Materials For African Development: Pan African School of Materials (PASMAT)

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Materials for African Development

- **With its rich array of minerals and waste materials – Africa has the potential to become a leader in materials science and engineering**
- This requires a **strategic approach to research, education and outreach in ways that can impact a continent** with **basic needs in health, water, infrastructure, transportation and energy**
- This is the **motivation for the Pan African Materials Institute to train the next generation of African that can add value to Africa's resources through partnerships**
  - **Education** (MSc/PhD programs, short courses)
  - **Research** (Health, Energy and the Environment, Multifunctional Materials)
  - **Outreach** (WISE, middle and secondary schools, industry)
  - **National/Regional/International Collaborations**

The Launching of The Pan African Materials Institute (PAMI)

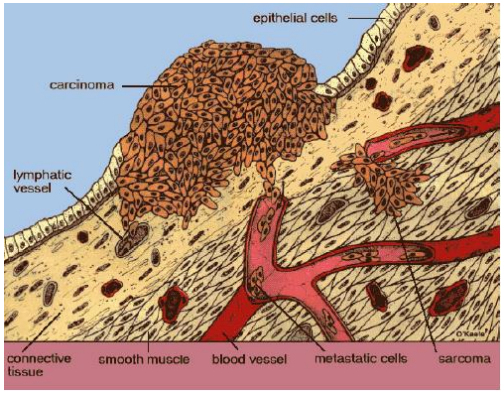
- The Pan African Materials Institute (PAMI) was recently funded by ACE at AUST - $8,000,000
- PAMI is one of the 44 Regional African Centers of Excellence announced by the World Bank following a competitive selective process
- The West and Central African Center (PAMI) focuses on
  - Training and capacity development across West and Central Africa (short courses and MSc/PhD programs)
  - Interdisciplinary materials research (biomaterials, materials for energy and multifunctional materials)
  - Outreach to girls (WISE), high schools and industry

The Pan-African Strategy of PAMI

- Builds on materials culture and partnerships established over the past 5-15 years **(USAMI, AMRS, AUST, PASMAT & PAMI)**
- **AUST materials culture – demand driven interdisciplinary research** in **materials for health, energy and the environment and multi-functional materials**
- **Open to all departments at AUST – math, computer science, physics, petroleum engineering and materials science and engineering**
- **National Partners** – SHESTCO, NASENI, Nnamdi Azikiwe University, Obafemi Awolowo University, Ahmadu Bello University, Kwara State University, University of Lagos
- **Regional Partners** – University of Ghana, Kwame Nkrumah University of Science & Technology , University of Buea, Cheikh Anta Diop University and University of Gambia
- **International Partners** – Princeton, Rutgers, Arizona State University, WPI, University of Sao Paulo, Blaise Pascal

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 & indus waste
  - Value addition to people, minerals and natural products



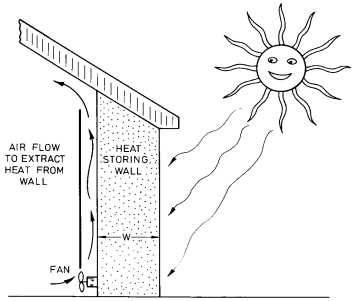
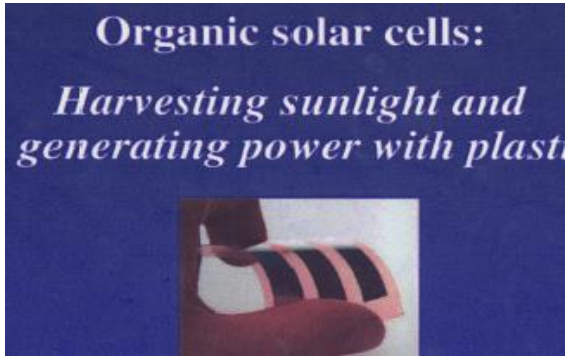
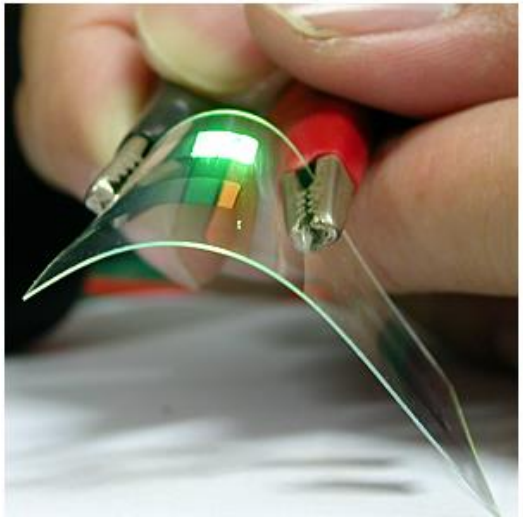


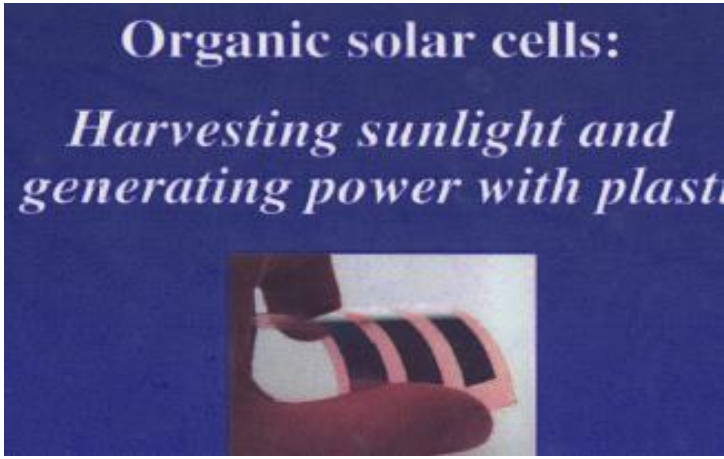
FIG. 6.32 A heat-storing wall. The sun shines on the outside during the day; heat is extracted from the inside at night. The heat diffusion time through the wall must be about 12 hours.



Strategy for Materials for Energy Research

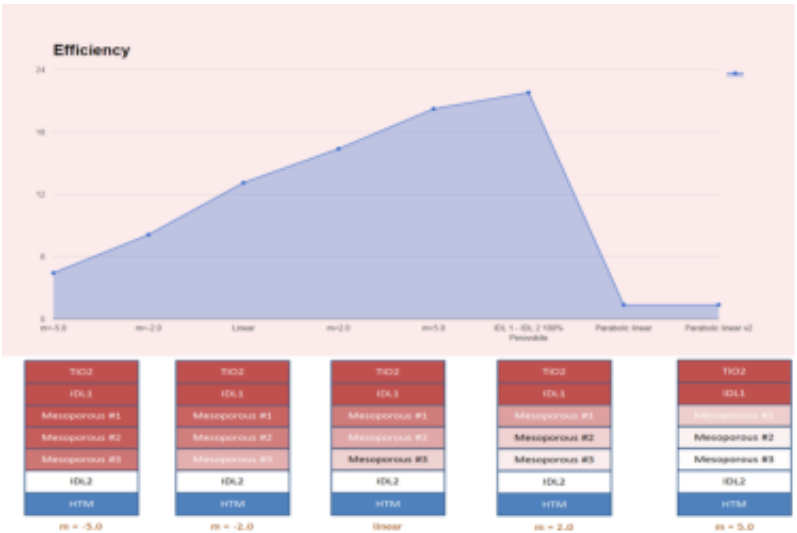
- Interdisciplinary approach that includes combination of modeling and experimental research
- Goal is to develop the next generation of solar cells, light emitting devices and batteries for energy storage (organic and perovskite solar cells/LEDs, Li ion batteries/ultra-capacitors)





Perovskite Solar Cell Research

- Perovskite solar cells represent the next frontier of low cost flexible solar cell/LED research
- Pioneering work by Snaith et al. and Graetzel et al. - Photo-conversion efficiencies as high as 19.3%
- Recent work by Friend et al. on Perovskite LEDS
- PAMI modeling of solar cell performance – meso-porous solar cells and FGMs (SCAPS & FEA)



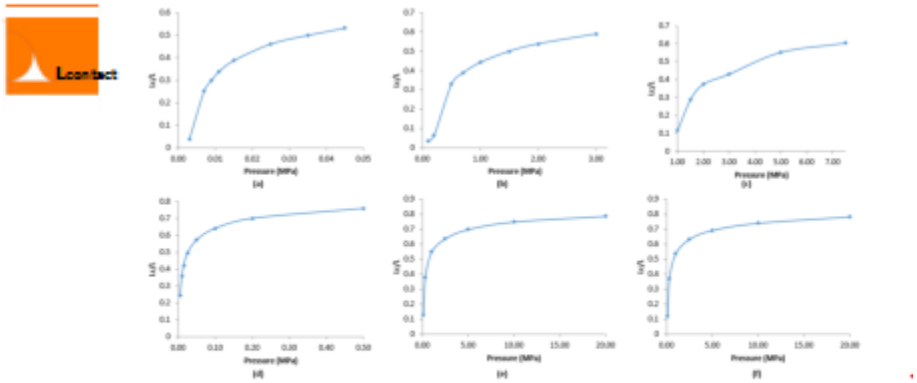
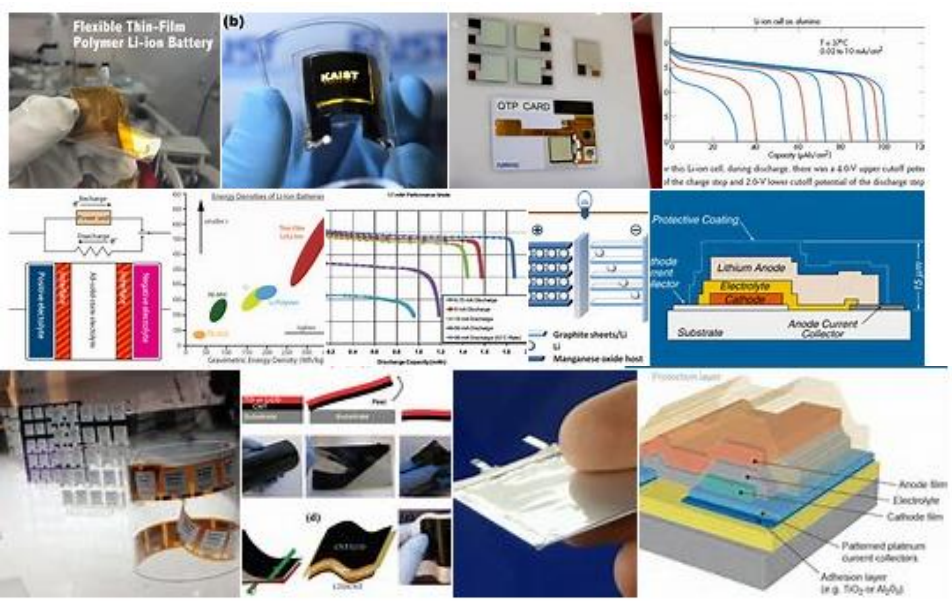


Figure 14: Contact trends observed with different configurations: (a) PEDOT:PSS-Al-ITO. (b) MEH:PPV-Al-PEDOT:PSS. (c) Al-PEDOT:PSS-MEH:PPV. (d) Perovskite-TiO_2-TiO_2. (e) TiO_2-Perovskite-ITO. (f) TiO_2-TiO_2-ITO

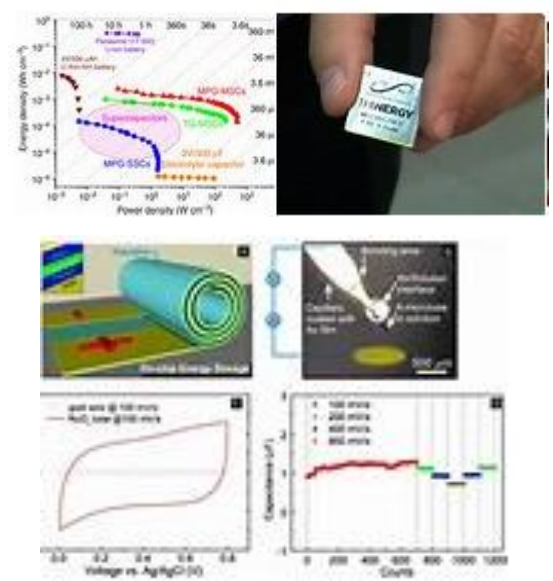
Proposed Research to Energy Storage

- Need to combine efforts in solar cells/LEDs with research on materials for energy storage
- This could include research on batteries and ultra-capacitors – modeling and experiments
- Collaborate with Prof. Clare Grey and Wynton Center at Cambridge + Prof. Ncholu Manyala at Pretoria

