



**Center for Energy Science and  
Technology Advanced Research  
(CESTAR)**

Mohamed Abdou

Professor, Mechanical and Aerospace Engineering Dept.  
Director, CESTAR

Presented to HSSEAS Industry Advisory Council  
Wednesday, October 26, 2005

Relevant web sites:

[www.cestar.seas.ucla.edu](http://www.cestar.seas.ucla.edu)

[www.fusion.ucla.edu](http://www.fusion.ucla.edu)

(both also have links to many web sites on HSSEAS' energy-related research)

# World Energy Scene\* (I)

## 1) The world uses a lot of energy

Average power consumption = 13.6 TWs, or 2.2 kW per person

World energy market ~ \$3 trillion/yr (electricity ~\$1 trillion/yr)

- very unevenly (OECD 6.2 kW/person; Bangladesh 0.20 kW/person; China 1.3kW/person)

## 2) World energy use is expected to grow

- growth necessary to lift billions of people out of poverty

## 3) 80% is generated by burning fossil fuels

→ *climate change* & debilitating pollution

- *which won't last for ever*

**Need major new (clean) energy sources  
- requires new technology**

\*See Sir Chris Llewellyn-Smith, FPA, October 11, 2005

# World Energy Scene (II)

## 4) Use of primary energy

- In USA: 34% residential & commercial; 37% industrial; 26% transport (~30% domestic)

**~1/3 of primary energy => electricity (@ ~ 35% efficiency => 12.4% of world's energy use)**

- Fraction → electricity ~ development (14.3% USA; 6.0% Bangladesh) and is likely to grow

- Fuel → electricity very country dependent

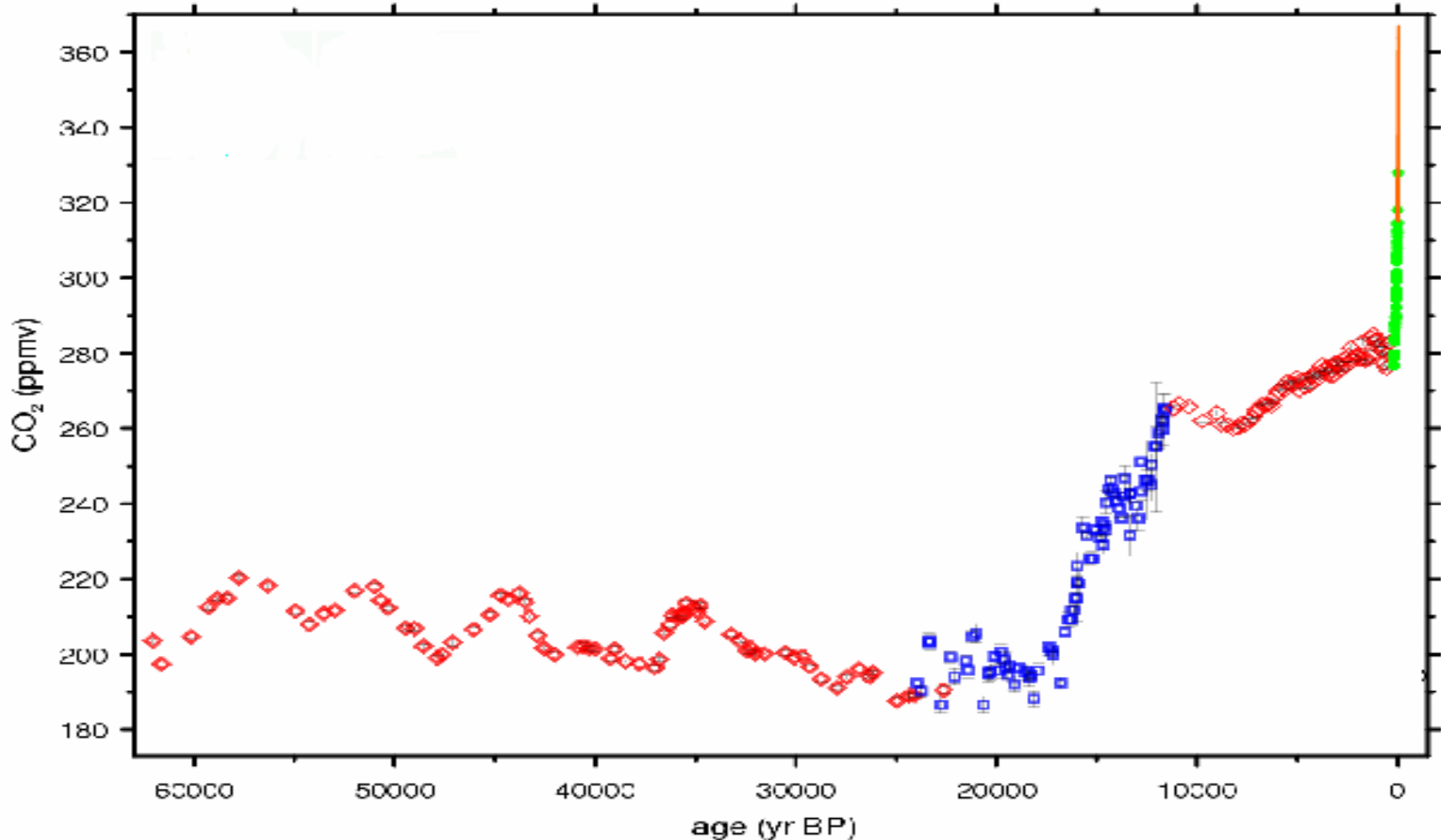
e.g. coal = 35% in UK\*, 54% in USA, 76% in China

