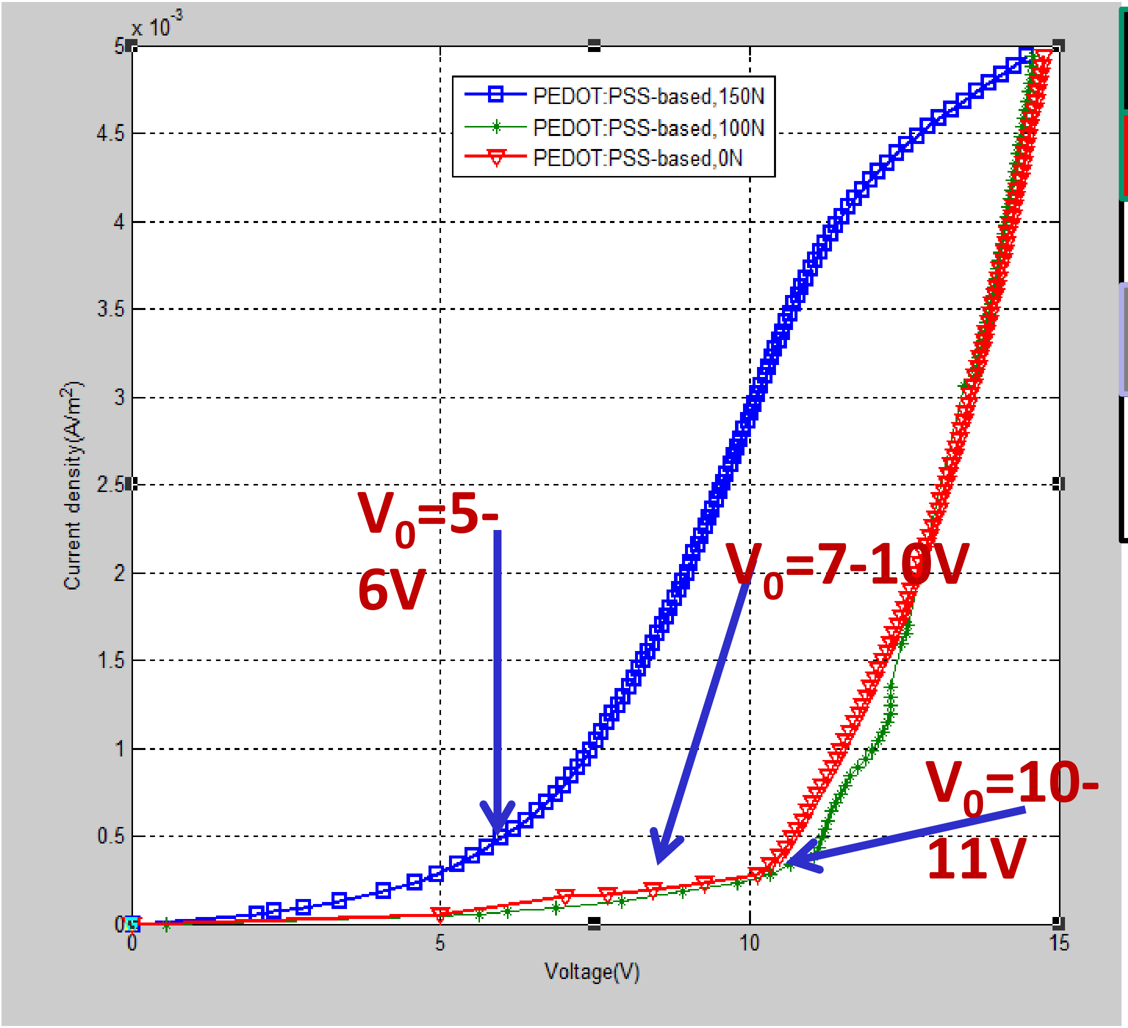


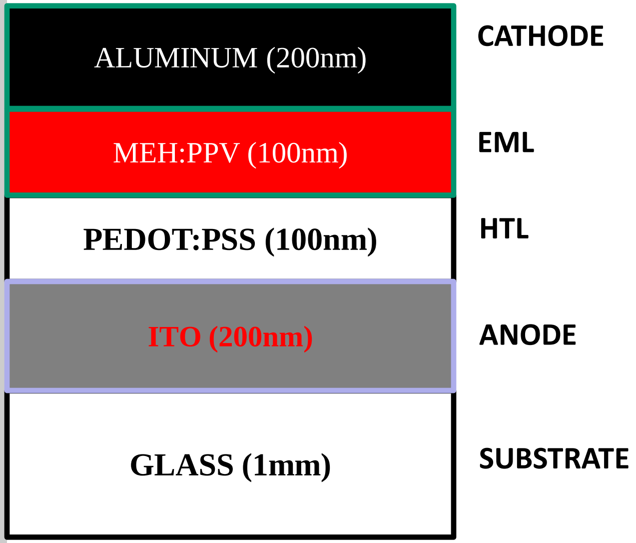
Double-sided tape on the upper mold

MEH-PPV pre-laminated onto PEDOT:PSS



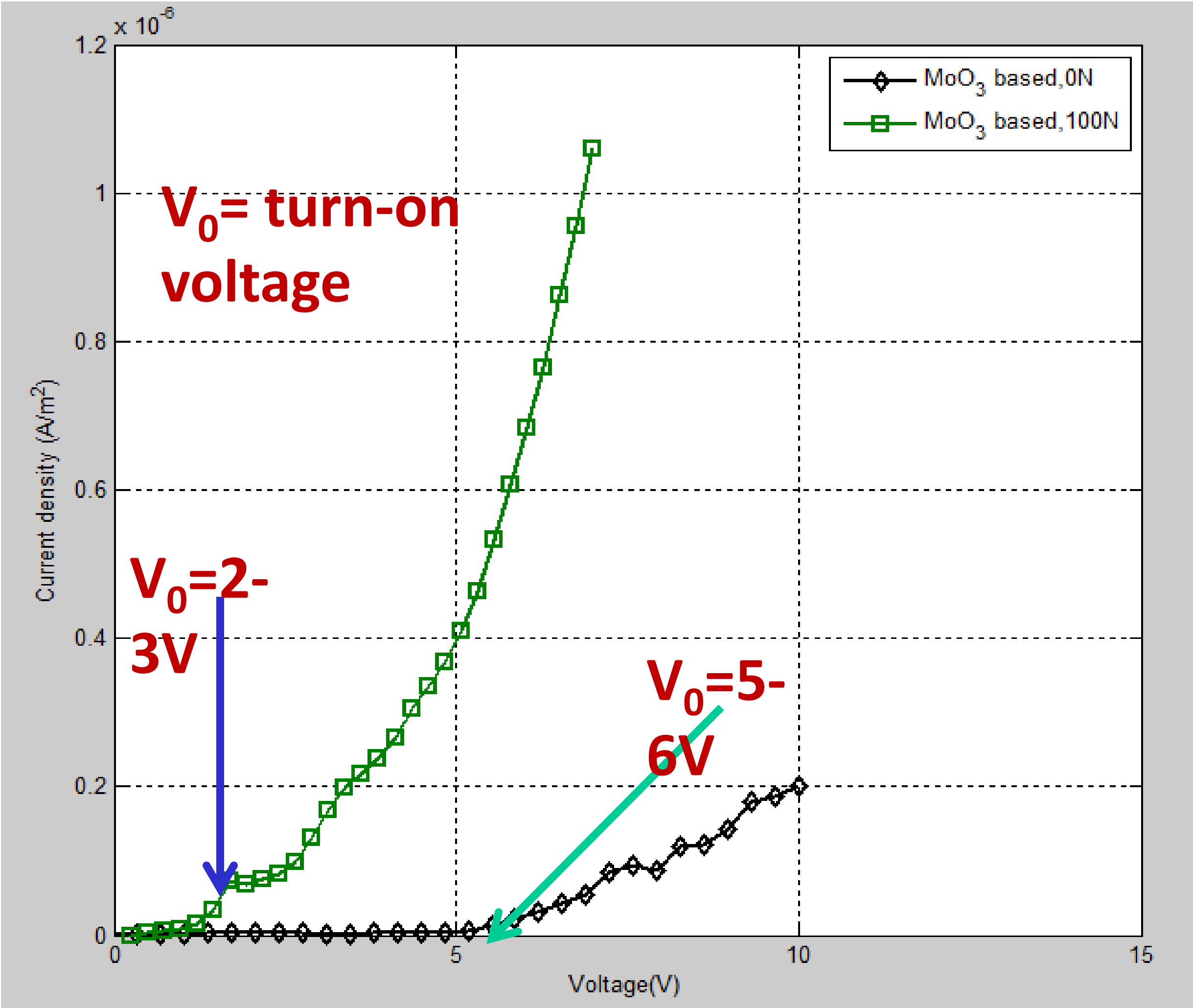
J-V CHARACTERISTICS

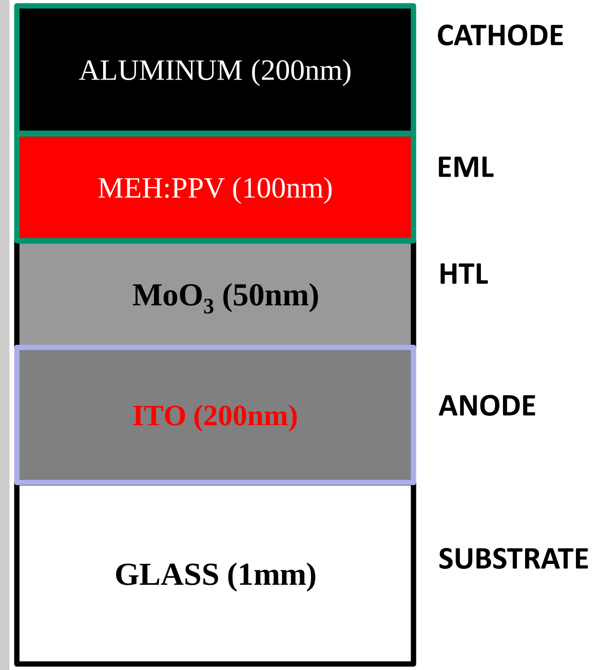


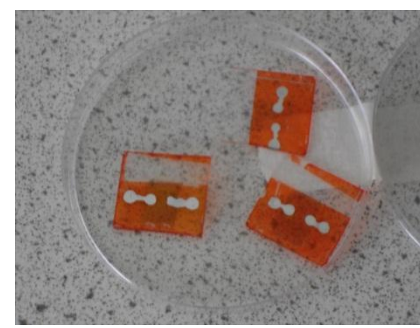


J-V plots for PEDOT:PSS -based device treated with 0N ,100N and 150N loads

J-V CHARACTERISTICS

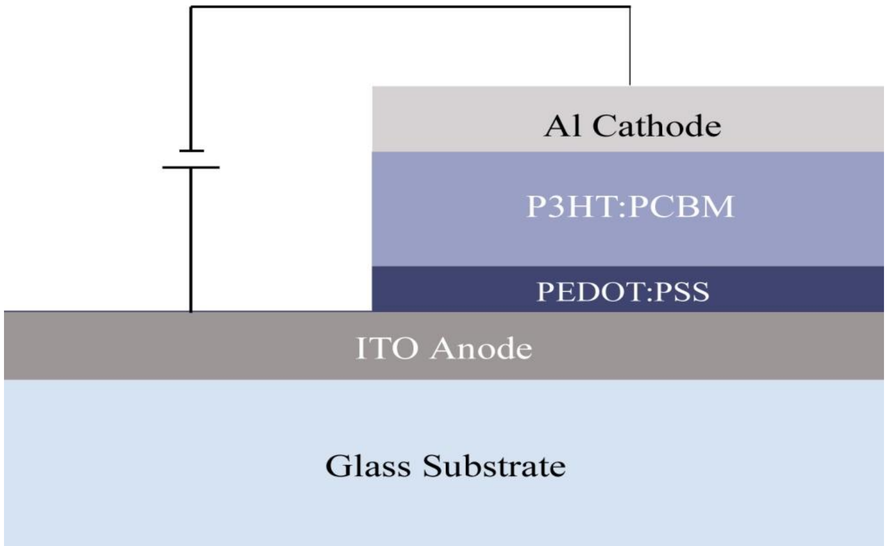