Thin Film Batteries

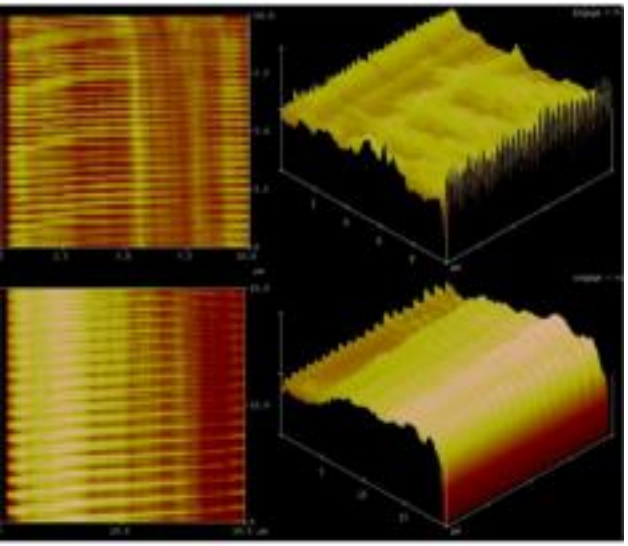


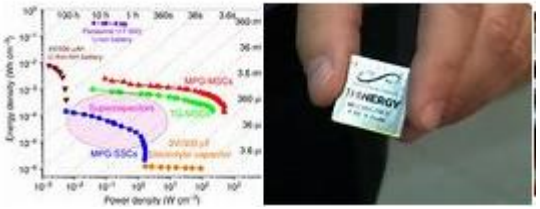
Thin Film Ultra-capacitors

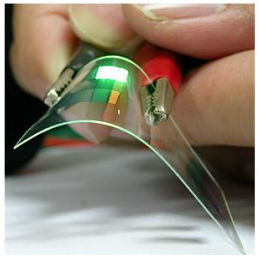


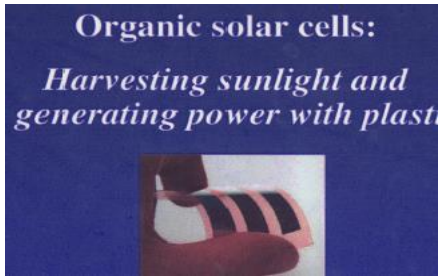
Stretchable and Bendable Solar Cells/LEDs and Batteries/Ultra-capacitors

- Pre-stretching of flexible/stretchable substrate followed by retraction
- Micro-buckles or micro-wrinkles increase stretchability or flexibiity
- Can now deposit and test flexible/bendable solar cells/LEDS and batteries/ultra-capacitors





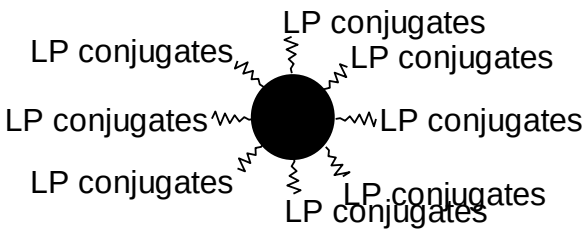


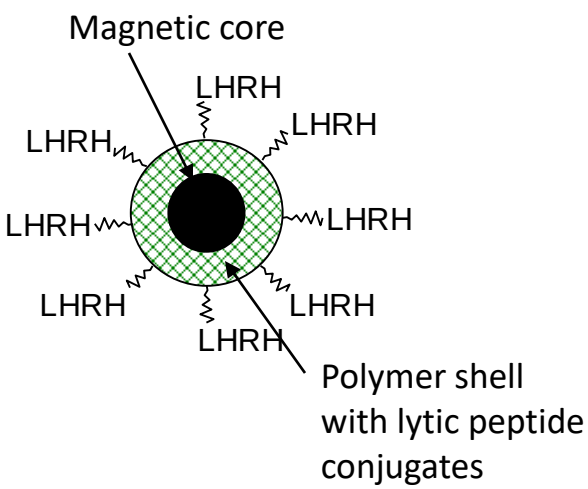


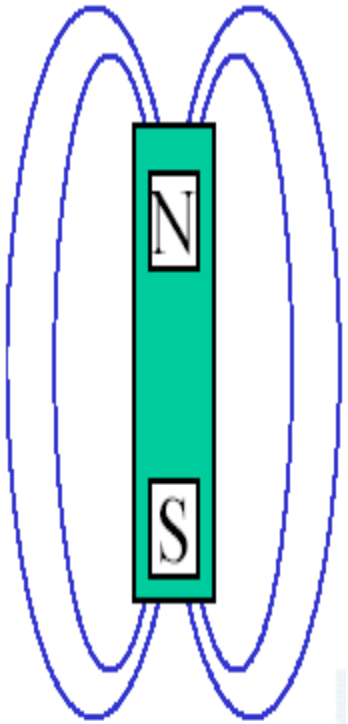
CAMD

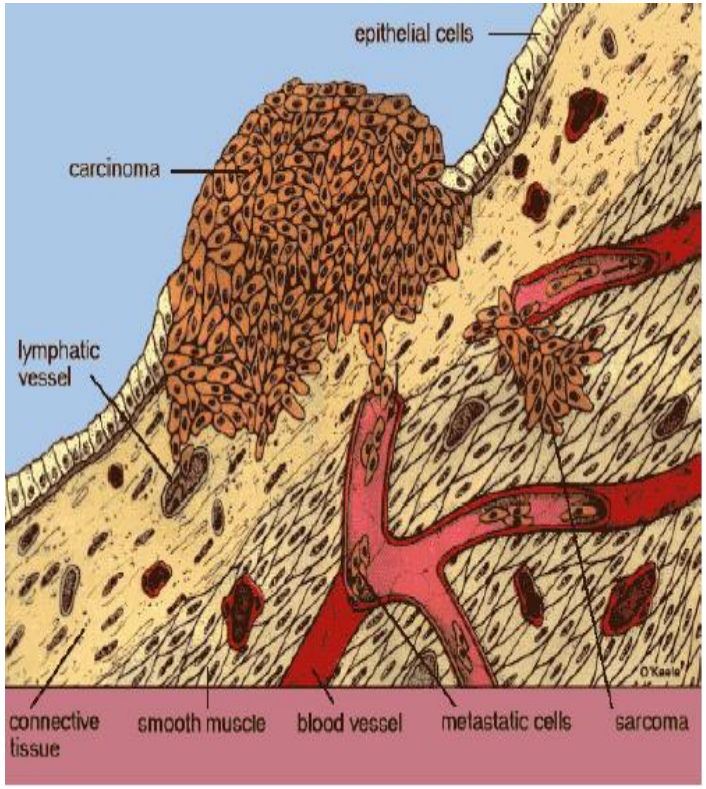
Our Approach to Early Cancer Detection and Treatment!

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.

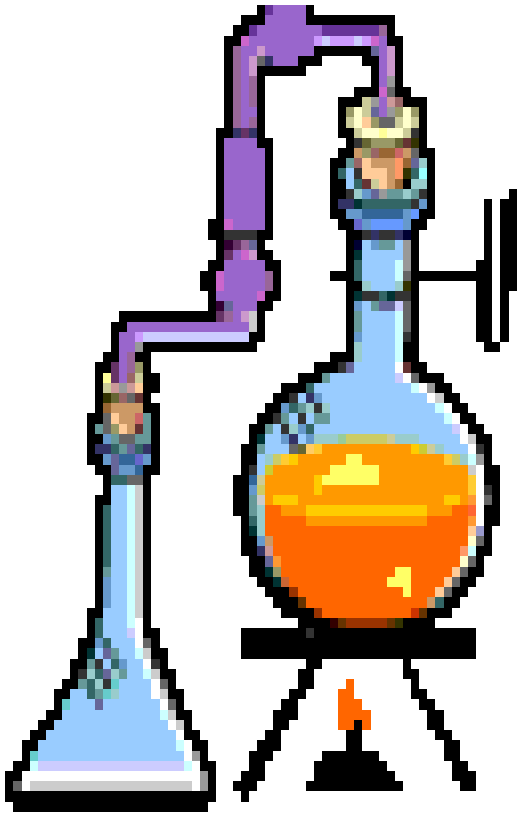






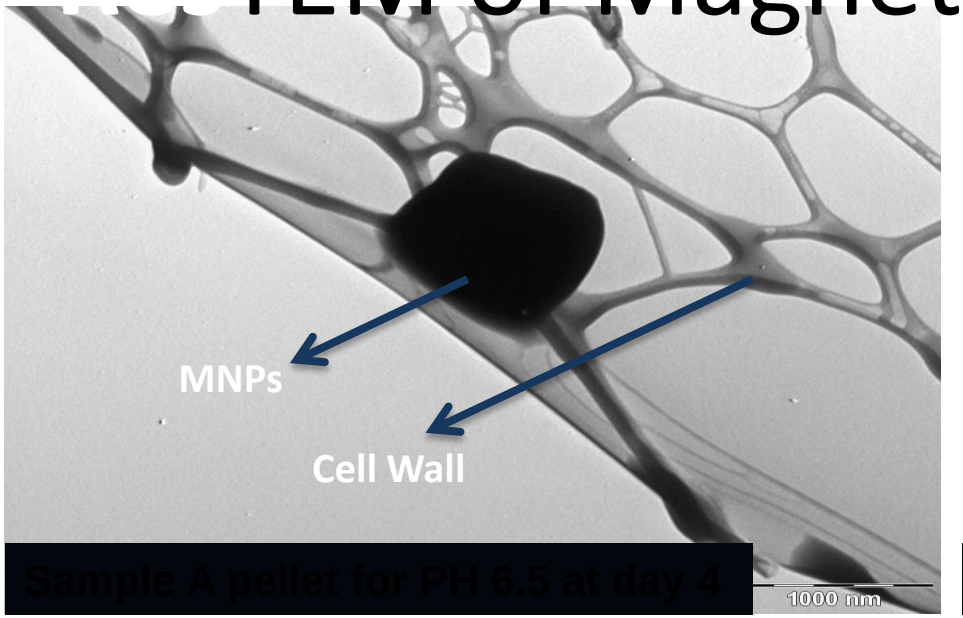


Wet Chemical Synthesis of Nano-particles



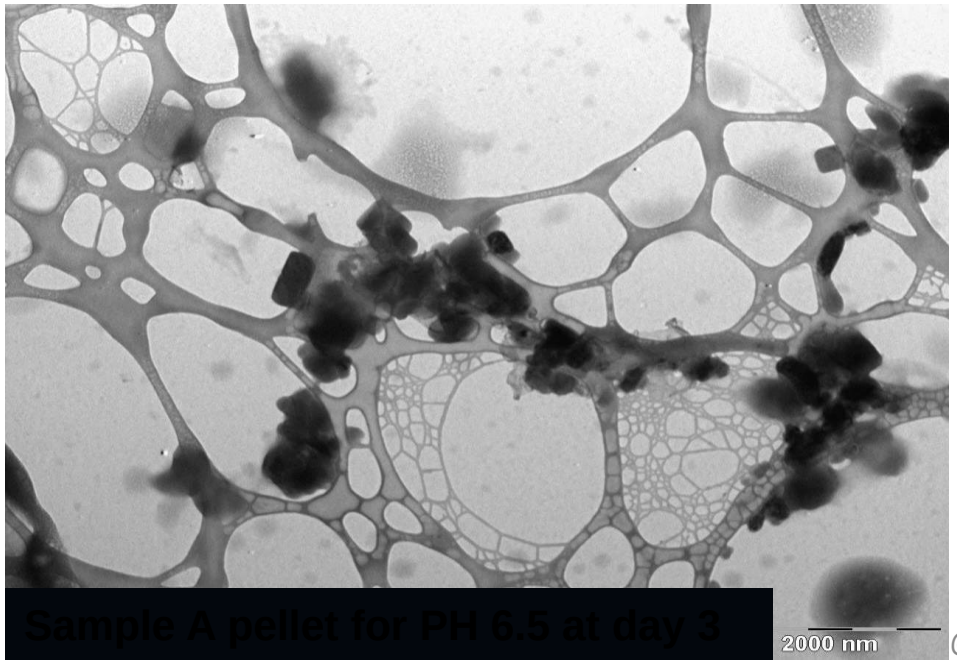
- Metallic, polymeric and metal-polymer Nano-particles using bottom-up approaches
- Novel Micro reactor technology for scale-up and controlled synthesis
- Synchrotron radiation based X-ray absorption Spectroscopic characterization
- Capability to attach bio-molecules