\* falling as EU emission directives => closure of coal power stations; without new nuclear build the UK likely to be 70% reliant on (mainly imported) gas by 2020

# Future Energy Use

- The International Energy Agency (IEA) expects **the world's energy use to increase 60%** by 2030 (while population expected to grow from 6.2B to 8.1B) - driven largely by growth of energy use and population in India (current use = 0.7 kW/person, vs. OECD average of 6.2 kW/person) and China (current use = 1.3 kW/person)
- **Strong link between energy use and the Human Development Index** (HDI ~ life expectancy at birth + adult literacy and school enrolment + gross national product per capita at purchasing power parity) – need increased energy use to lift billions out of poverty

# Carbon dioxide levels over the last 60,000 years - we are provoking the atmosphere!



# Meeting the Energy Challenge Requires:

- **Fiscal measures to change the behaviour of consumers, and provide incentives to expand use of low carbon technologies**
- **Actions to improve efficiency** (domestic, transport, ...)
- **Use of renewables where appropriate** (although locally useful, not hugely significant globally)

**BUT only four sources capable in principle of meeting a large fraction of the world's energy needs:**

- **Burning fossil fuels** (currently 80%) - develop & deploy CO<sub>2</sub> capture and storage
- **Solar** - seek breakthroughs in production and storage
- **Nuclear fission** - hard to avoid if we are serious about reducing fossil fuel burning (at least until fusion available)
- **Fusion** - with so few options, we must develop fusion as fast as possible, even if success is not 100% certain

## **CESTAR** Initiated at HSSEAS to address the Energy Challenge

Energy is one of the most serious challenges facing humanity in the XXI Century

Another challenge is water , which can be solved by Energy (desalination)

Universities, particularly engineering schools, can make substantial contributions to addressing the energy challenge:

- Research on providing new clean energy sources and better utilization
- Training future leaders in energy production and utilization

The Center for Energy Science and Technology Advanced Research (**CESTAR**) was established at HSSEAS in 2005 to help develop Energy-related research into a major thrust in the School.

CESTAR was established in response to a request from Dean Vijay Dhir. Professor Mohamed Abdou was appointed as Director.

# CESTAR

**Mission:** *to provide a common focal point for collaboration and synergism among researchers at UCLA involved in energy related research*

## **Model for Center Operation: “ACTIVE”**

- Exchange information and facilitate collaboration among faculty, students and researchers
- Capitalize on and strengthen the already existing energy-related research activities, emphasize niche areas
- Undertake initiatives for research proposals in energy-related engineering fields
- The Center should proceed gradually, aim for national and international recognition, and ultimately influence national and international energy policy

*(Note: Some niche areas of the Center already have very high levels of recognition and influence, nationally and internationally)*



# CESTAR Members

The response from faculty and researchers to participate in CESTAR has been very enthusiastic.

## **CESTAR currently has 40 members (not counting students):**

- 30 regular faculty, 4 adjunct or emeritus faculty, 6 researchers
- 22 MAE, 7 Material Science, 6 EE, 3 Civil, 2 Chem. Eng.