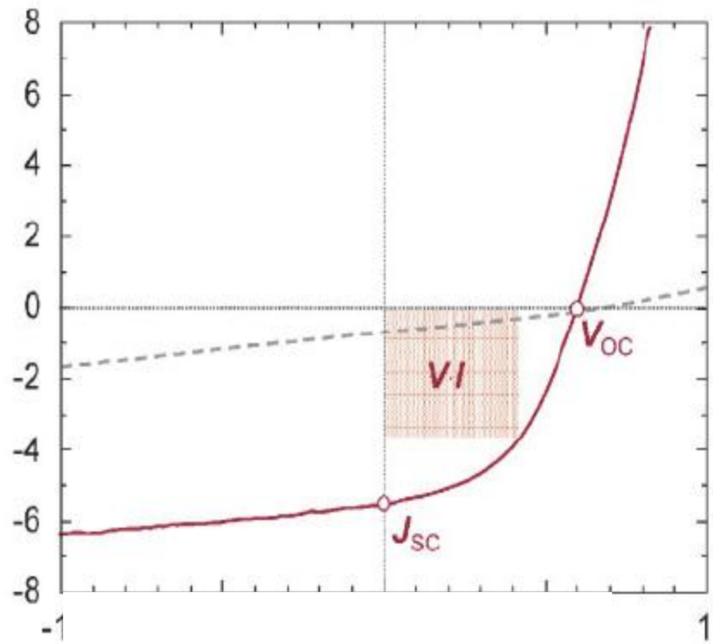


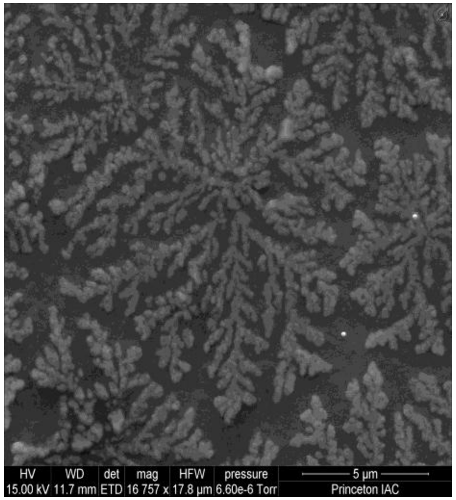


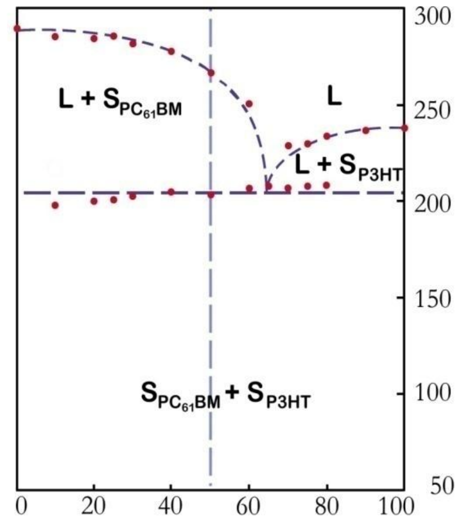
J-V plots for MoO_3 -based device treated with 0N and 100N loads compared

Low Cost Organic and Perovskite Solar Cells







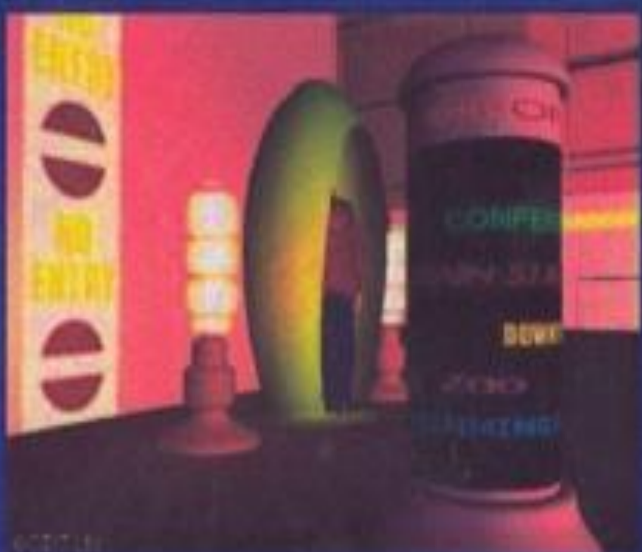


Integrated Systems and E-Textiles

…

- Consumer applications (smartcards) will pave the way for large area PV systems (industrial coating technologies)