TEM of Magnetite Nanoparticles

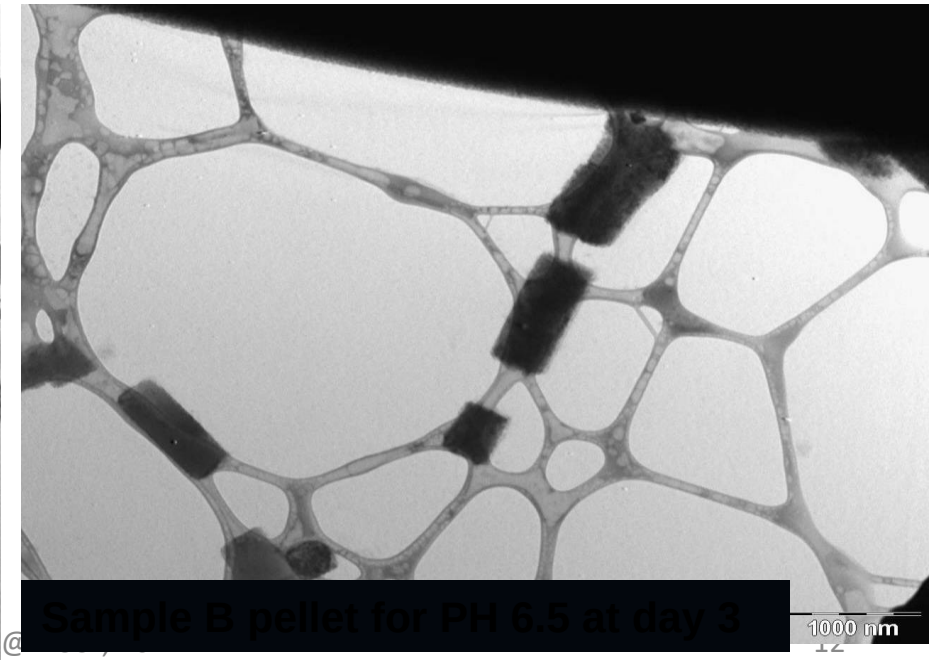


Sample A pellet for PH 6.5 at day 4

Sample B pellet for PH 6.5 at day 4

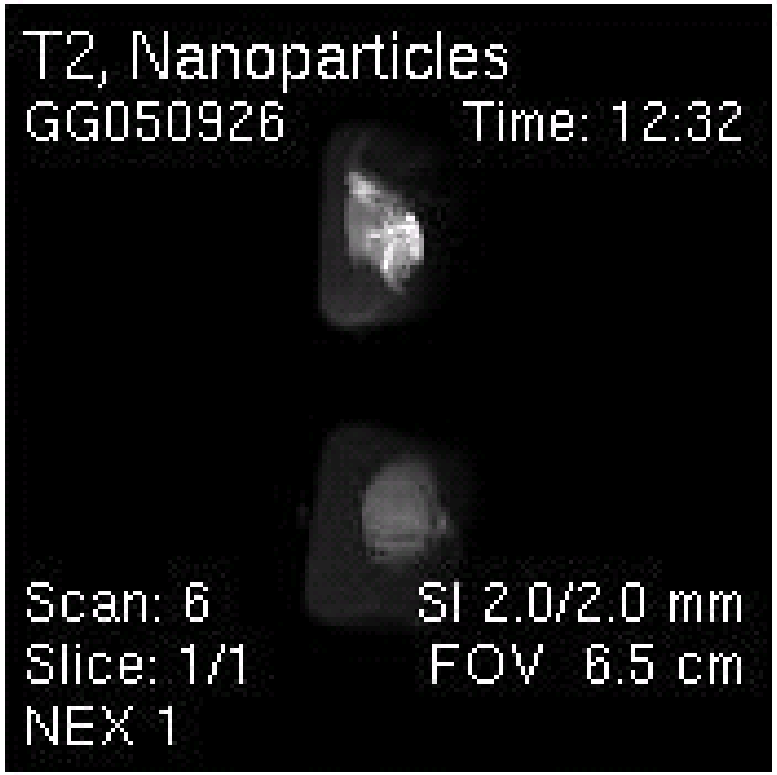


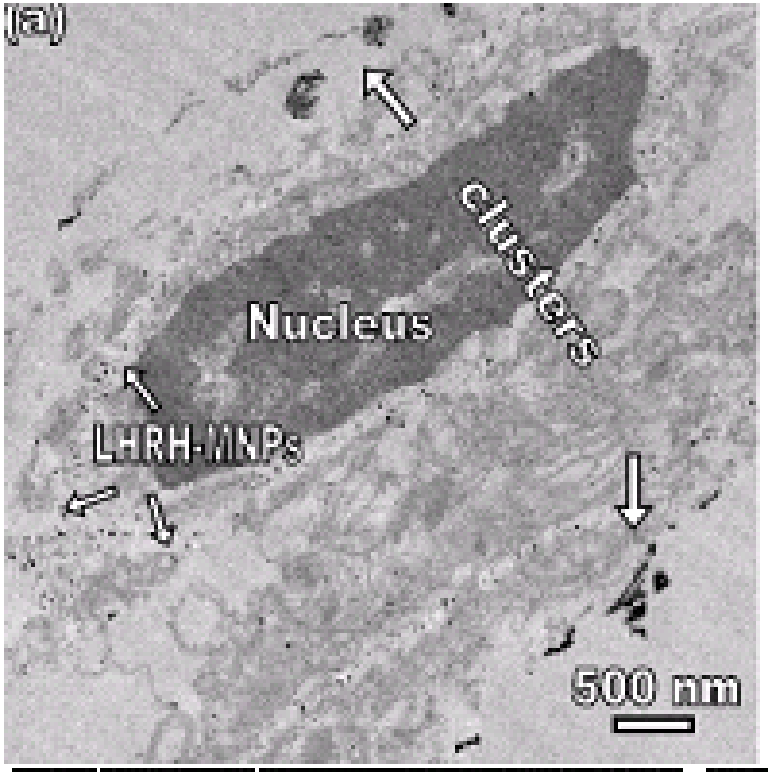
Sample A pellet for PH 6.5 at day 3



Sample B pellet for PH 6.5 at day 3

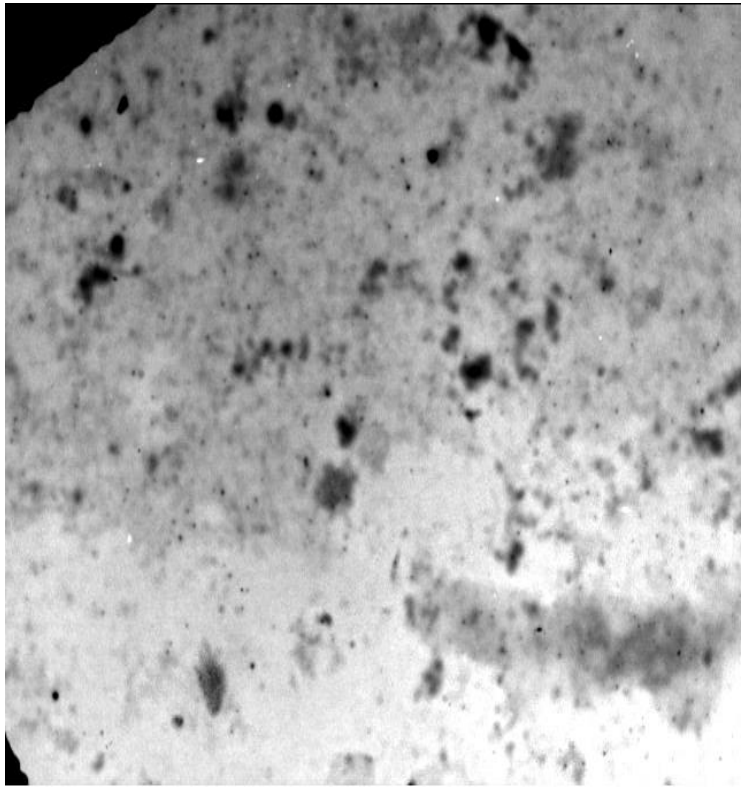
T2 Images of Tumors – Contrast Enhancement Due to LHRH-MNPs