## **CESTAR Focus (niche) Areas and Area Leaders:**

- Fusion (Prof. Abdou)
- Hydrogen (Prof. Manousiouthakis)
- Materials for Energy Applications (Prof. Pei)
- Energy Conversion and Conservation (Prof. Catton)

# **EXAMPLES of Current Research Programs in CESTAR**

# Fusion:

## An Example of a Focus Area in CESTAR

The Fusion Research Program in CESTAR is recognized nationally and internationally as having a leadership role in:

- Advanced Energy Extraction
- High Heat Flux Technology
- Tritium Production, Extraction and Control
- Materials
- Neutronics
- Reactor Core Design and Engineering

Technical Disciplines involved: particle transport, fluid mechanics, MHD, heat and mass transfer, structural mechanics, radiation damage

UCLA is designated as the lead US organization for several major projects:

- ITER Test Blanket Program
- Collaborative US – Japanese Universities (MEXT) Program in Thermofluids
- Conceptual Definition and Design of Component Test Facility

# Incentives for Developing Fusion

## **Fusion powers the Sun and the stars**

- It is now within reach for use on Earth

**In the fusion process lighter elements are “fused” together, making heavier elements and producing prodigious amounts of energy**

## **Fusion offers very attractive features:**

- Sustainable energy source  
(for DT cycle; provided that Breeding Blankets are successfully developed)
- No emission of Greenhouse or other polluting gases
- No risk of a severe accident
- No long-lived radioactive waste

**Fusion energy can be used to produce electricity and hydrogen, and for desalination**

# UCLA has the US Lead Role in the ITER Test Blanket Program

The World is about to construct the **next step** in fusion development, a device called **ITER** (as a joint project among Europe, Japan, US, Russia, China and Korea)

- **ITER** will demonstrate the **scientific and technological feasibility** of fusion energy for **peaceful purposes**
- **ITER** will produce **500 MW** of fusion power
- Cost, including R&D, is **10 billion dollars**

A key element in ITER is the testing of “blankets” (technology for simultaneous power extraction and tritium breeding/control)

- UCLA leads the US effort, which involves about 12 organizations
- Prof. Abdou is the US leader in the International ITER Test Blanket Program

# UCLA is Recognized as World Leader:

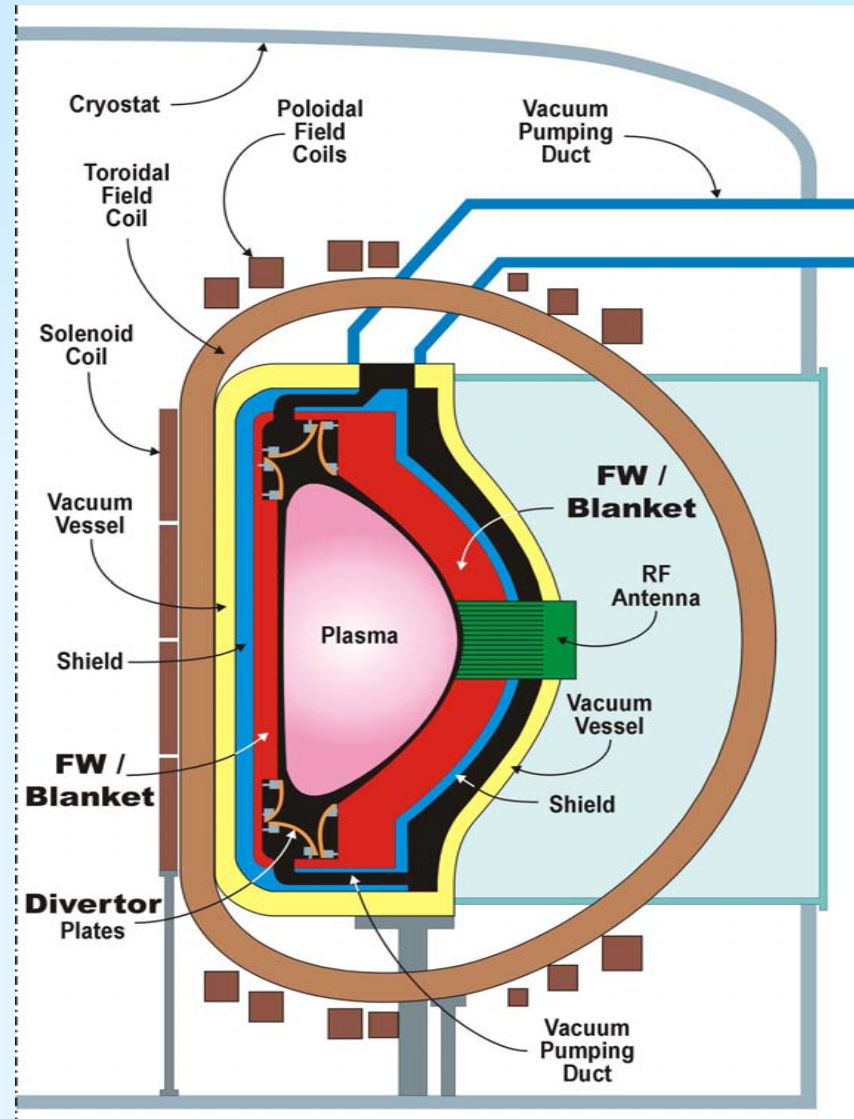
## *Fusion Power & Fuel Cycle Technology*