- Full plastic integrated systems containing solar cells, transistors and LEDs

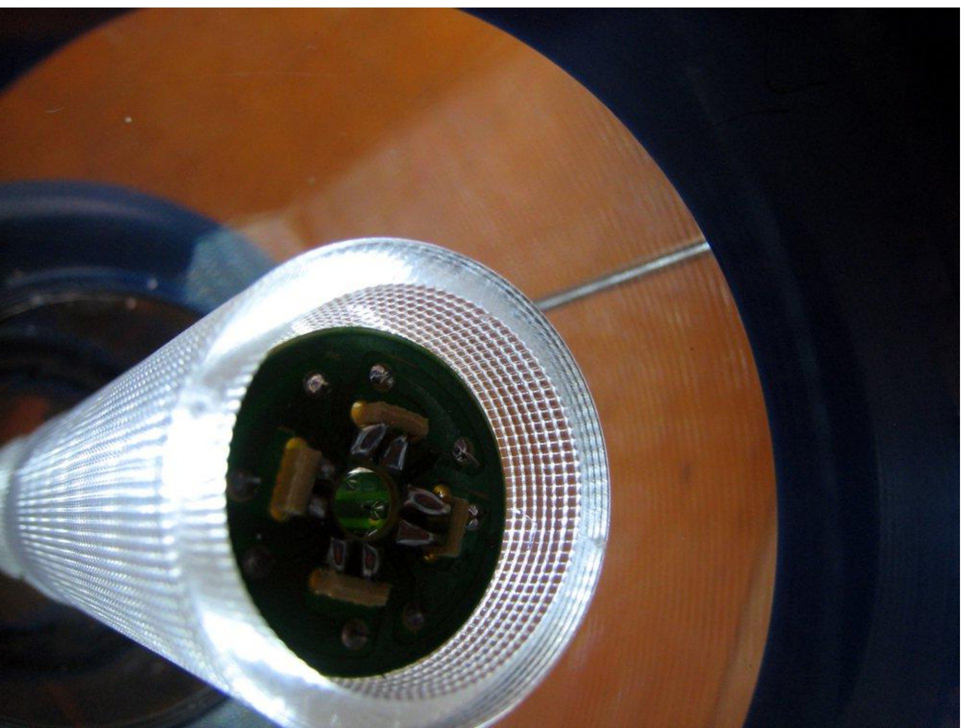


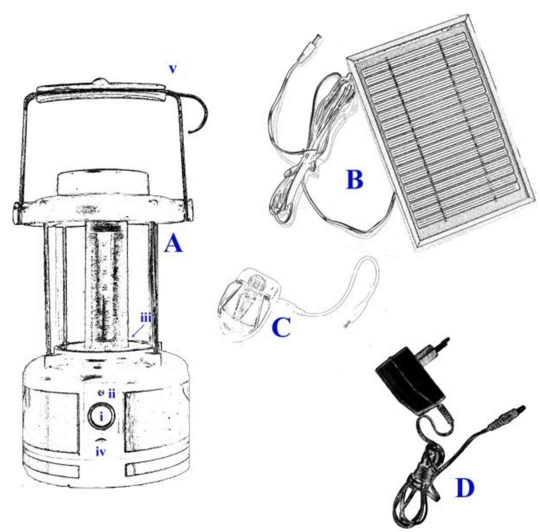
Mpala Research Center

- 49,107 acres of savannah and dry woodland, 1 hour from Nanyuki, on the Laikipia Plateau in North Central Kenya
- MRC staff members and immediate families housed in various community villages
  - Homes were generally a single 20-ft diameter room. People used old bed-sheets to partition the space to create a living room and 1-2 bedrooms. Household sizes ranged from 1-8 persons.
- Because it is in a remote area, access to basic necessities is a challenge.
  - Clean drinking water is available to staff and researchers through boreholes and purified rainwater collection.
  - Electricity, however, is only provided to the research community, through a combination of solar panels and generators

Solar Lanterns:

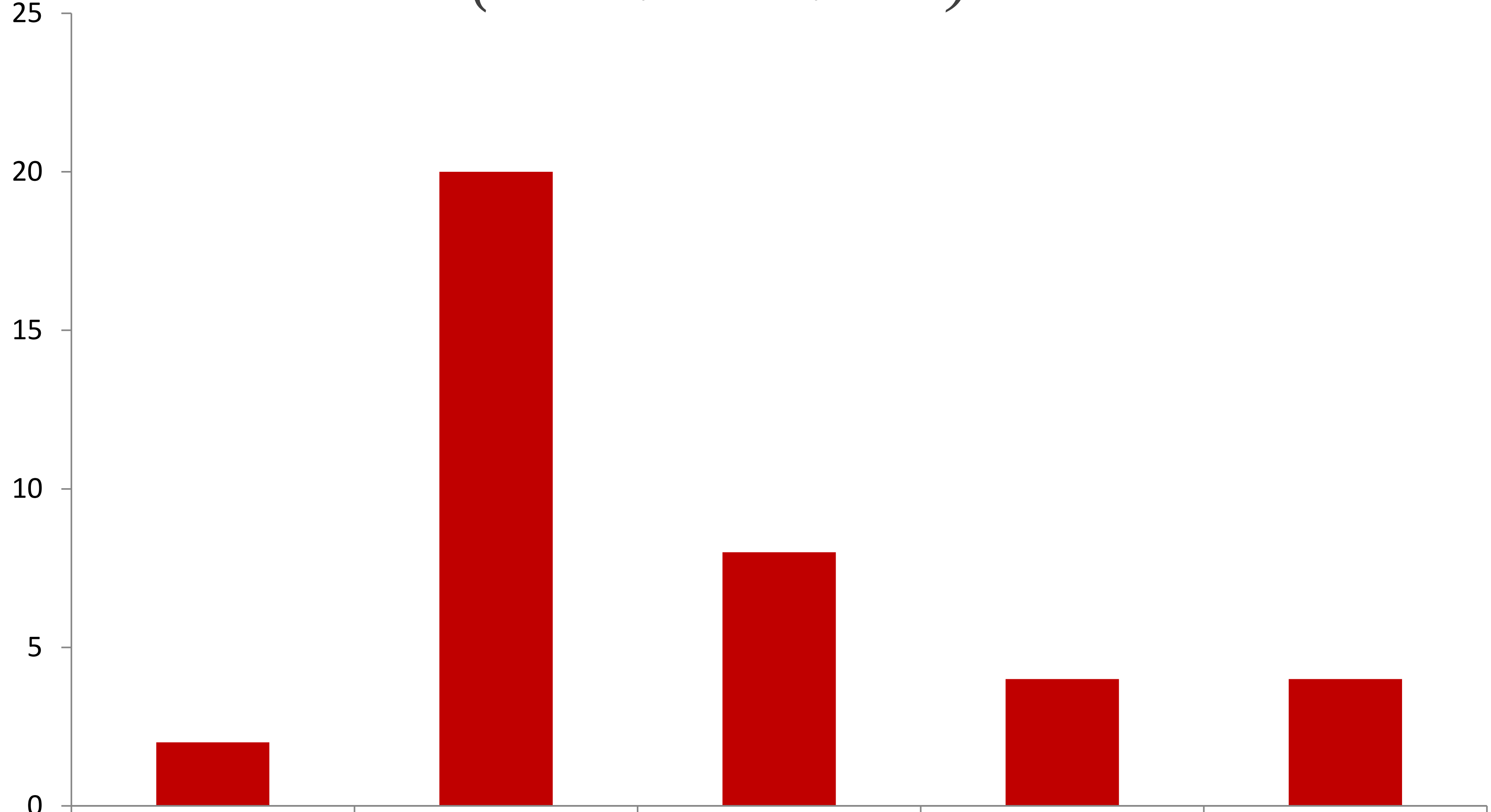
- 28-pc LED light
- 6V Battery
- 9V Solar Panel
- 6V AC Charger
- Universal charger for mobile phone batteries