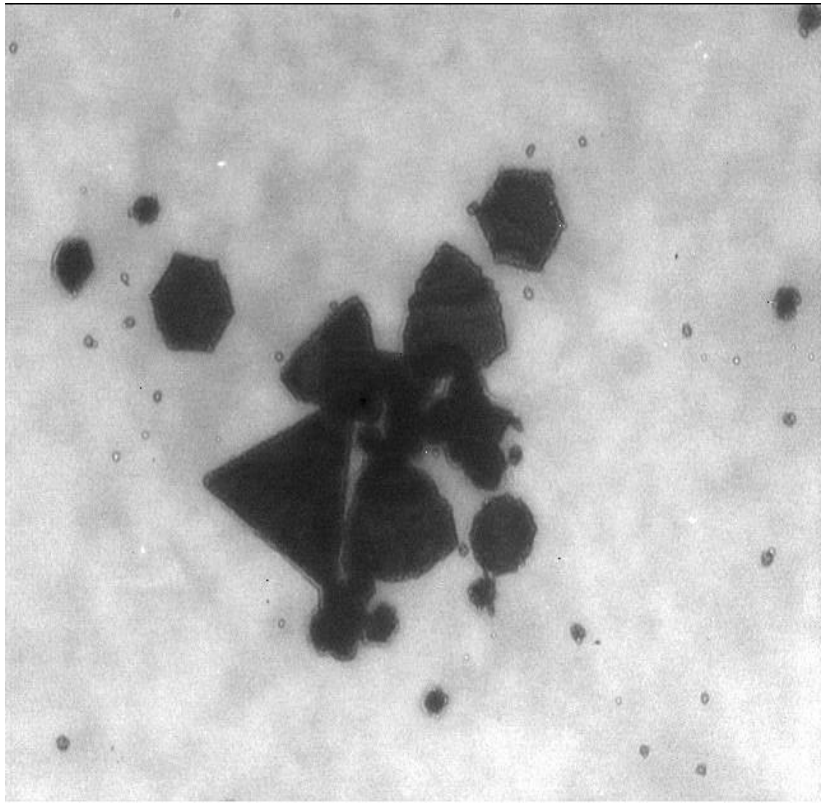


TEM of Au NPs in *Serratia Marcescens*

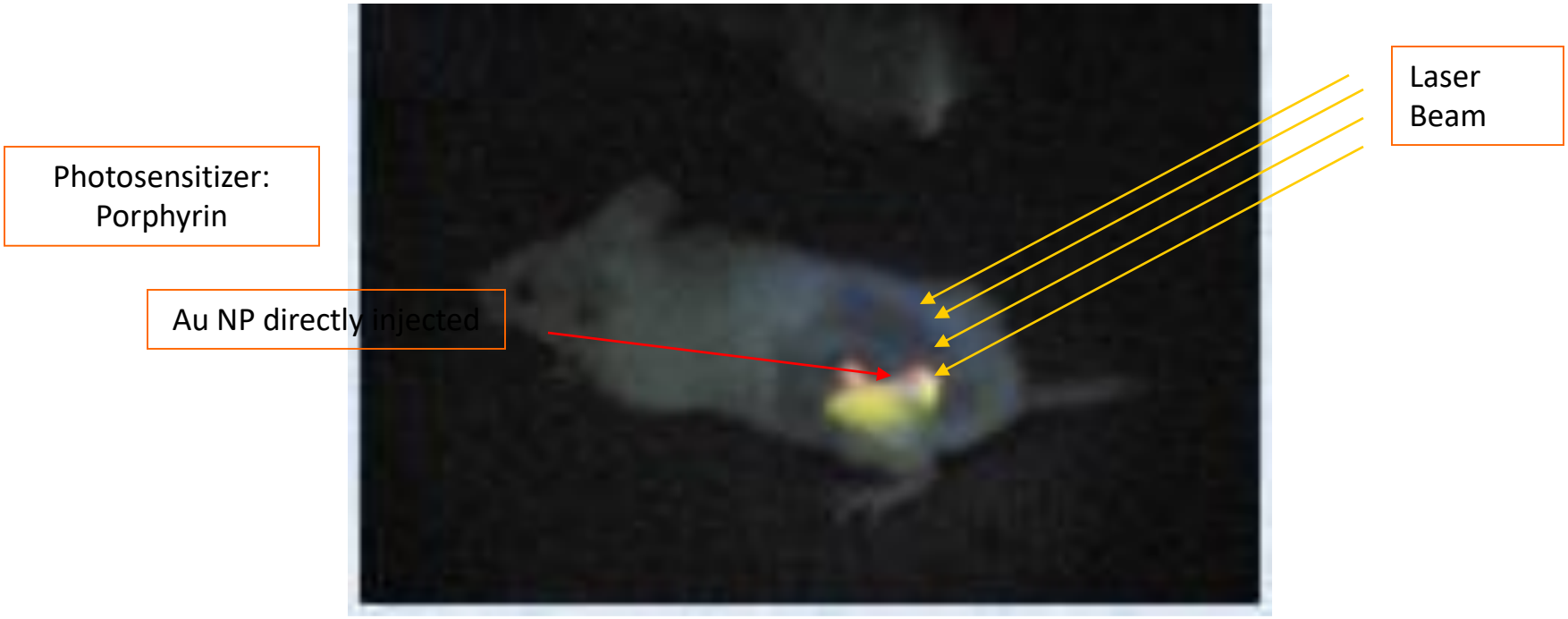
pH 3



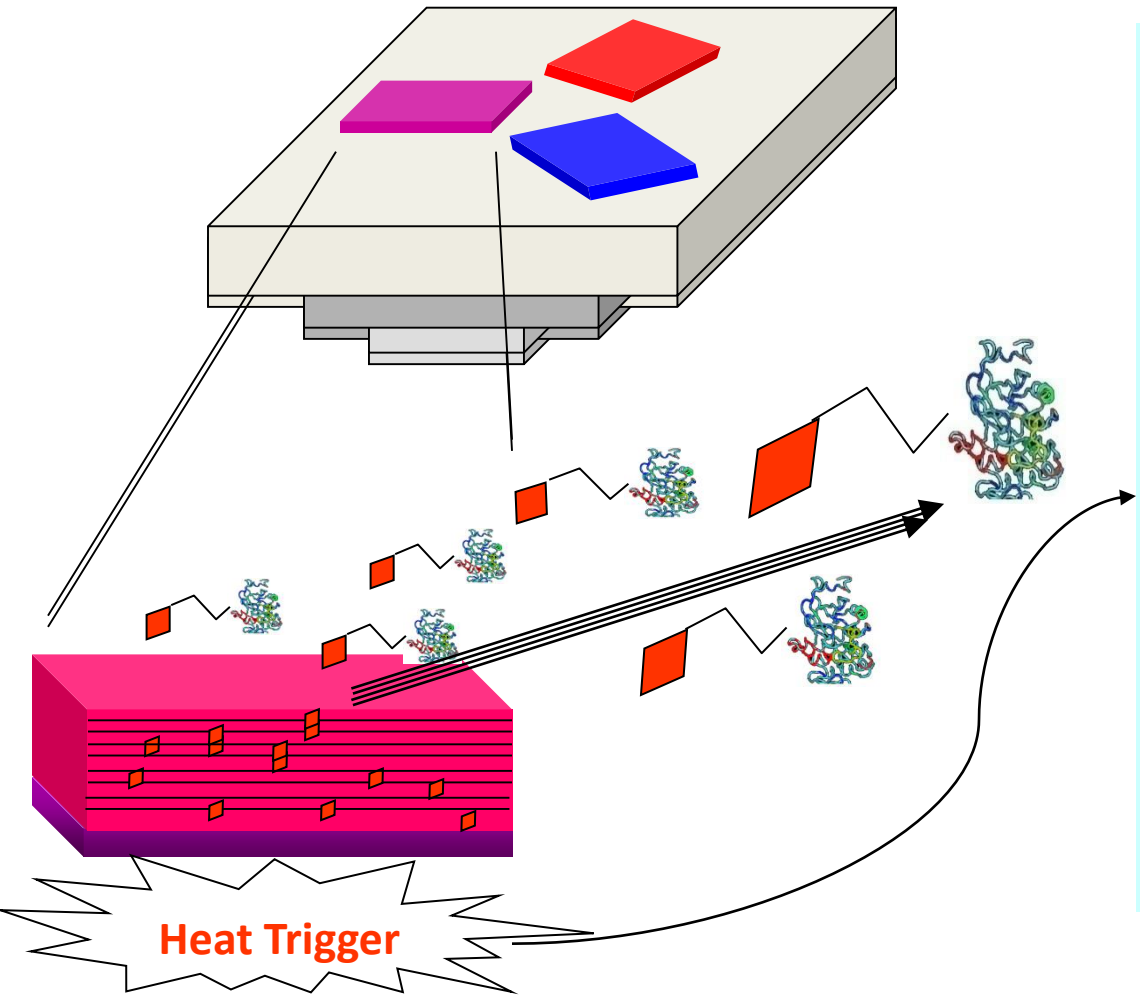
pH 4



Gold Nanoparticles Research Strategy

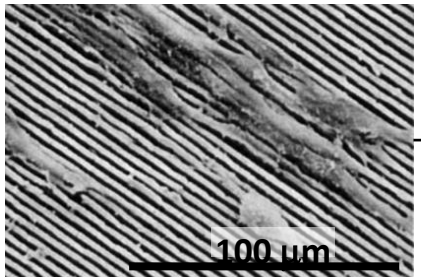


Drug Delivery by Resistive Heating

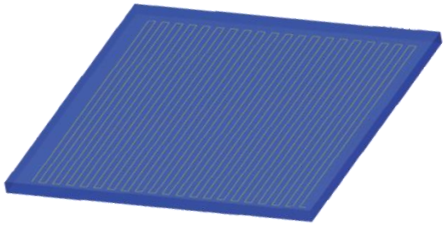


- Hydrogels sit on metallic plates
- Current running through plates heat plates
- Temperature controlled by current
- Current controlled by open/closed switch programming