### Fusion Nuclear Technology Components and Materials from the edge of the Plasma to TF Coils (Reactor “Core”)

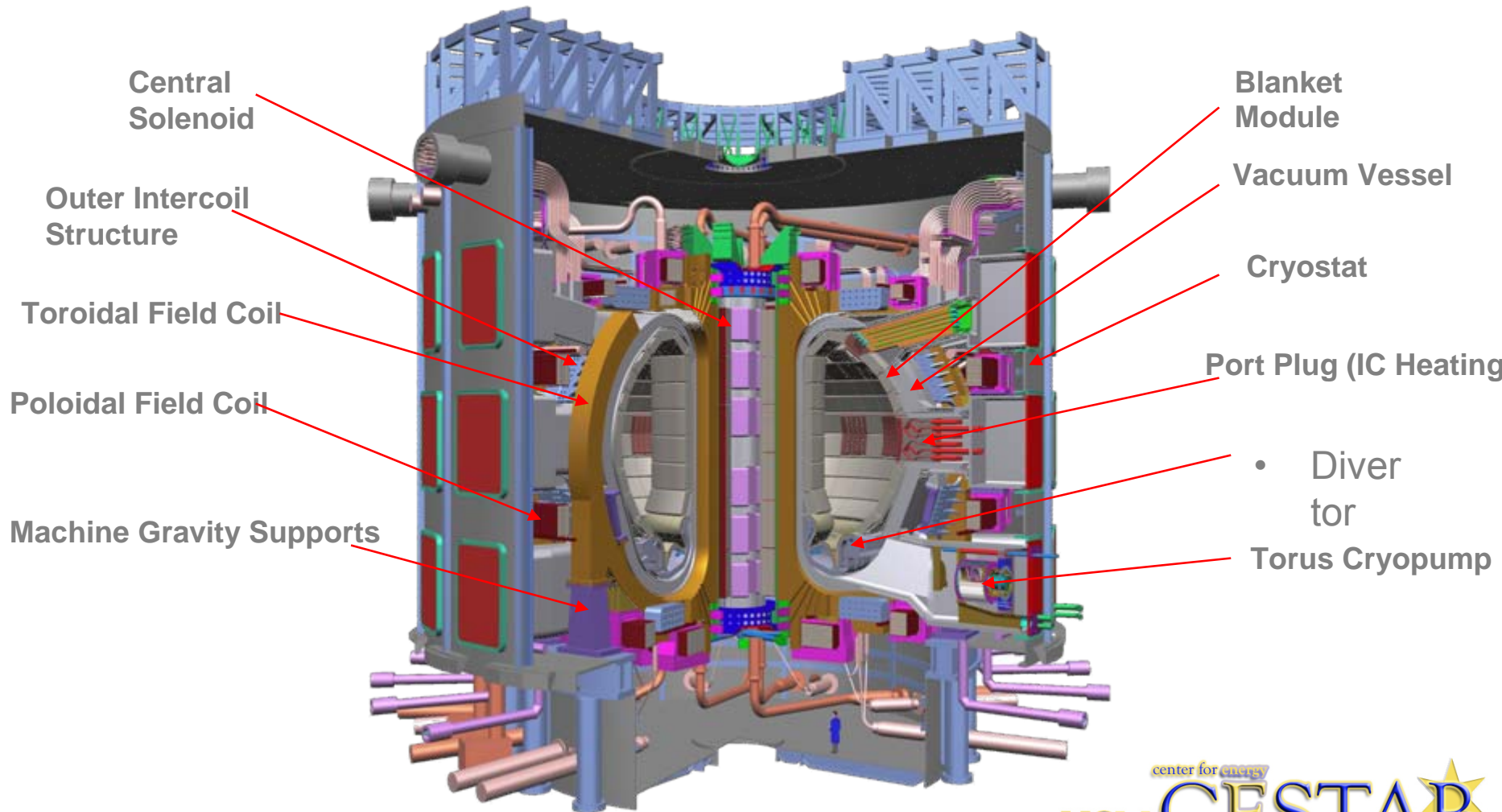
1. Blanket Components
  - a. divertor, limiter
  - b. rf antennas, launchers, wave guides, etc.
2. Plasma Interactive and High Heat Flux Components
3. Vacuum Vessel & Shield Components