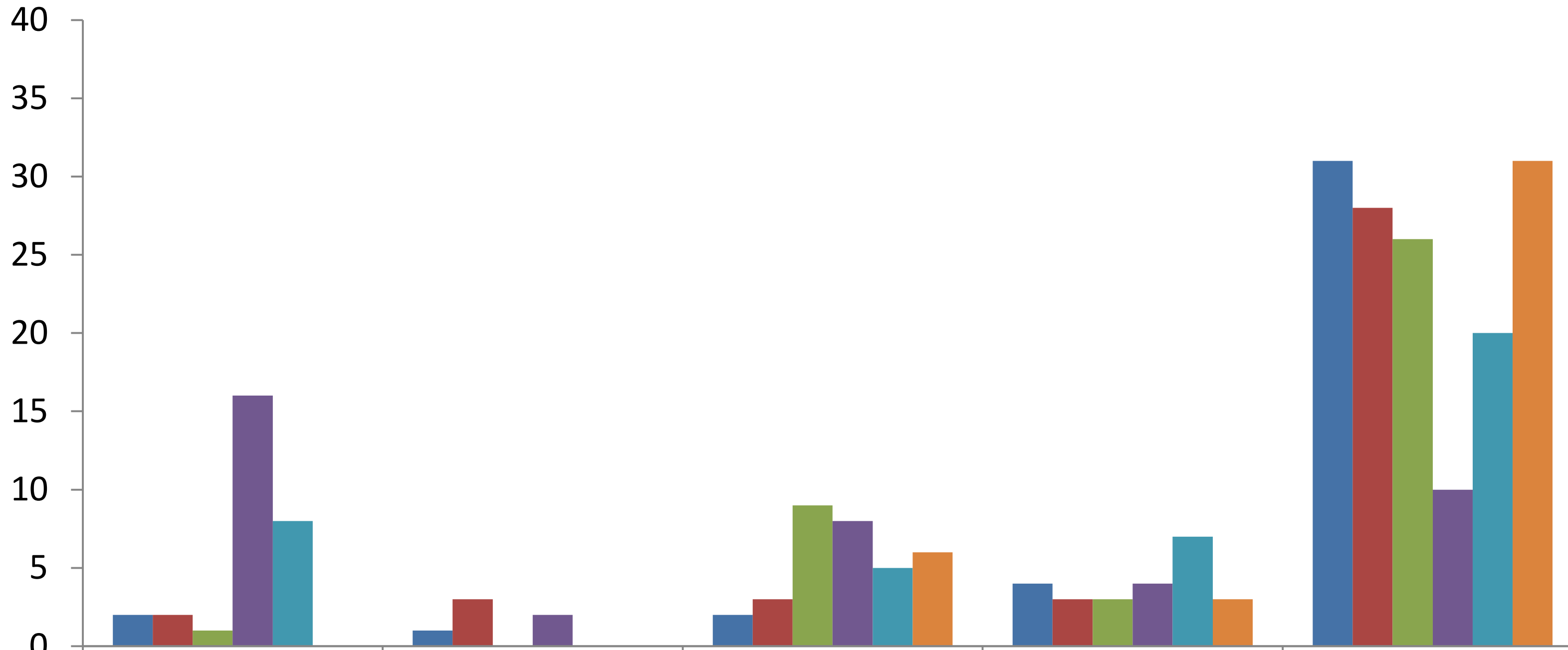
Monthly Income Levels (USD)

(75-80:1 kshs:USD)



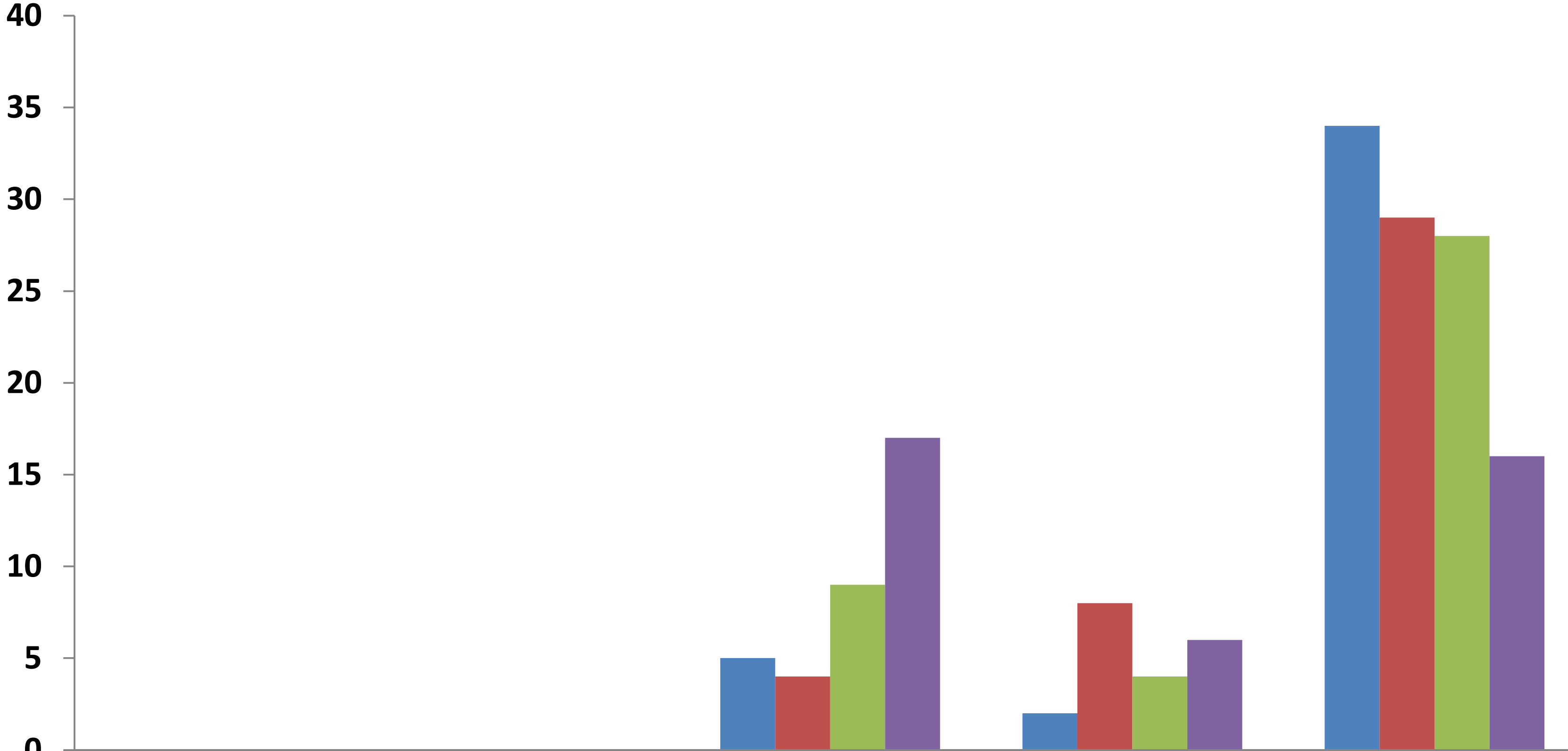
	0-62.50	62.51-125	126-187.50	187.51-225	>225
Income	2	20	8	4	4

Component Satisfaction



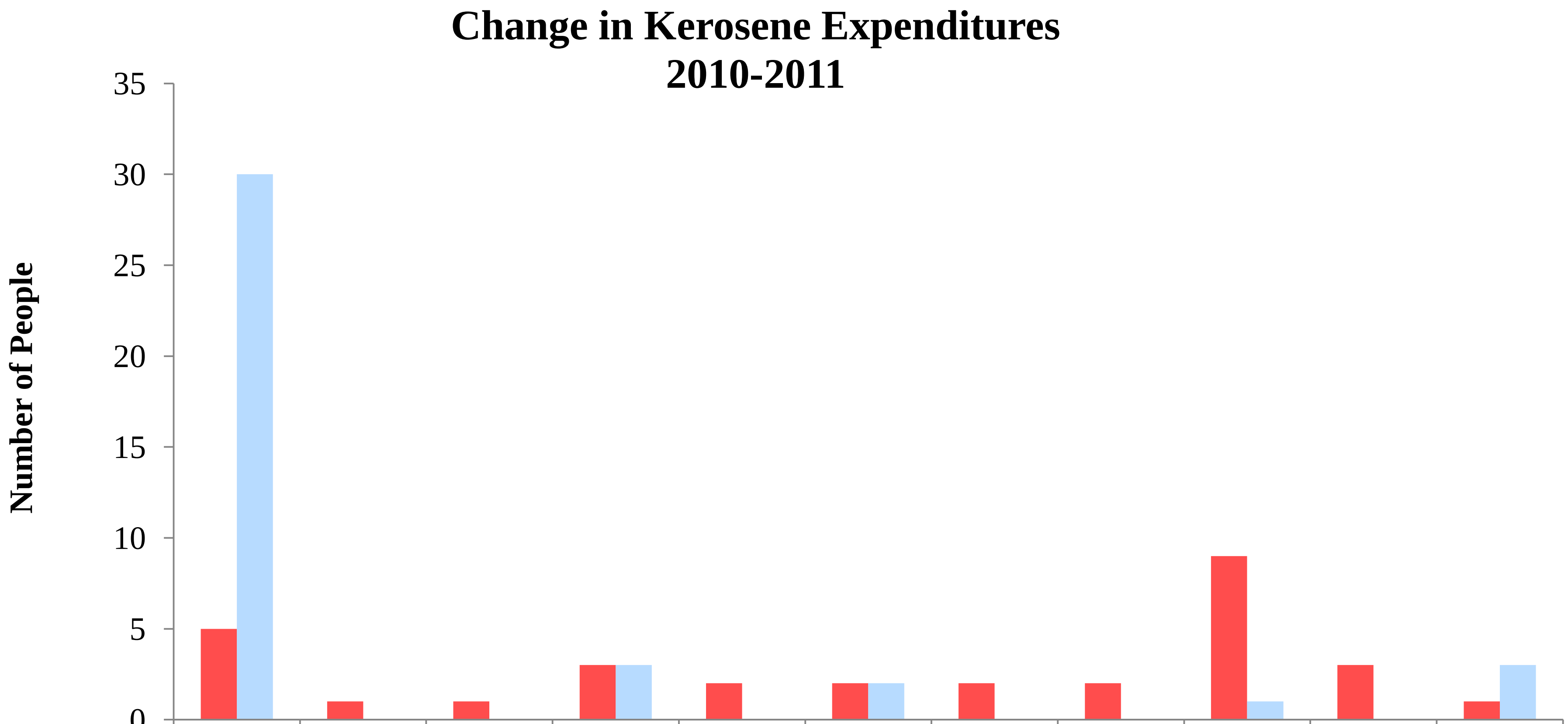
	I Hated It or Never Used It	I Somewhat Disliked It	I Thought It Was Average	I Somewhat Liked It	I Loved It
Light	2	1	2	4	31
Solar Panel	2	3	3	3	28
Battery	1	0	9	3	26
DC Charger	16	2	8	4	10
Cell Phone Charger	8	0	5	7	20
Overall	0	0	6	3	31