Hyperthermia + Drug Delivery

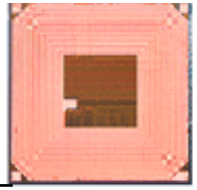


Surface Texture

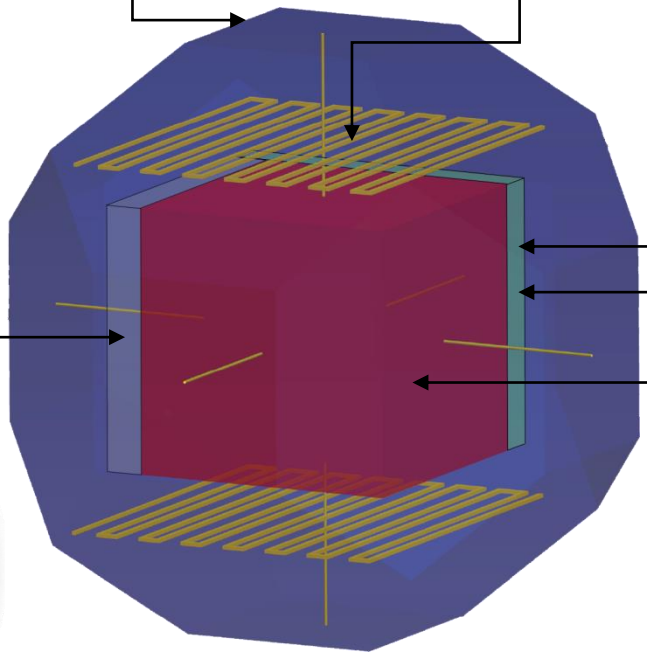


Hyperthermia Device

RFID Tag

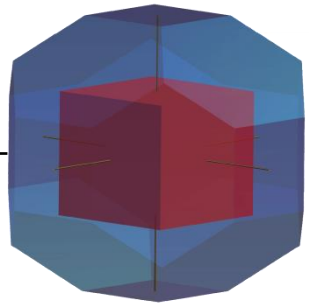


Battery



Microprocessor

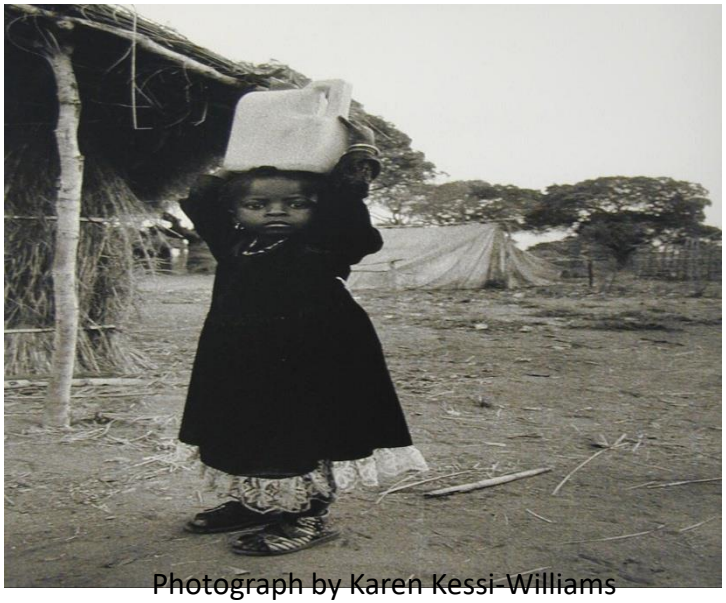
Multi-Modal Implant



Drug Delivery Device

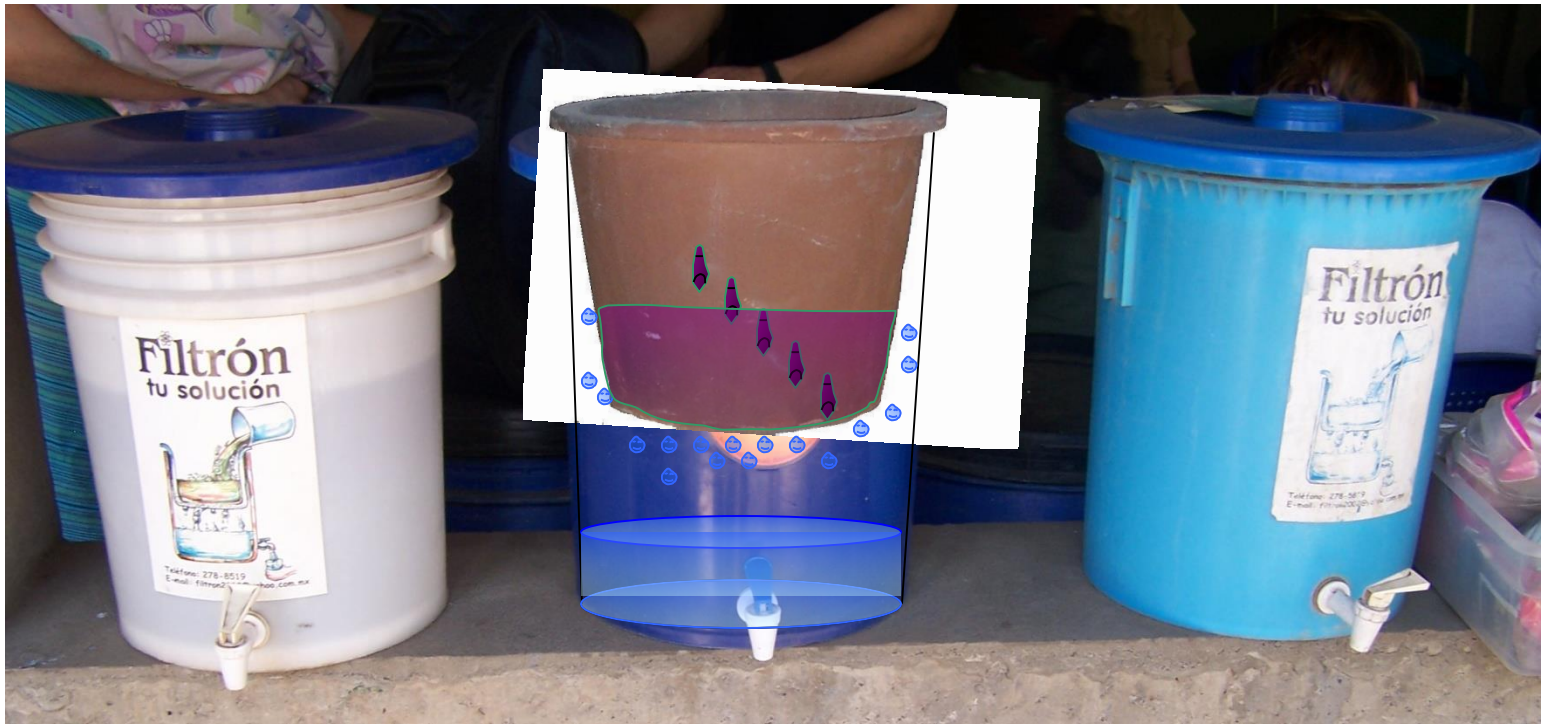
Background and Introduction

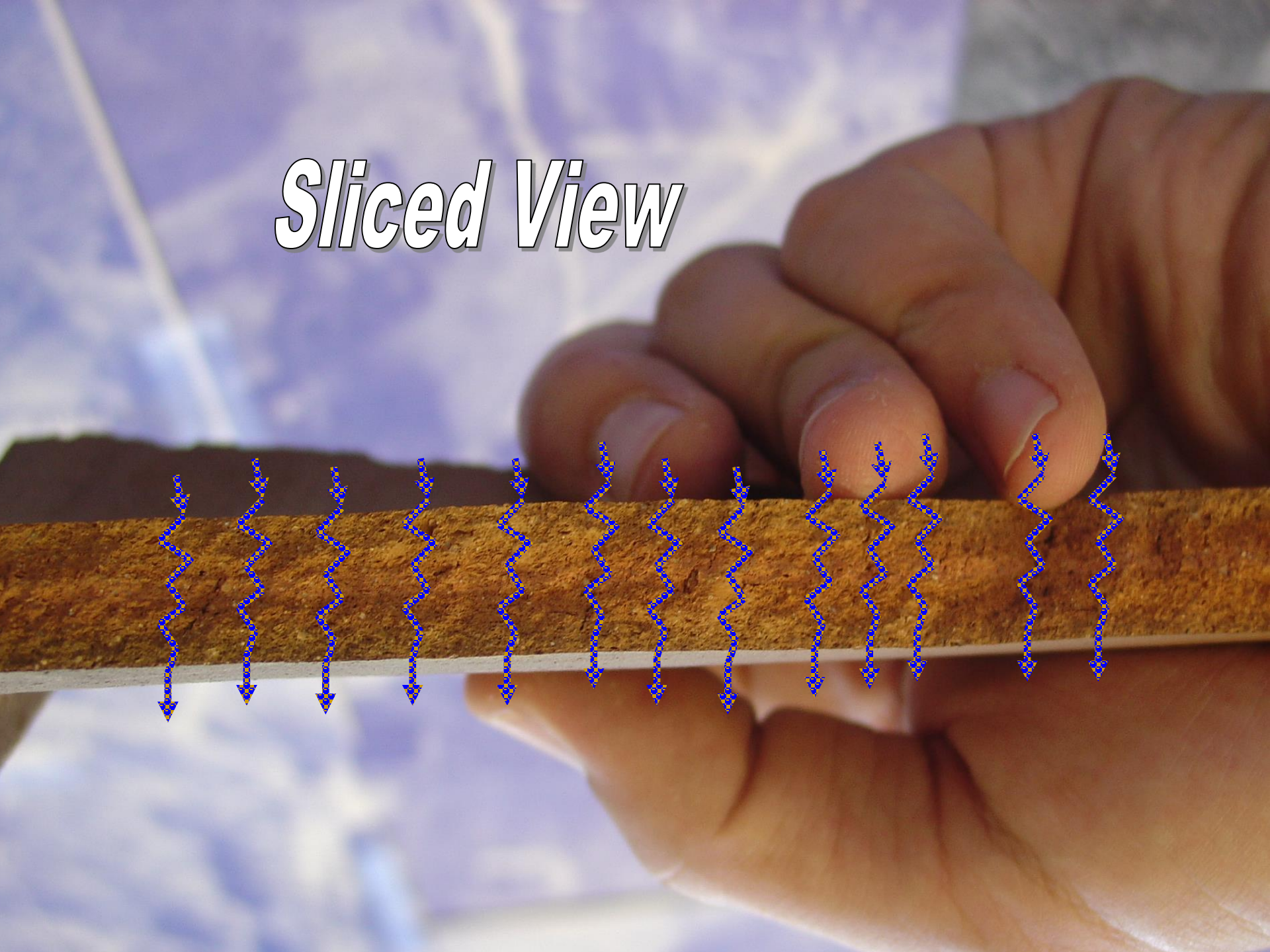
- The problem of contaminated water is the single biggest cause of the steep decline in life expectancy in Africa and other developing regions
  - Impact bigger than that of HIV
  - Example of Nigeria
  - 5000 lives lost per day
- However, this is also a need to ensure that the water is pure at the point-of-use
- 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



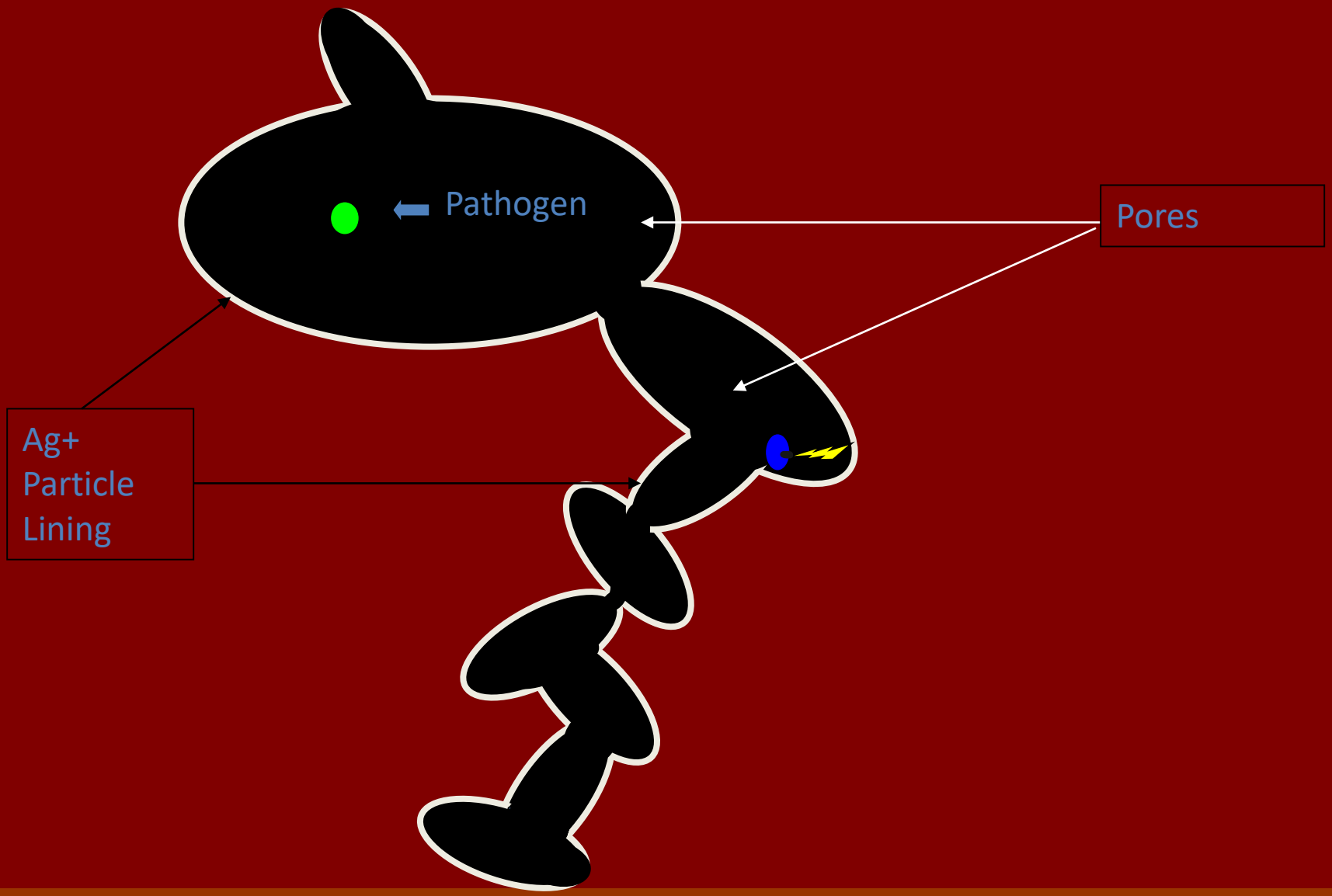
Photograph by Karen Kessi-Williams

Point-of-Use Water Filtration Systems



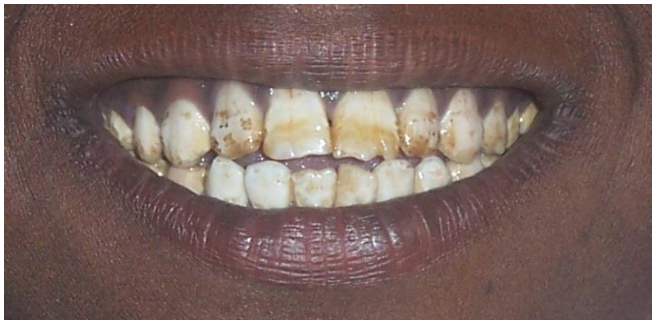

Sliced View

Schematic Diagram



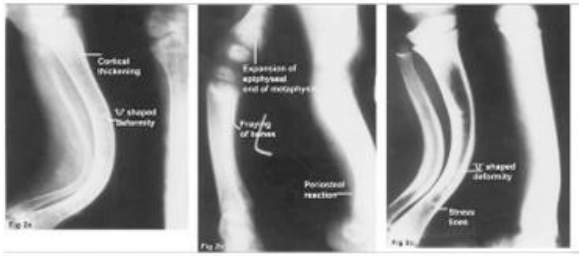
Microbial and Fluoride Removal

- High fluoride content can cause serious health problems[1]
  - Occurs naturally in deep bore holes
  - Groundwater with high fluoride concentrations can be found in many areas of the world, including large parts of Africa, China, Mexico, the Middle East and southern Asia (India, Sri Lanka)[1]
  - Example: A "national health problem" in India
    - 17 out of 32 states and territories have naturally high concentrations of fluoride (UNICEF, 1999). As high as 48 mg /L in Rewari District of Haryana. [2]
    - 60–70 million people in India are at risk
- High fluoride intake causes dental and skeletal fluorosis; osteoporosis; nausea; adverse effect on kidneys
- The question is – can we combine fluoride and microbial removal?



Dental fluorosis: Soft, pitted teeth

Skeletal Deformities: Bihar, India



1: UNICEF Handbook on Water Quality, Released: 16th April, 2008
2: UNICEF 1999 *State of the art report on the extent of fluoride in drinking water and the resulting endemicity in India. Report by Fluorosis Research & Rural Development* Foundation for UNICEF, New Delhi.