### Other Components affected by the Nuclear Environment

4. Tritium Processing Systems
5. Instrumentation and Control Systems
6. Remote Maintenance Components
7. Heat Transport and Power Conversion



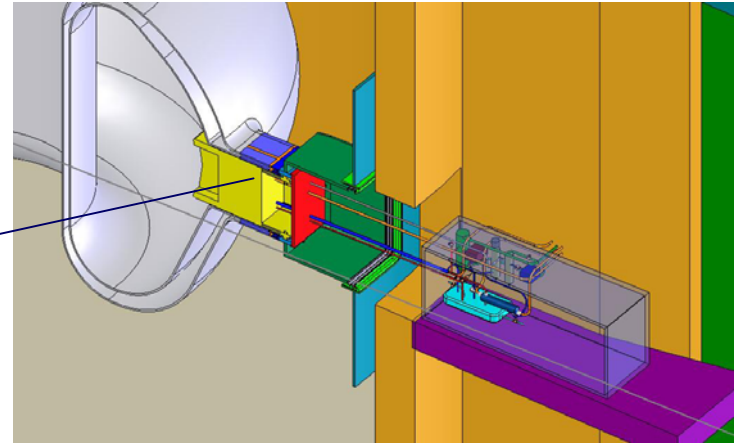
# ITER Design - Main Features





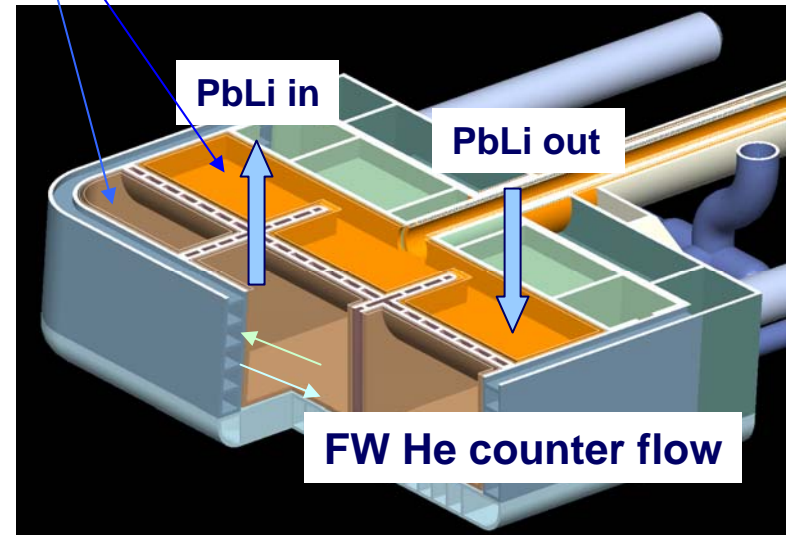
# US DCLL TBM module

All structures are He-cooled @ 8MPa  
self-cooled PbLi flows in poloidal direction