Lantern Impact



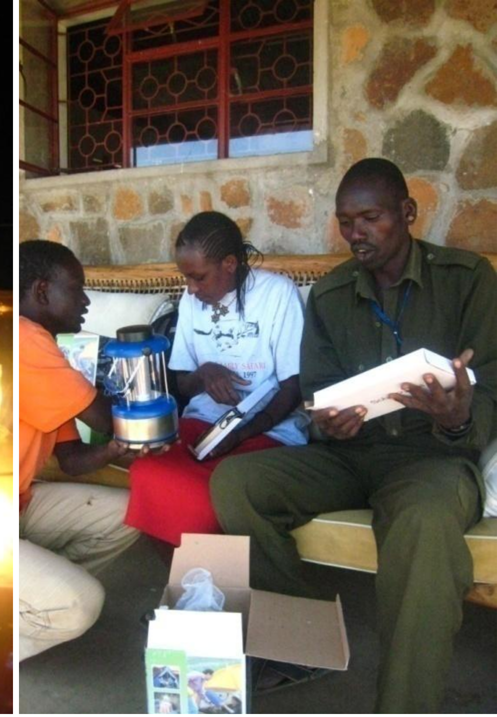
	Much Worse	A Little Worse	About the Same	A Little Better	Much Better
Health	0	0	5	2	34
Income	0	0	4	8	29
Education	0	0	9	4	28
Social Status	0	0	17	6	16

Impact on Kerosene Usage



	0	0-6.25	6.26-12.50	12.51-18.75	18.76-25	25.01-31.25	31.26-37.50	37.51-43.75	43.76-50	50.01-56.25	56.26-62.50
2010	5	1	1	3	2	2	2	2	9	3	1
2011	30	0	0	3	0	2	0	0	1	0	3

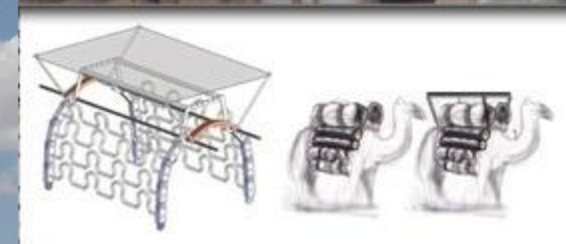

RT064



Community-Based Solar Power Implementation

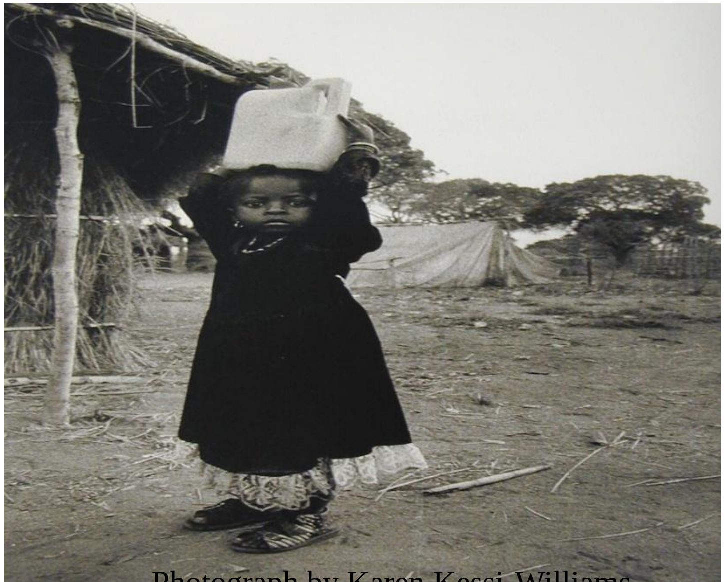
- One 85W panel in each:
  - Ranchhouse village
  - Research Center village

Solar-Powered Vaccine Delivery System for Medical Clinics in Rural Communities



Background and Introduction

- The problem of contaminated water is the single biggest cause of the steep decline in life expectancy in Africa and other developing regions
  - Impact bigger than that of HIV
  - Example of Nigeria
  - 5000 lives lost per day
- However, this is also a need to ensure that the water is pure at the point-of-use
- Rural solutions should also use locally available materials
- Need sustainable solutions such as those represented by the Filtron clay filter that integrate technology and entrepreneurship