Clay/HA Filters for Fluoride Removal

- Hydroxyapatite (HA): $Ca_5(PO_4)_3(OH)$
  - Made from simple acid/base reaction
  - Mechanism of removal involves:
    - Crystal substitution (OH^-/F^-)
    - Fluorite précipitation (CaF_2)
    - Surface sorption
- Redart Clay
  - Previously used to remove bacteria and microbial organism in the form of frustum-shaped filter
- Mixing of Clay with HA
  - "A combo" with the potential to remove both Fluoride and Bacteria
  - Ease of forming
  - Cost
- Strategy
  - Fundamental Study (Adsorption study)
  - Proof-of-concept
    - Disc-shaped filter
    - Frustum-shaped filter

Two simple routes for synthesis of HA:

1. $10\ Ca(NO_3)_2{,}4(H_2O) + 6\ NH_4H_2PO_4 + 14\ NH_4OH = Ca_{10}(PO_4)_6(OH)_2 + 20\ NH_4NO_3 + 50\ H_2O$
2. $10\ Ca(OH)_2 + 6\ H_3PO_4 = Ca_{10}(PO_4)_6(OH)_2 + 18\ H_2O$

The principal reaction is hydroxyl-fluoride exchange of apatite:

1. $Ca_5(PO_4)_3(OH) + F^- = Ca_5(PO_4)_3(OH_{1-x}, F_x) + (1-x)F^- + xOH^-$
   where x is the degree of fluoridation
2. $Ca_5(PO_4)_3(OH) + 10F^- = 5CaF_2 + (PO^{3-}{}_4)3 + OH^-$


WATER FILTER
FILTRON (NIG)
WATER FILTER
FILTRON (NIG)
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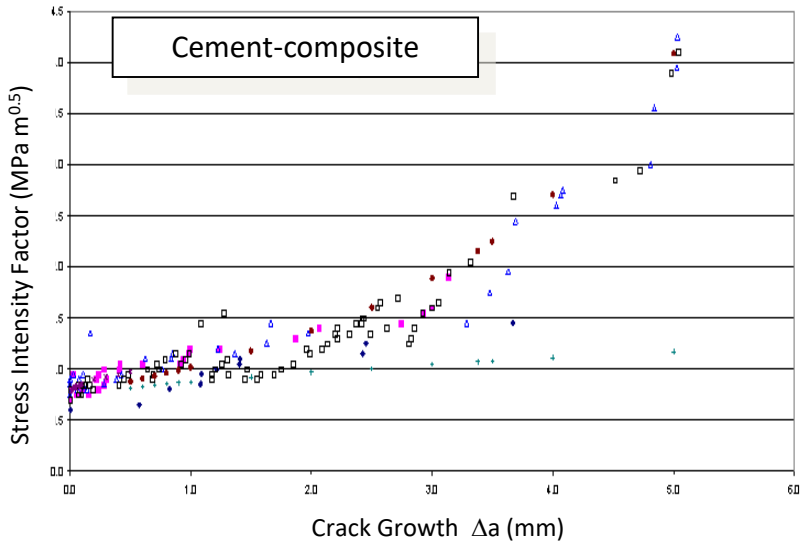
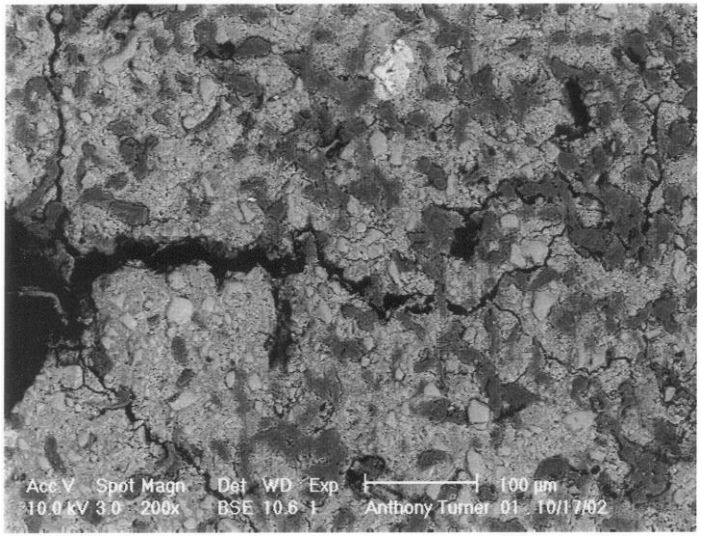
Alternative Eco-Friendly Materials

- All countries have industrial and agricultural wastes that can be combined with earth or cement based materials to make building elements
- Examples include straw-reinforced earth, cementitious composites reinforced with natural fibers and polymers reinforced with wood chips
- Such reinforcement gives rise to toughening by crack bridging which increases durability and earthquake resistance of homes and roads



Resistance-curve behavior in natural fiber composites



Backscattered electron image showing cracks and composite bridges. Fibers are seen in dark gray

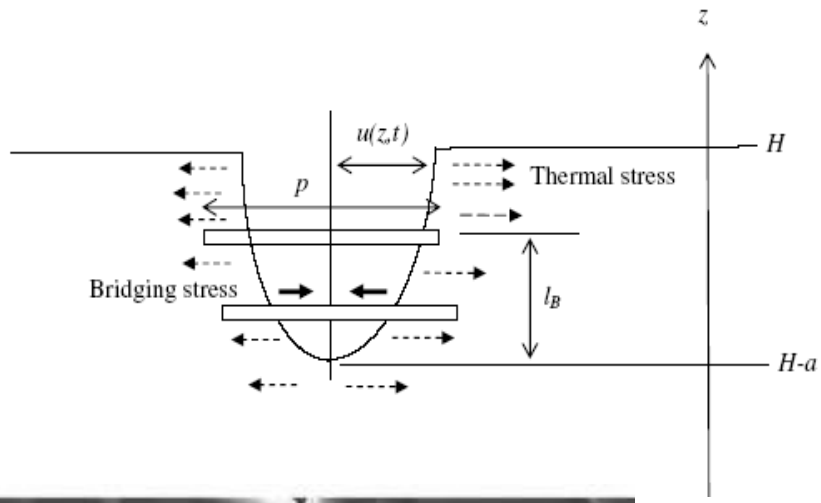
Modeling of Crack Bridging and Materials Design

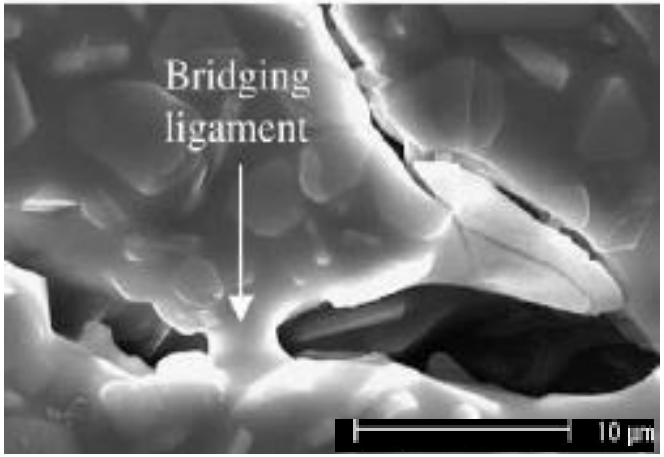
- Fracture mechanics concepts can be used to quantify crack bridging – multifunctional materials (NFRCs/PWRCs/clay hybrids)

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

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

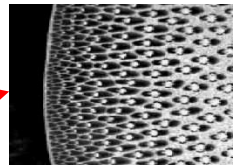




Schematic and Actual Bridging Ligaments

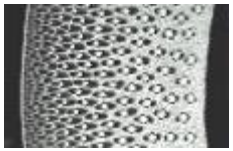
Bamboo:
A Functionally Graded Material in Nature

Head region

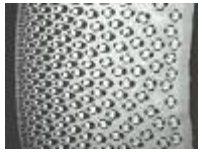


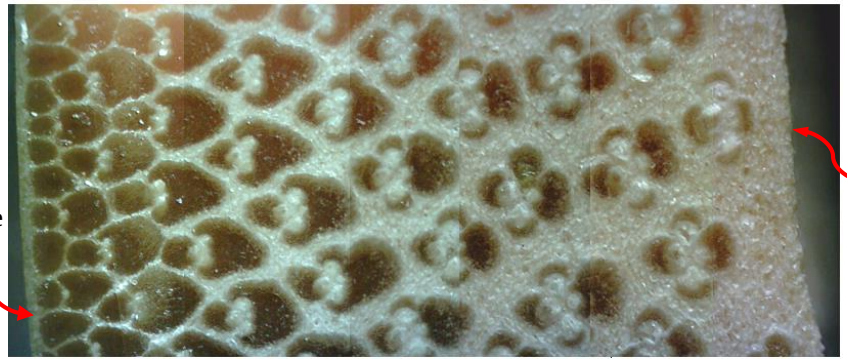
Optical Microscopy

Middle region

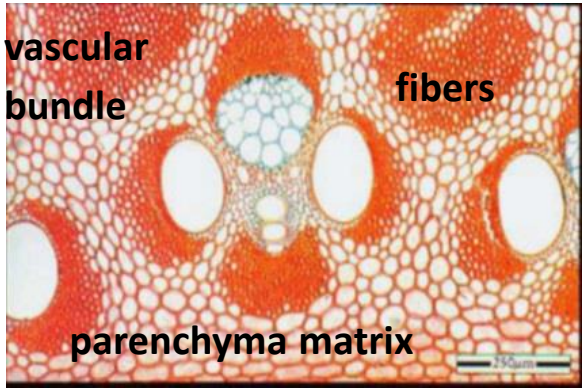


Ground region





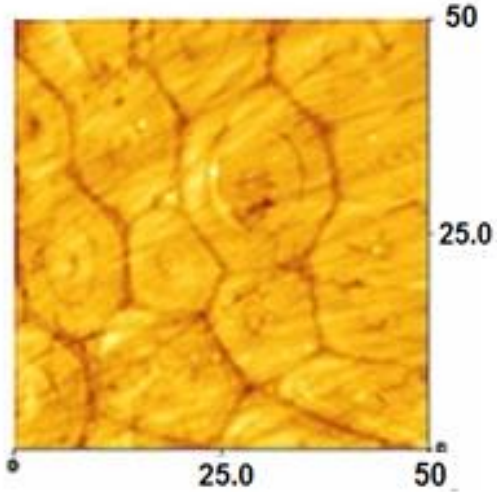
(Adapted from Tan et al., 2011)

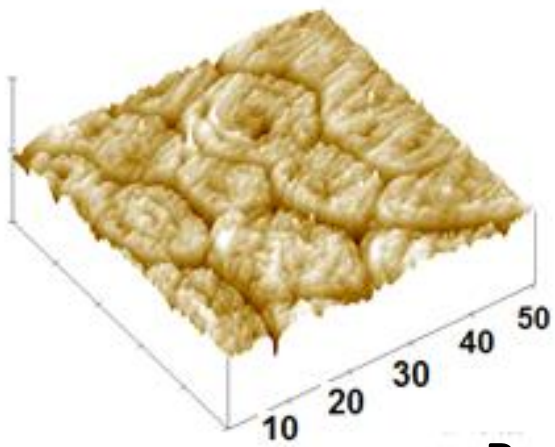


(Adapted from Lease, 1998)

Functionally Graded Material (FGM)

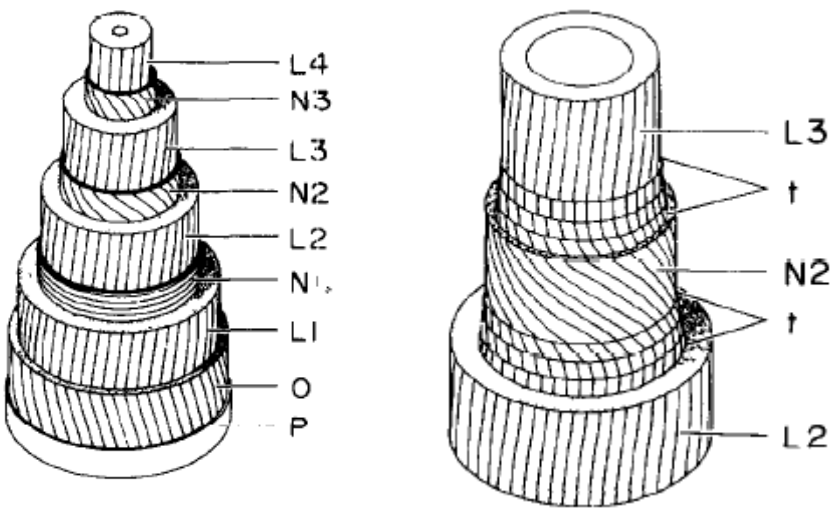
Bamboo Fibers





(Units: μm)

(Adapted from Tan et al., 2011)



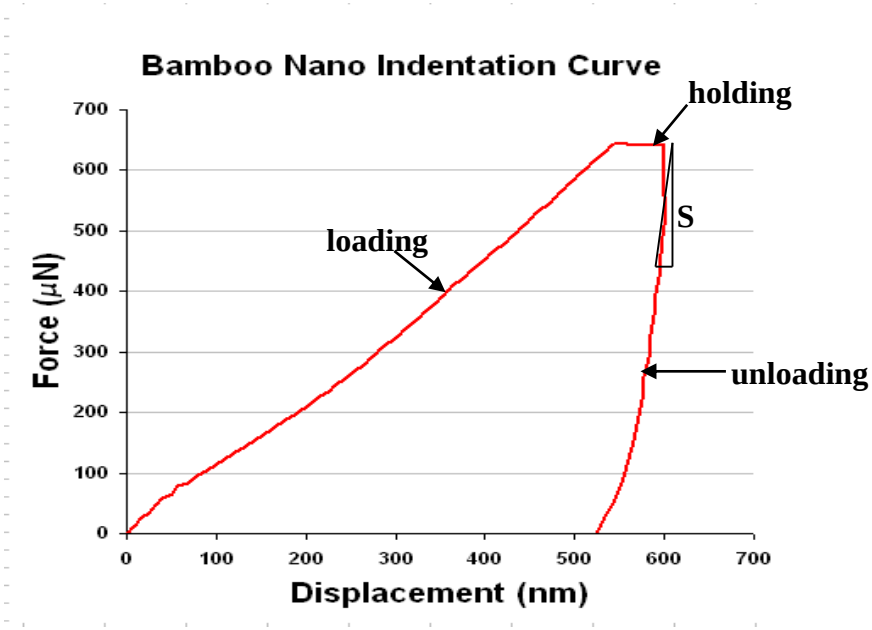
(Adapted from Wai et al., 1985)