SS frame

FCI is the Thermal and MHD Insulator lining all PbLi channels



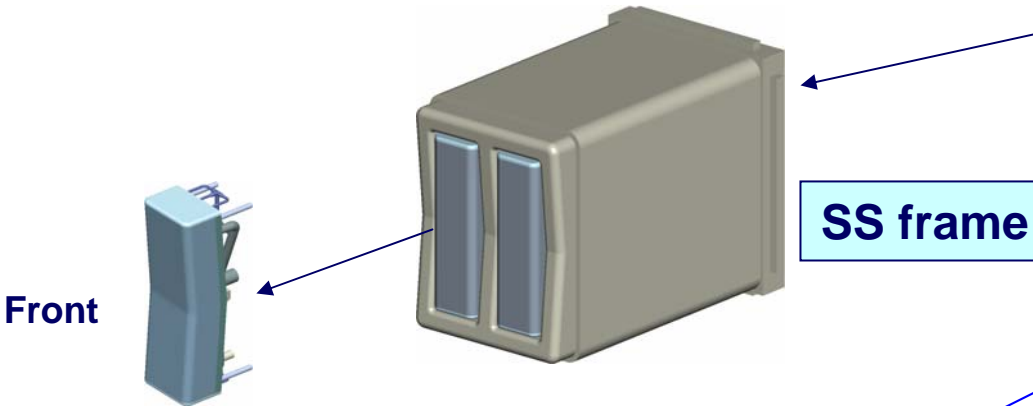
PbLi in

PbLi out

FW He counter flow

He in  
He out

PbLi in  
PbLi out



Front

FS structure

Back

Be front face



# UCLA MTOR Lab

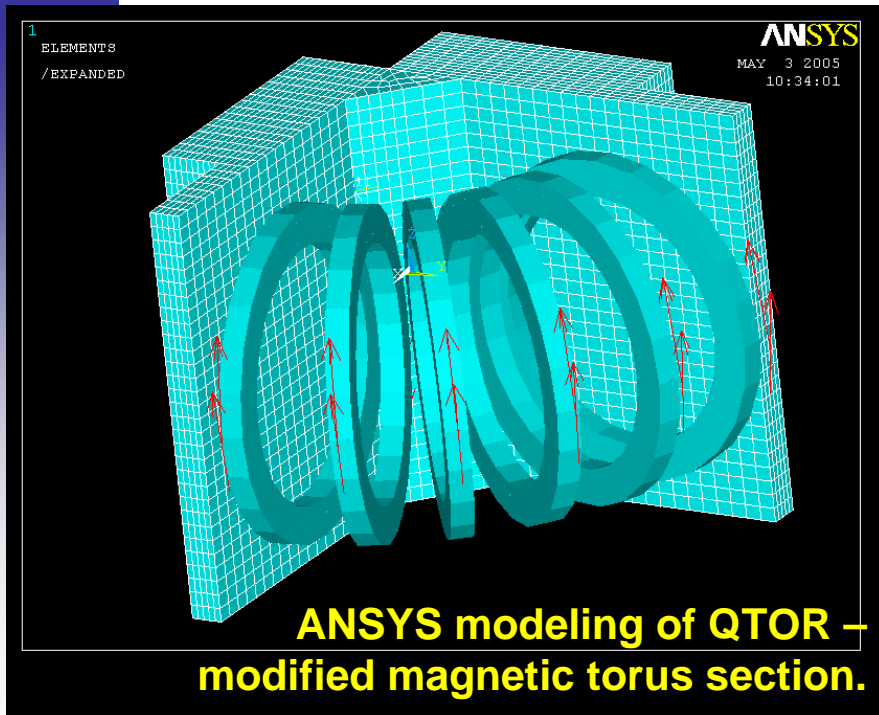
**FLIHY  
Electrolyte loop**

**BOB  
magnet**

**QTOR  
magnet and  
LM Flow  
Loop**

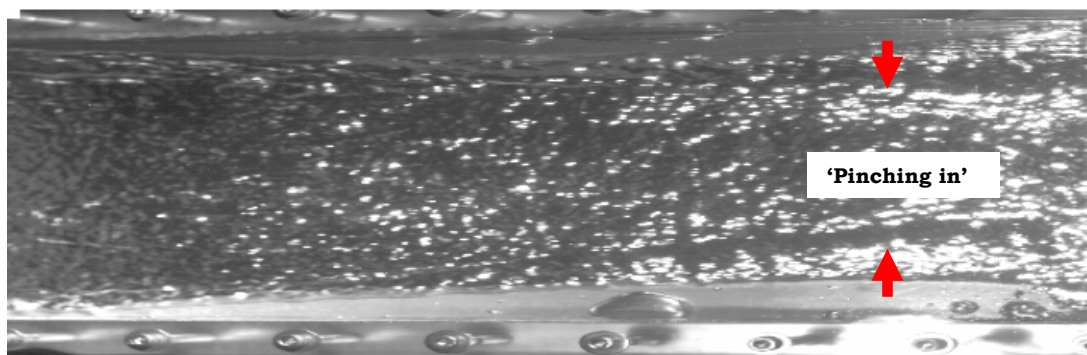
# The UCLA toroidal field simulation facility has been enhanced to 1.1 T on the inboard to do wide channel experiments

- ❑ Renamed QTOR - Size reduced to  $\frac{1}{4}$  torus – flux closed through steel plates.  $1/R$  field dependence preserved,  $R = 80$  cm,  $a = 40$  cm
- ❑ This will allow for space to carry out toroidal field tests on wide channels with gallium alloy in a field scaled to NSTX divertor region – experiments are upcoming