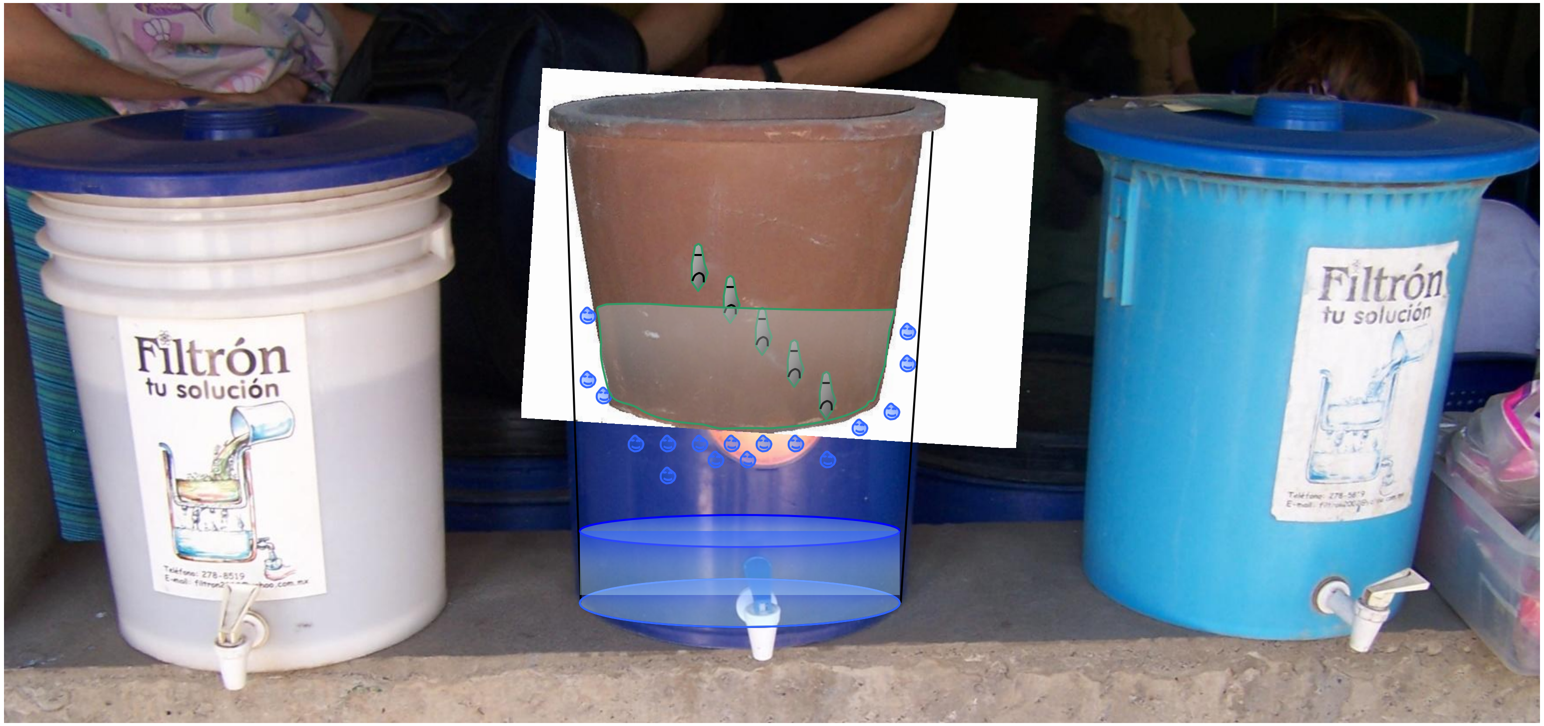


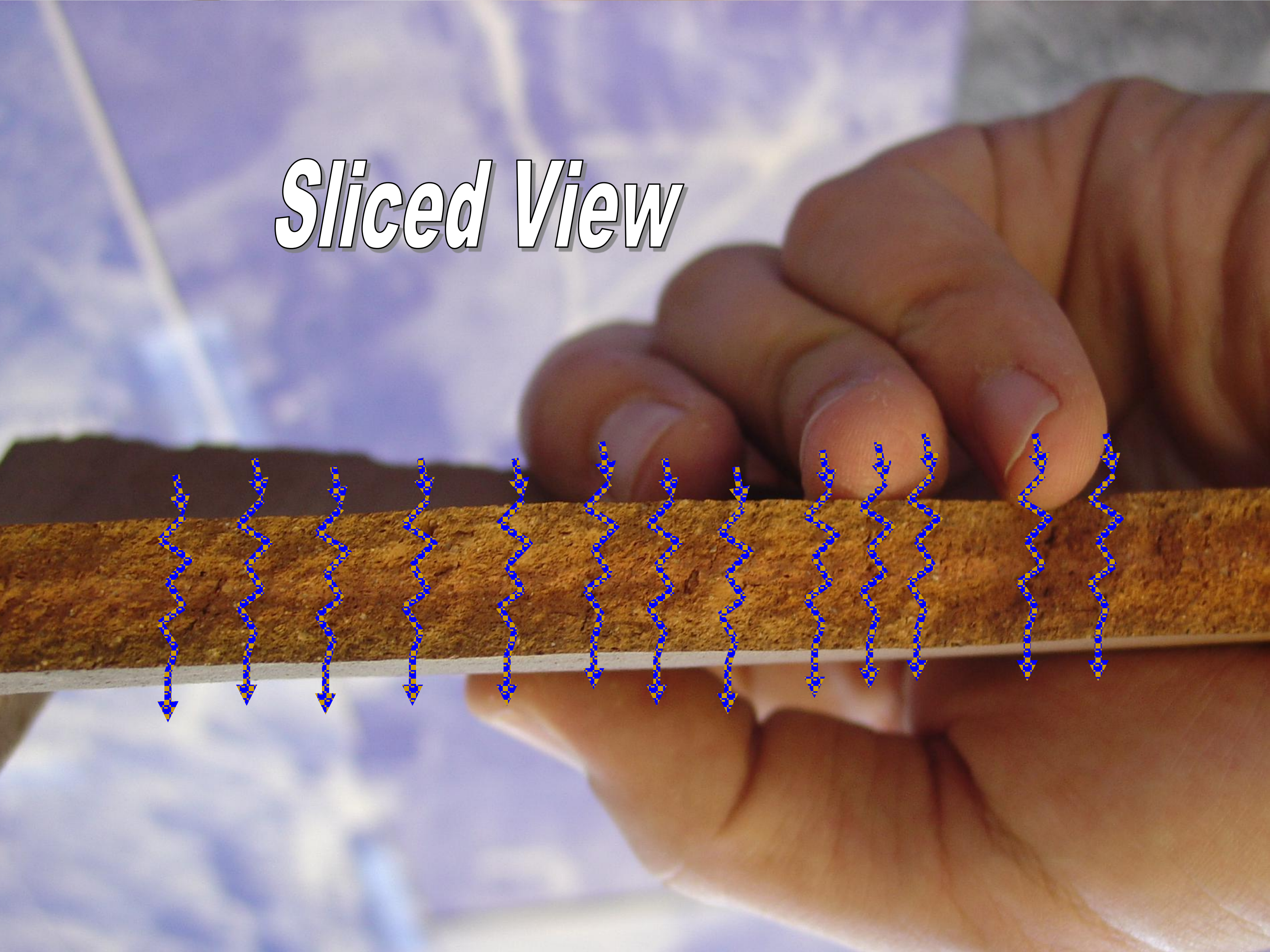
Photograph by Karen Kessi-Williams

Water Treatment Methods

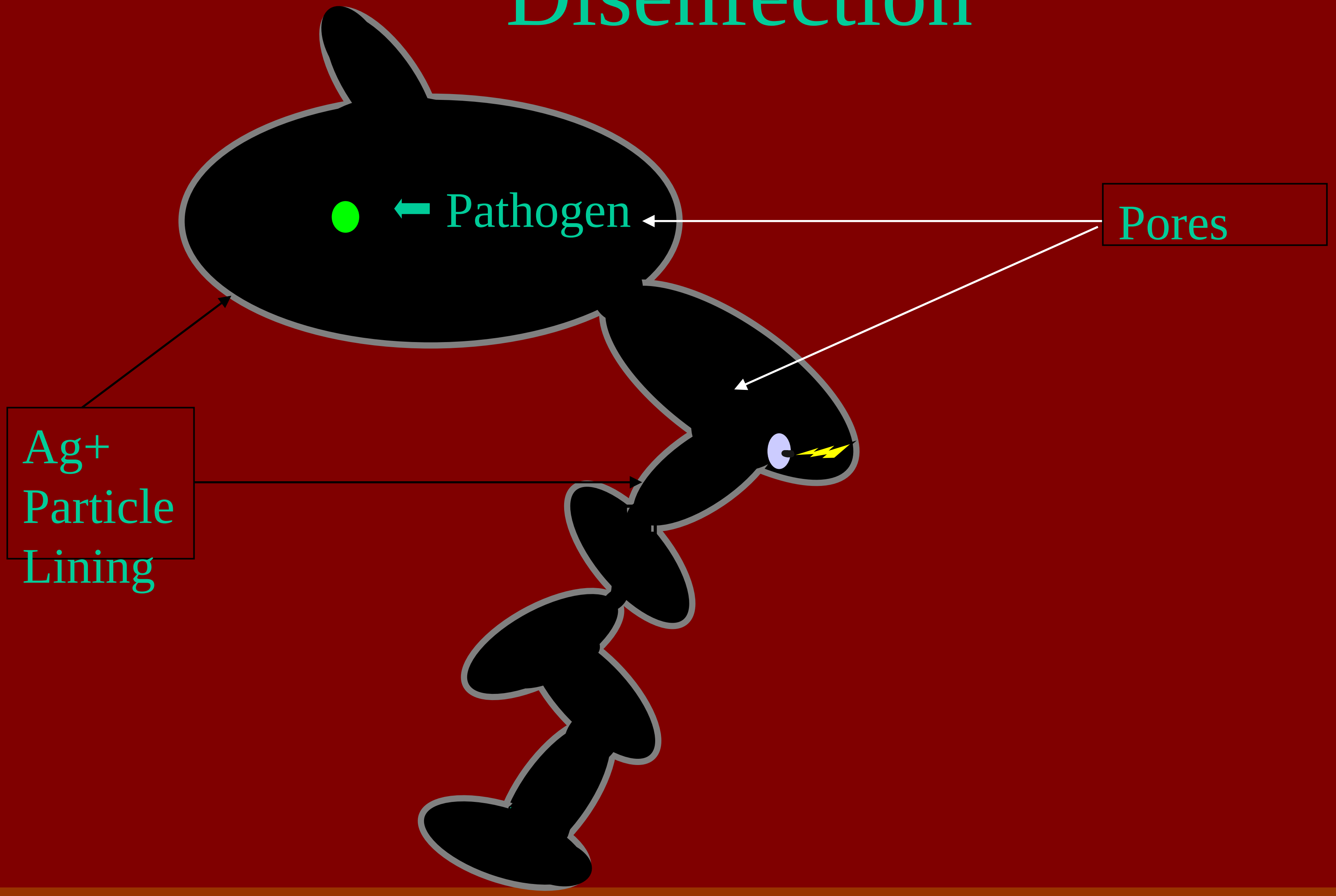
Solutions	Pros	Cons
Boiling Water	- 100% potable if boiled for at least 20 min. - Can be done in the home all year round.	- Requires time to gather fuel (fire wood) - Requires time for heating and cooling - Causes a Change in the taste of water - Method does not remove turbidity
Adding Chlorine	-Effectively kills bacteria -Simple to use -Can be used anytime -Low cost technology	-Effects the taste of water -Must be applied periodically -Does not remove turbidity -Most be purchased and transported
SODIS	-Low cost -Can be large or small -Remove turbidity -Can be us	-Does not work in shade, night or rainy season -Requires 4-6 hours to reach required to heat -Requires Time for water to cool -Change in the taste of the Water. -Does not remove turbidity
Bio Sand Filter	- Can be large or small -Easy to use -Local materials	-Appropriate sand must be available. -Does not remove microbio. contaminants -Time to cultivate bio-sand.
Filtròn Water Filter	- Kills bacteria 99% - Easy to use -One time transportation -No change of taste -Culturally acceptable - Self-encased water Container permits serving. - Made locally -Works all year around 24 hours a day. -Low cost	- Cost, US$ 7.50 to $25.00 (depending on country) - Heavy compared to the other systems. - Fragile, easy to break - Periodic cleaning is required (turbid water clogs the filtering element). - Combustion for the production process - Should be replaced after two years
PuR (P&G)	-Effective -Good for emergencies	-expensive (US $ 4.20 a month) US $0.14 cents a day for 20 liters