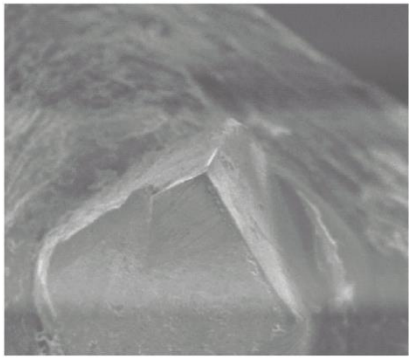
Bamboo fibers

- ✓ Cellulose, hemicellulose and lignin
- ✓ Broad and think walls
- ✓ Microfibril orientations

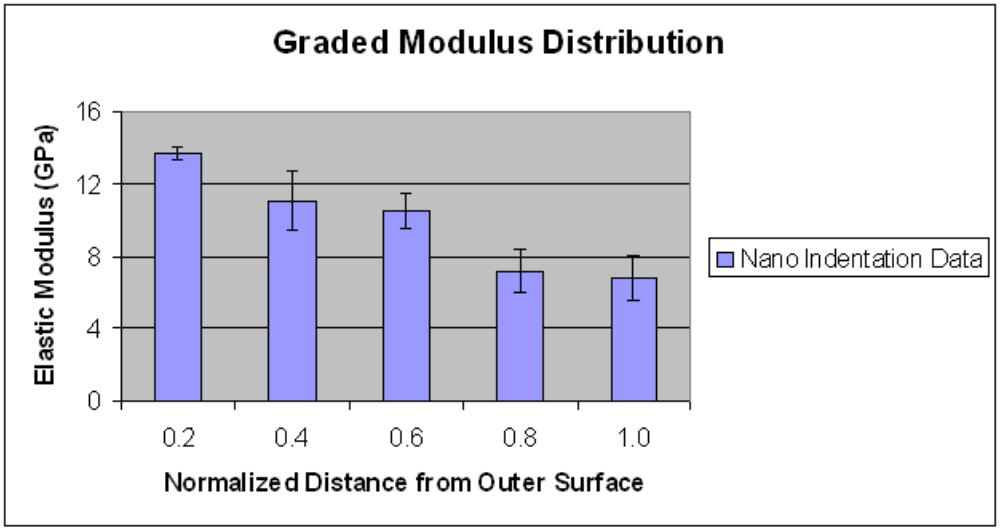
  3-10˚ (broad); 30-90˚ (thin)