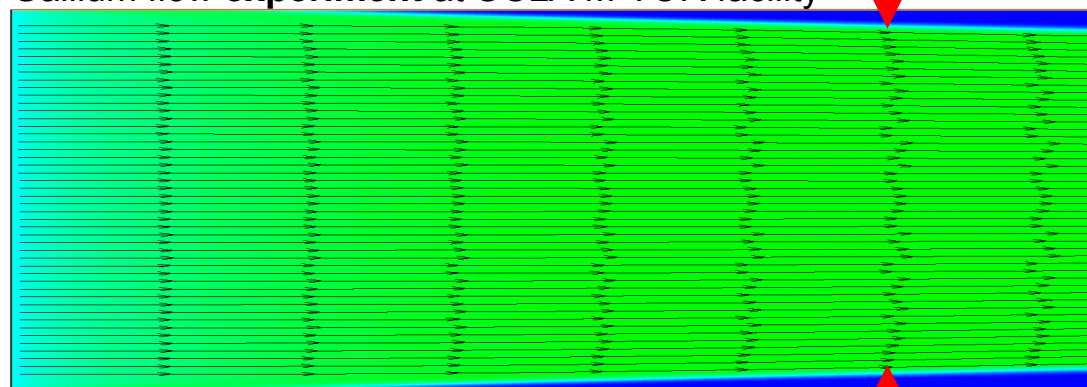


# New 3-D MHD codes and experimental facilities used to address flowing liquid metals in NSTX divertor fields – now being applied to DCLL-TBM

- New phenomenon observed in both experiments and numerical simulation for film flows in NSTX divertor: the liquid film tends to ‘pinch in’ away from the wall under a positive surface normal magnetic field gradient.



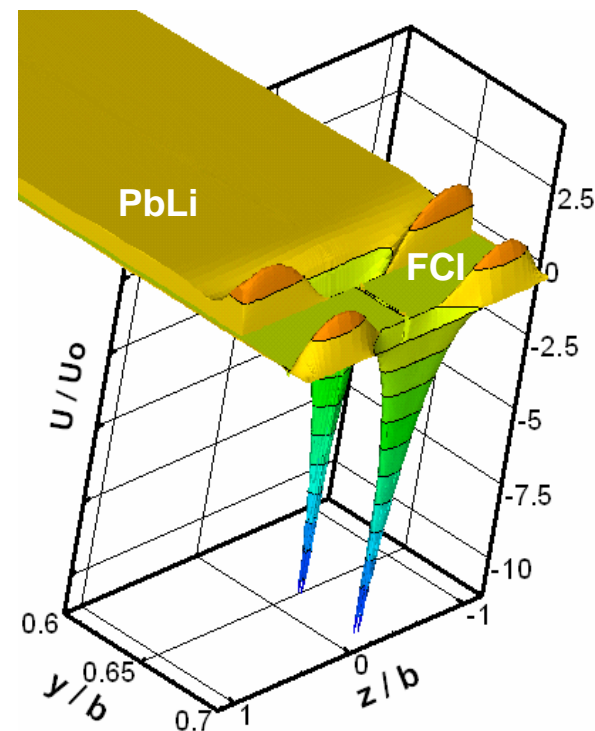
Gallium flow **experiment** at UCLA M-TOR facility