Point-of-Use Water Filtration Systems

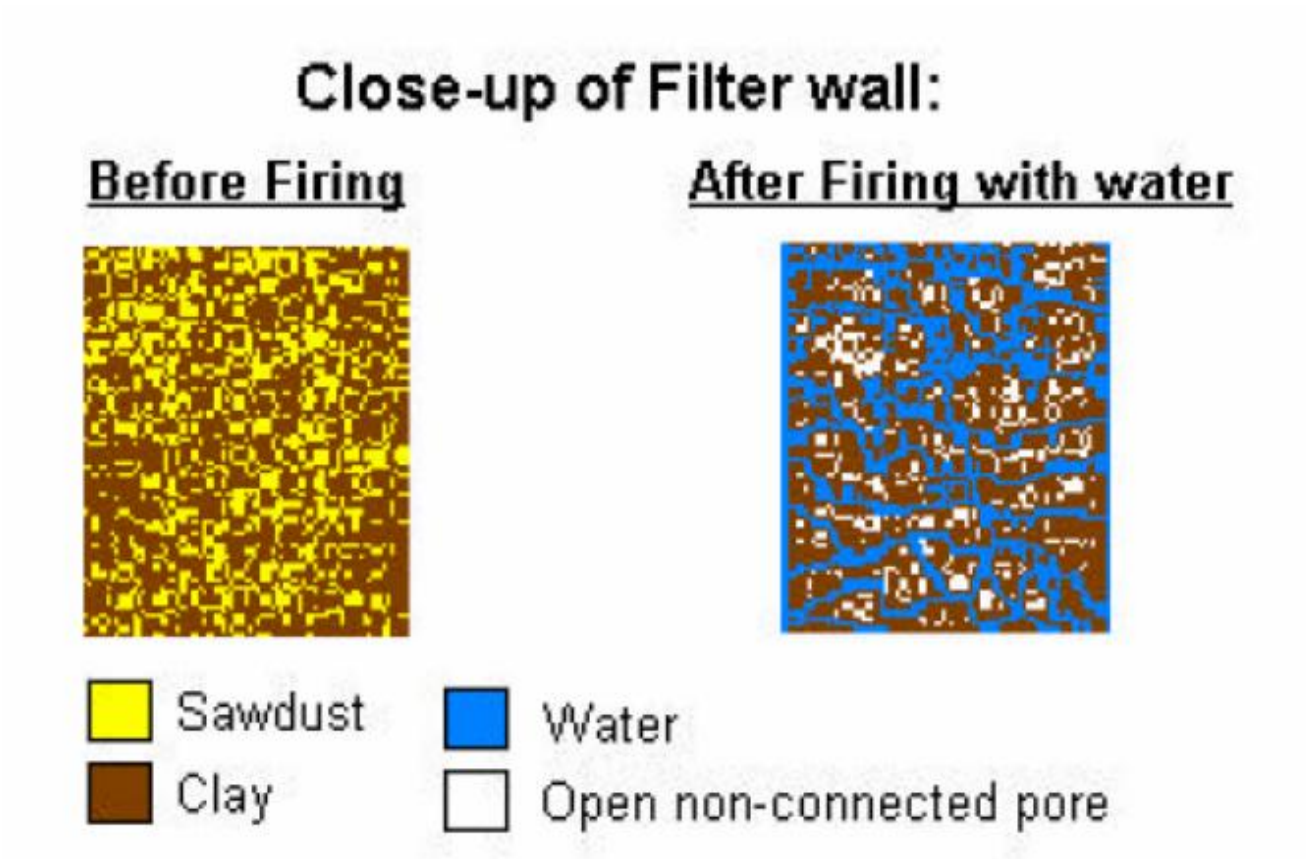



Sliced View

Schematic of Filtration and Disenfection



Inter-Connected Porosity & Water Filtration



Size Comparison

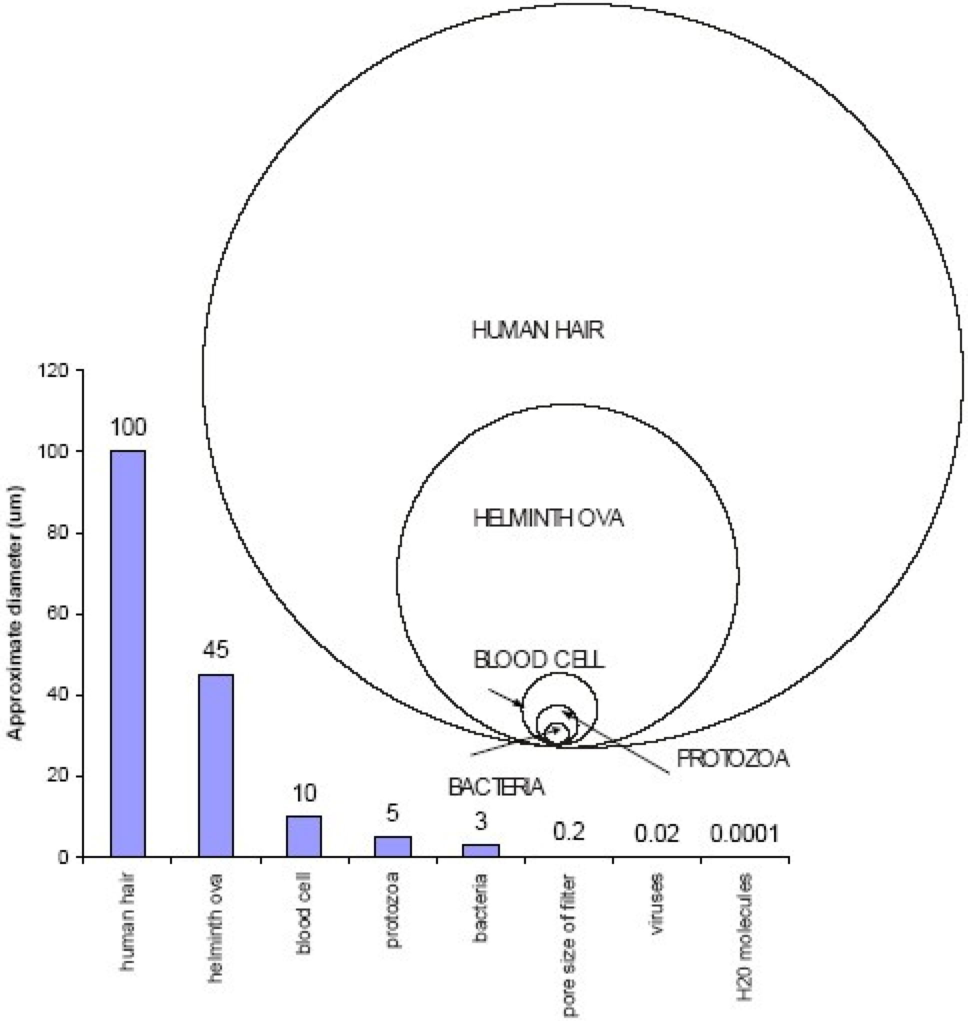


Figure 2. Comparison of relative sizes of various contaminants in water. Based on these, the pore size of the ceramic filter, at 0.2μm, would be about the size of a full stop on this page.