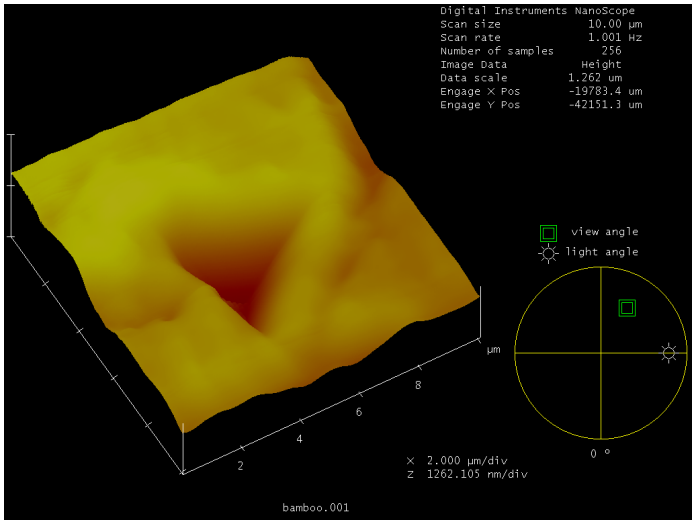
Functionally Graded Material



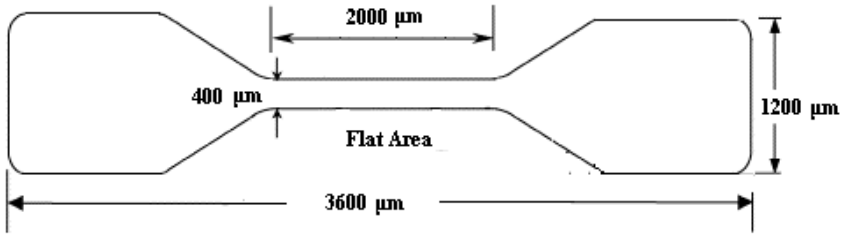


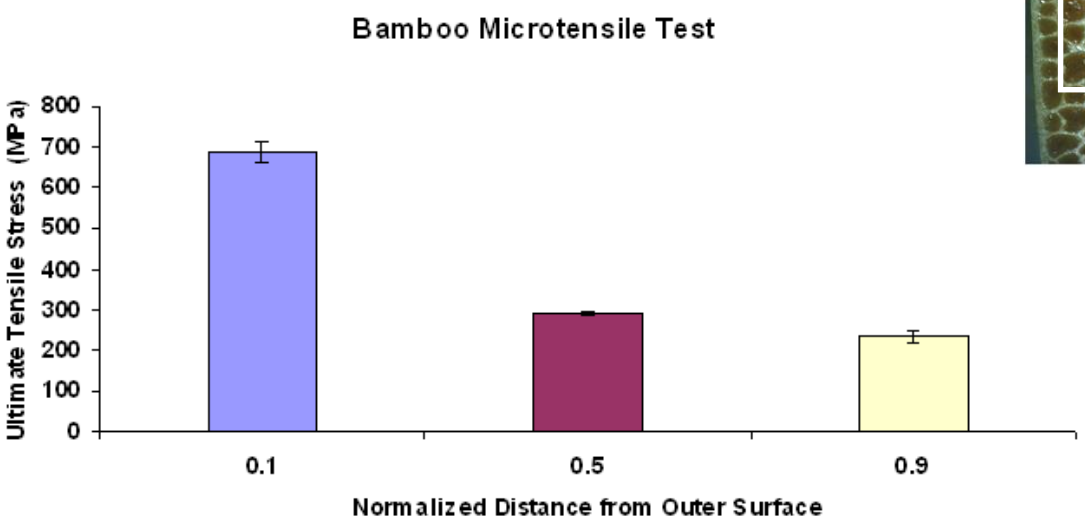
Cube-corner

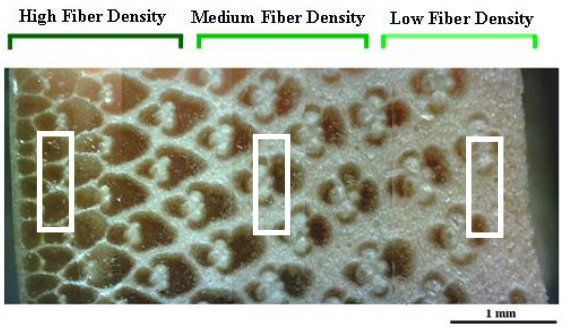




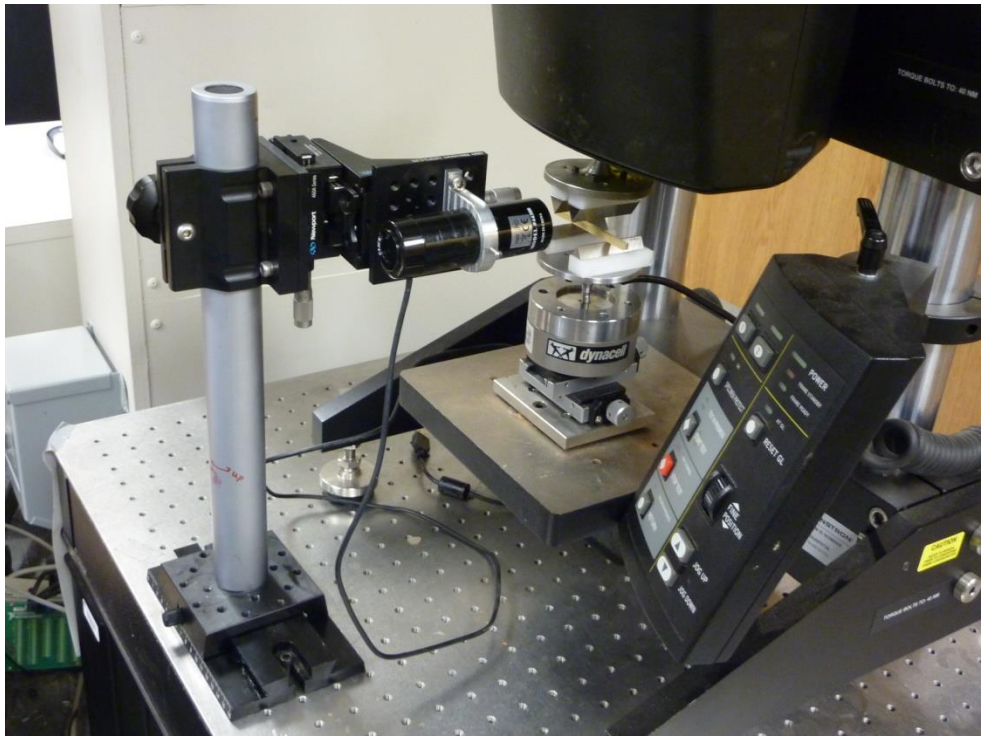
Microfiber Testing of Layers

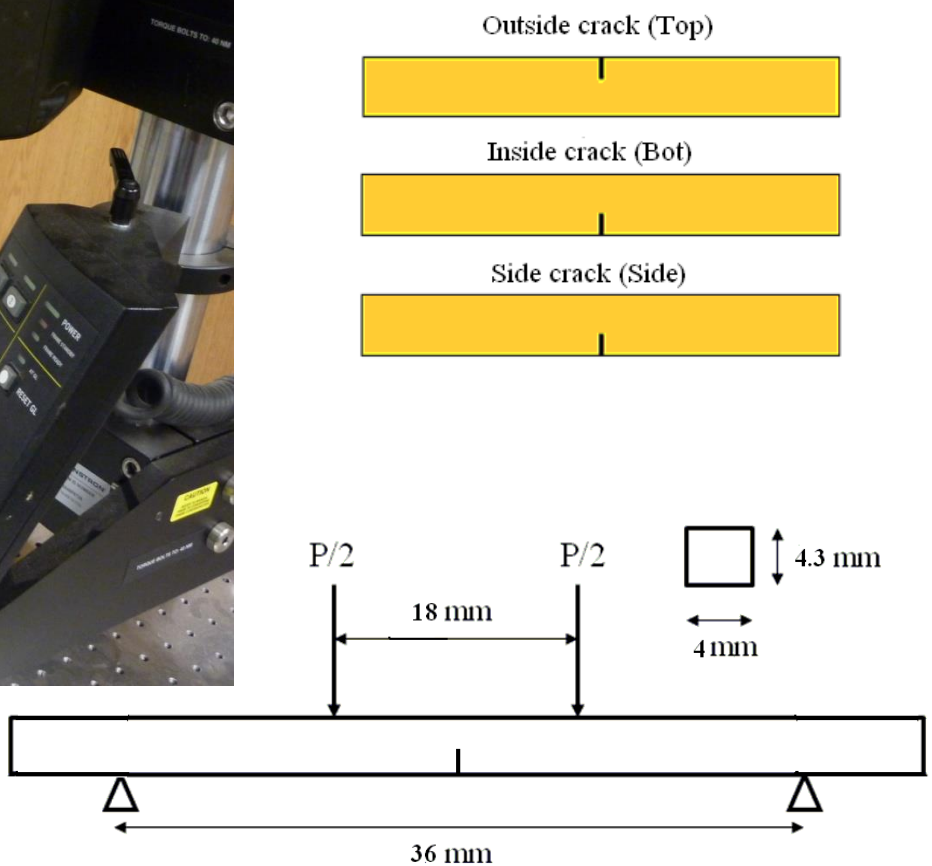




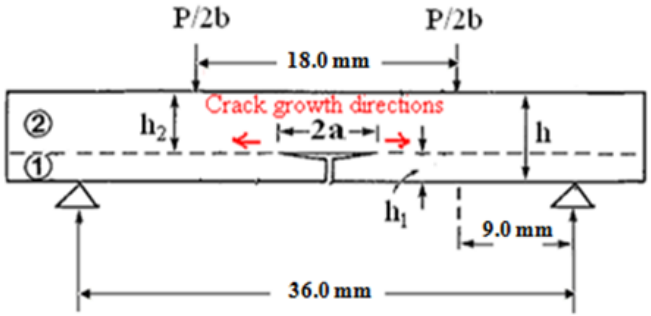


Fracture Experiments

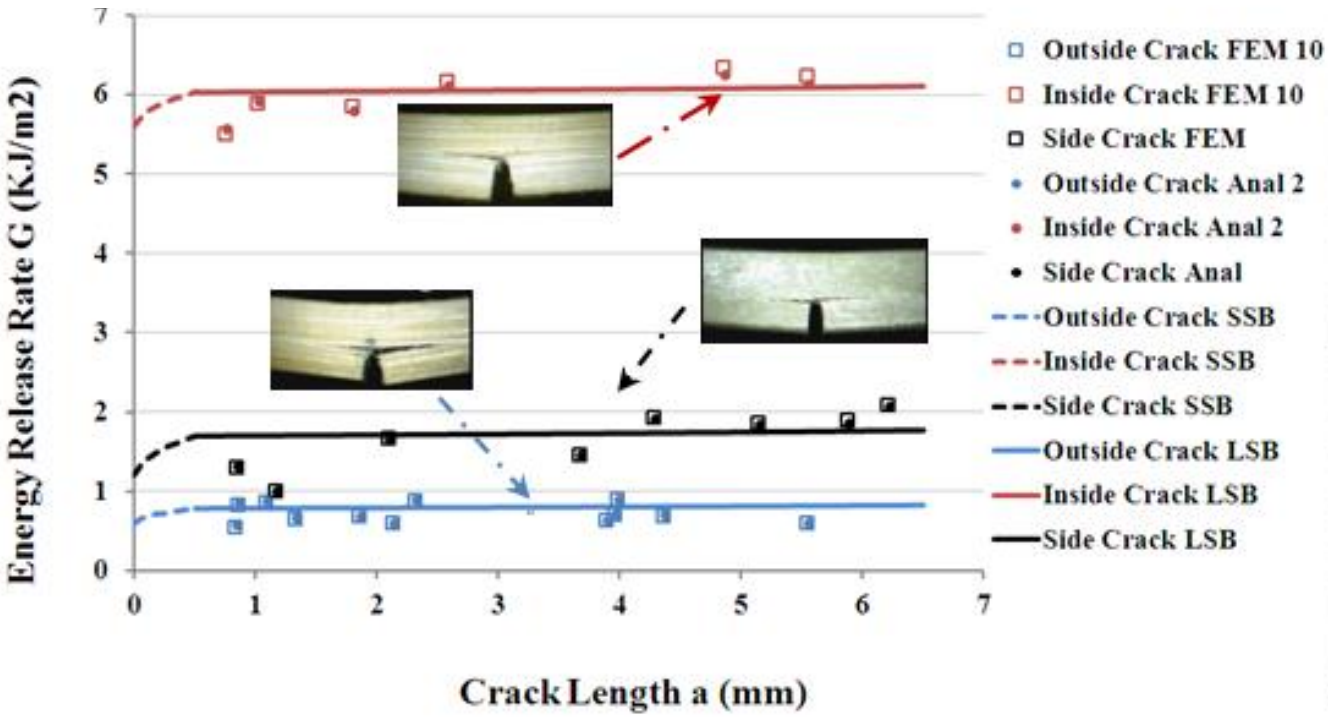


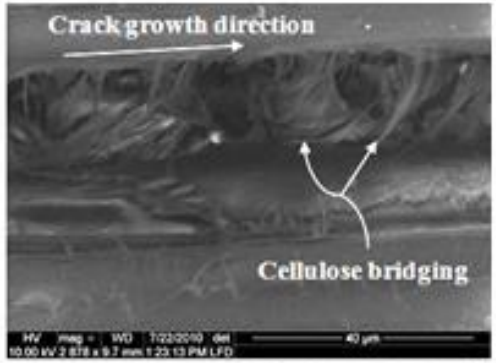


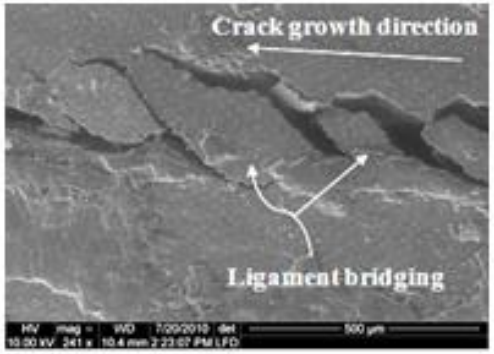
Mechanical Properties of Bamboo



Adapted from Charalambides et al., 1989; Tan et al., 2011; Budiansky et al., 1988; Bloyer et al., 1998 and 1999; Soboyejo, 2002



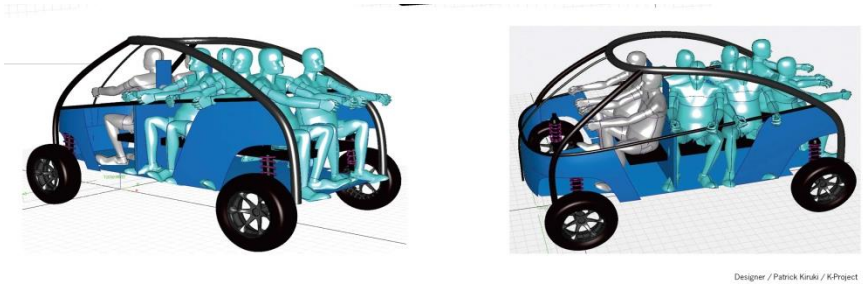




(Adapted from Tan et al., 2011)

Bamboo Applications

Bamboo Racing Bicycles



Bamboo People Mover
Patrick Kiruki

Pictures by courtesy of Princeton University Website

Bamboo Solar Vaccine Refrigerator

Bamboo Wind Turbine
Ting Tan – University of Vermont

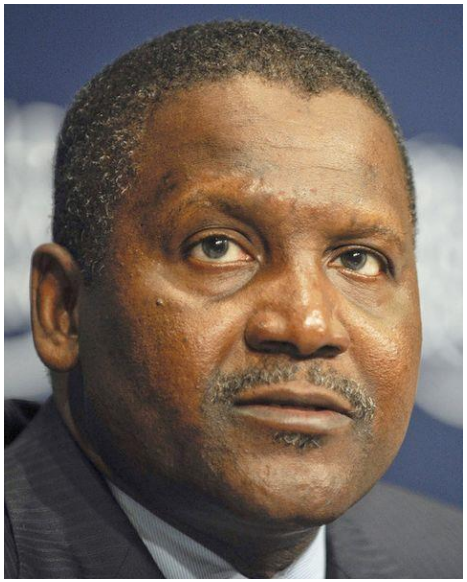
From Artisanal Mining to Wealth

- **Africa has a rich array of minerals and materials resources**
- **Artisanal Mining (Small-Scale)**
  - Difficult conditions
  - Limited profits
- **Industry (Mid- to Large-Scale)**
  - Africa's richest man (Aliko Dangote) manufactures cement from African raw materials
  - Value addition to people, minerals and natural products

The Materials of Africa

- Africa is a continent that is rich with mineral/material deposits
- These include gold, uranium, chromium, platinum and copper

http://poslovnisvijet.ba/prljave-igre-oko-cistih-izvora/

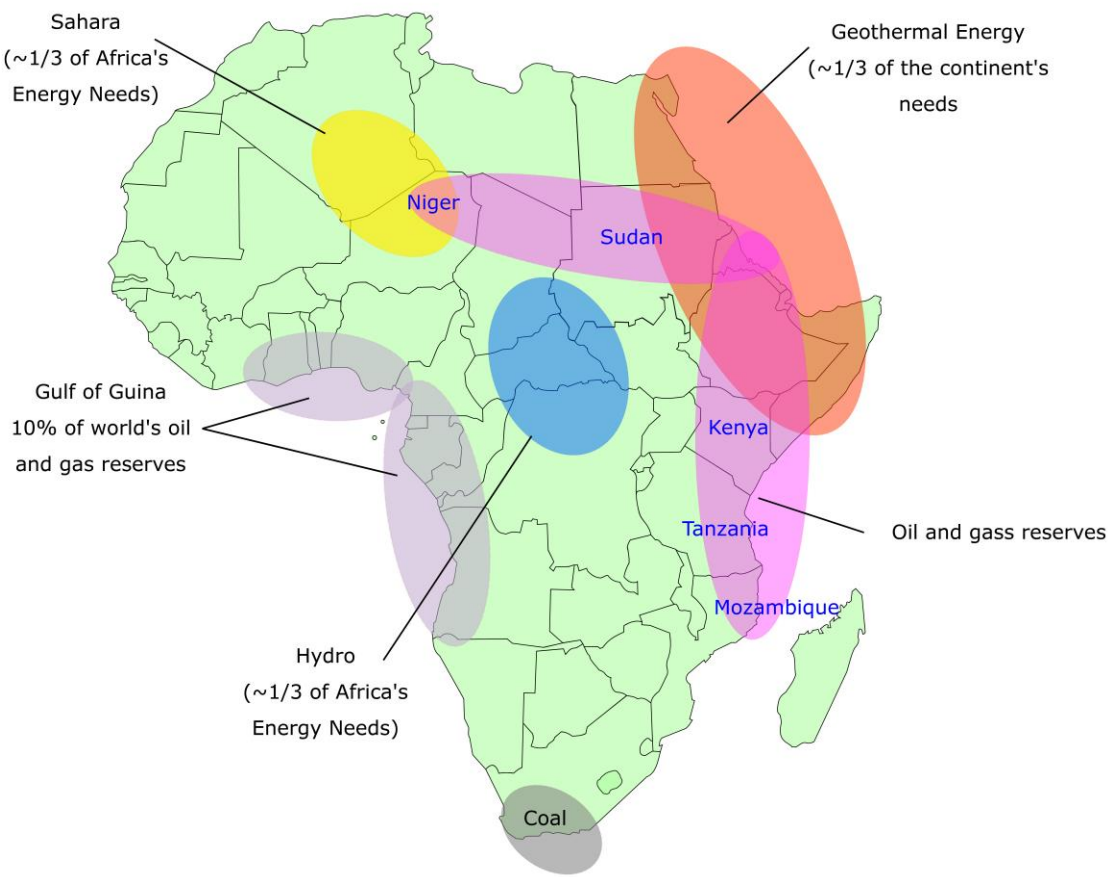


Africa's Richest Man- Aliko Dangote
(Biggest Producer of Cement)

https://en.wikipedia.org/wiki/Aliko_Dangote

The Energy Resources of Africa

- Africa is rich in energy resources
- The energy resources of Africa include
  - Fossil fuels
  - Solar energy
  - Hydro power
  - Wind energy
  - Geothermal energy
- These can be harnessed to produce and store energy in rural/urban areas
  - Energy generation
  - Energy storage



Strategy for Implementation

- PASMAT Week – Group Research Activities and Training
  - Biomaterials
  - Materials for energy
  - Multifunctional materials
- Education and outreach
  - MS4SSA and WISE
- Industrial collaboration
  - MIAB
  - Total

Materials Education and Outreach

- Need to integrate materials with minerals and manufacturing (PASET + Total)
- Women in Science and Engineering (WISE Africa)
- Outreach to schools (MS4SSA Program)
- Short courses for industry and policymakers + academia (knowledge diffusion)
- Industrial collaborations e.g. AIG, Total, Julius Berger, Karshi Solar Energy Plant, Neimeth, GE
- Transition from ideas to markets – add innovation components and industrial collaborations

Summary and Concluding Remarks

- This talk presents some examples of materials solutions to global problems – interdisciplinary solutions needed
  - Energy (Solar cells, Light Emitting Devices, Storage, Wind Turbines)
  - Water (Ceramic Water Filters)
  - Housing (Eco-materials)
  - Health (Nano-medicine, stents, poverty-related diseases)
- However there is a need to go from ideas to markets and communities (build on what we have)
- This requires a partnership with business, industry, government and policymakers
- Sustainable solutions must empower people to use science and innovation as engines of their development


THANK YOU!
THANK YOU!