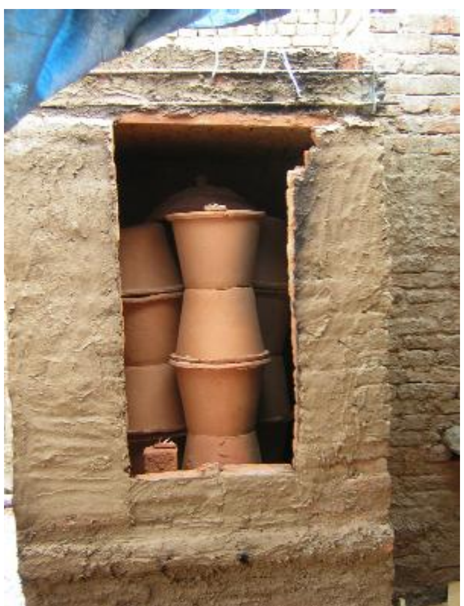
E. coli Filtration Tests of Non-Coated Ceramic Water Filters

Volume Fraction Clay:Sawdust	Test 1	Test 2	Average $\pm$ Range
45:55	99.97	99.85	99.91 $\pm$ 0.06
50:50	99.99	99.93	99.96 $\pm$ 0.03
55:45	99.52	99.84	99.68 $\pm$ 0.16
65:35	99.99	99.99	99.99 $\pm$ 0.00

Filter Processing - From Ideas to Markets







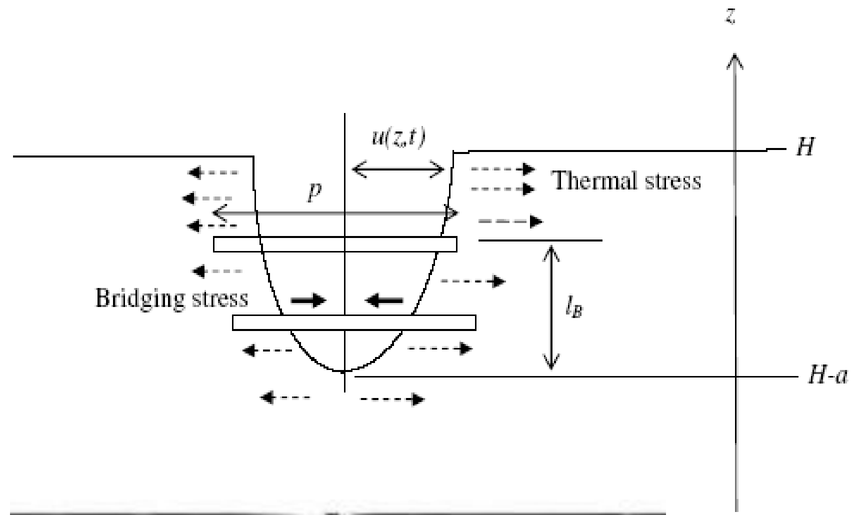
Modeling of Crack Bridging and Materials Design

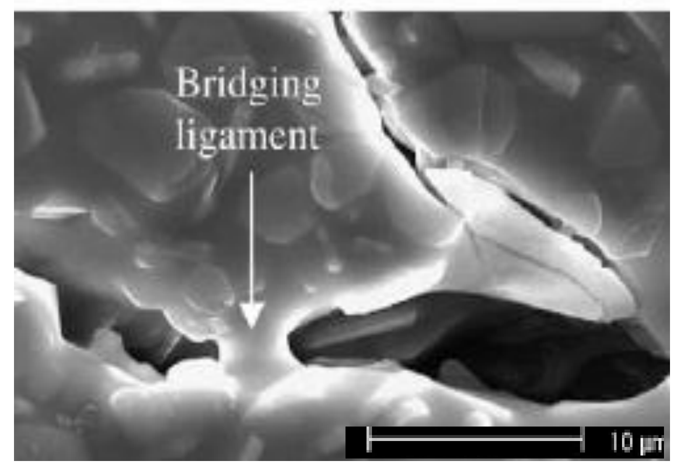
- Fracture mechanics concepts can be used to quantify crack bridging

$$K_{tip} = K_{app} - K_b$$

K_{tip} is the effective crack-tip stress intensity factor,
K_{app} is the applied stress intensity factor,
K_b is the stress intensity factor due to bridging

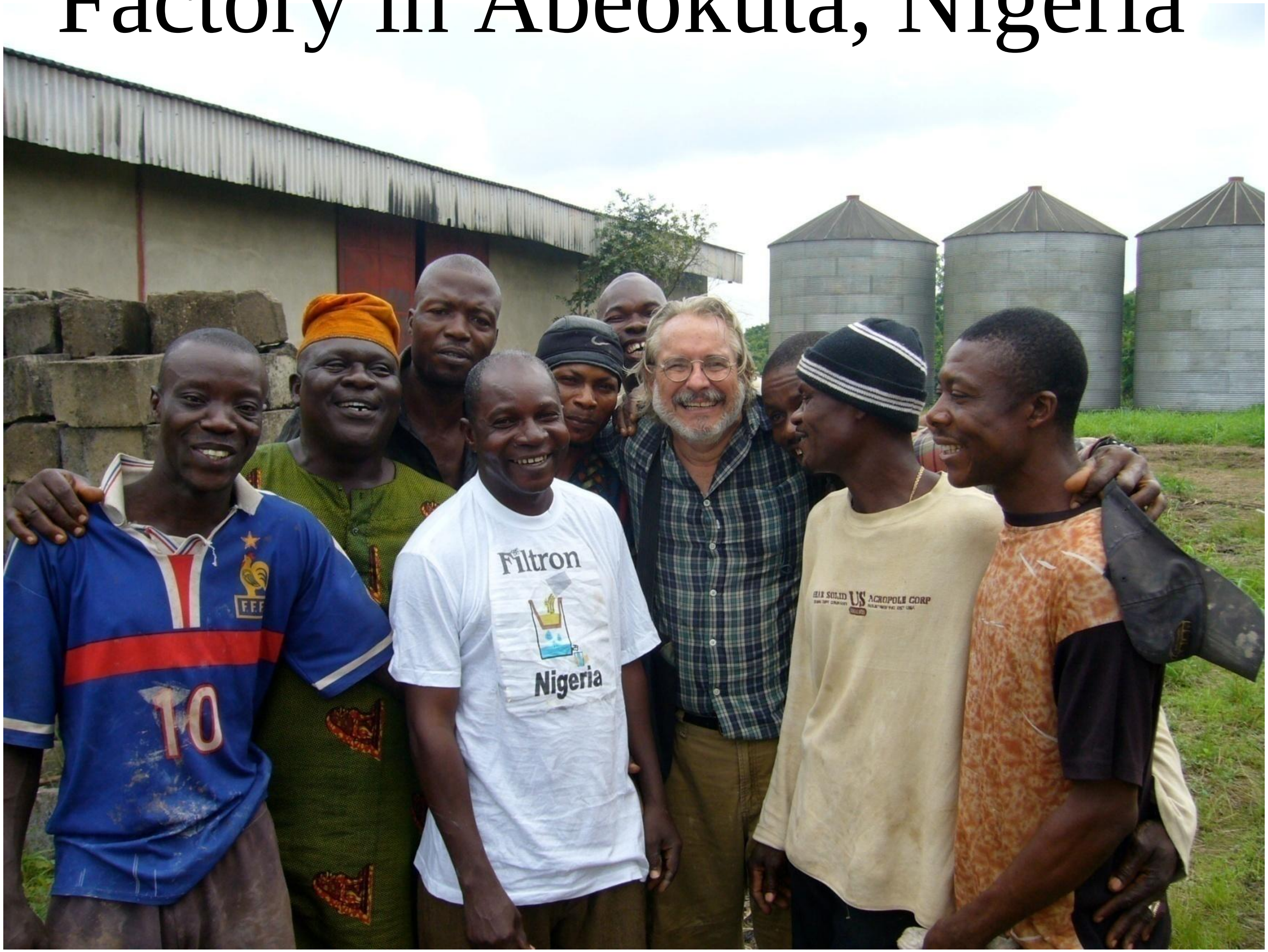
Porosity (%)	Predicted Toughness (MPam$^{1/2}$)	Fracture Toughness (MPam$^{1/2}$)
47.0	0.38	0.35
39.8	0.45	0.40
36.4	0.55	0.60





Schematic and Actual Bridging Ligaments

Factory in Abeokuta, Nigeria



Workers at New Factory

Public Health Impact: Eweje Village

Scale-up of Water Filtration System

Emerging Impact of Study of the Effects of Filter Use

- The study suggests that water-borne diseases can be eliminated from rural communities
- So far the filters have improved most measures of health and wellbeing of people in Eweje and rural/urban communities across Nigeria (Abuja, Lagos, Keffi, Bauchi, Jos)
- Filters have also been introduced to Burkina Faso (Ouagadougou factory) and Kenya (Mpala Village)
- Social franchise model (Potters for Peace) being used to diffuse technology across the rest of the world
- New research opportunities – fluoride and heavy element filters, carbon foams & improved aesthetics

Summary and Concluding Remarks

- This talk presents some examples **of science- and engineering-driven solutions to global challenges**
  - Energy (Solar Cells and Light Emitting Devices)
  - Water (Ceramic Water Filters)
  - Housing (Eco-materials)
  - Health (Cancer, Cardiovascular Disease, PRDs)
- **Need to go from ideas to markets and communities within a holistic interdisciplinary framework**
- This requires a **partnership with business/industry, development partners, government and policymakers**
- **Sustainable solutions must empower people to use and science and innovation as engines of their development**…


THANK YOU!
THANK YOU!