HIMAG **simulation** of the above experiment

Flow Velocity : 3 m/s

Average surface normal field gradient: 0.6 T/m

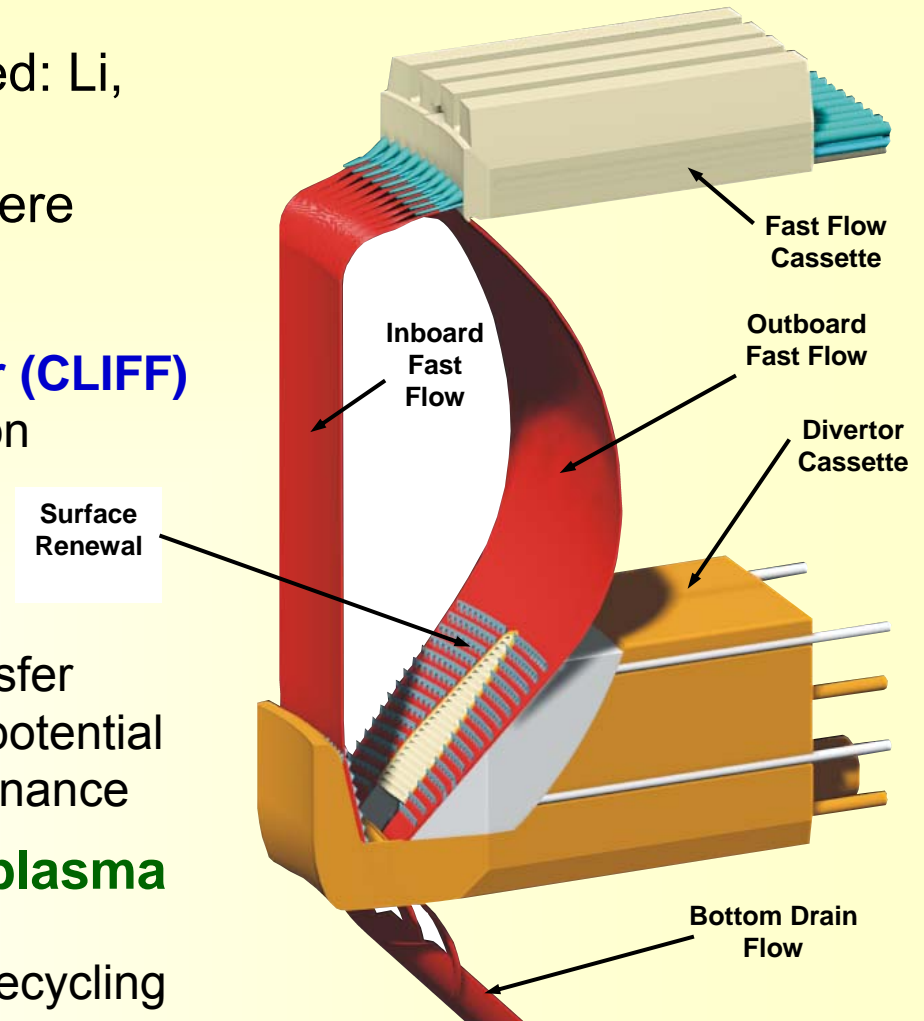


- Simulation with MHD research code (at UCLA) shows tendency for strong reversed flow jets near slot or crack in flow channel insert (MTOR experiments in development)



# Many liquid wall reactor concepts for high power density were conceived & analyzed in APEX

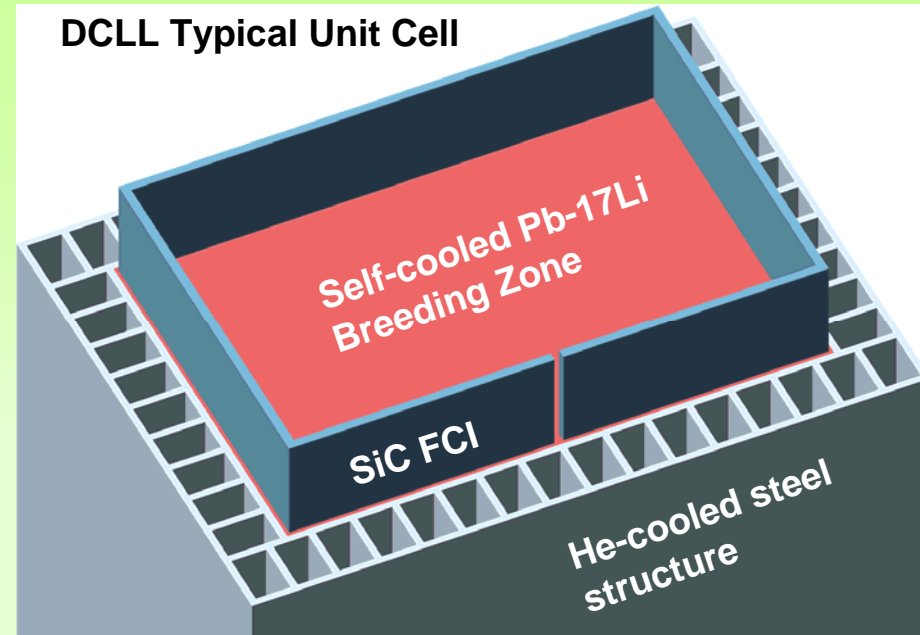
- ❑ Many candidate liquids were studied: Li, Sn-Li, Sn, Flibe and Flinabe
- ❑ Several liquid wall flow schemes were conceived:
  - Thick liquid walls
  - **Thin fast flowing protection layer (CLIFF)**
  - Inertial or EM assisted wall adhesion
  - Integrated or stand-alone divertors
- ❑ Concept performance was analyzed from many perspectives
  - Liquid wall flow MHD and heat transfer
  - Breeding, shielding and activation potential
  - Simplicity of system design, maintenance
- ❑ **Interactions of liquid walls with plasma operation were emphasized**
  - Plasma edge effects, impurities & recycling
  - Liquid metal motion coupling to plasma modes



*Thin liquid wall concept (blanket region behind LW not shown)*

# Pathway Toward Higher Temperature Through Innovative Designs with Current Structural Material (Ferritic Steel): *Dual Coolant Lead-Lithium (DCLL) FW/Blanket Concept*

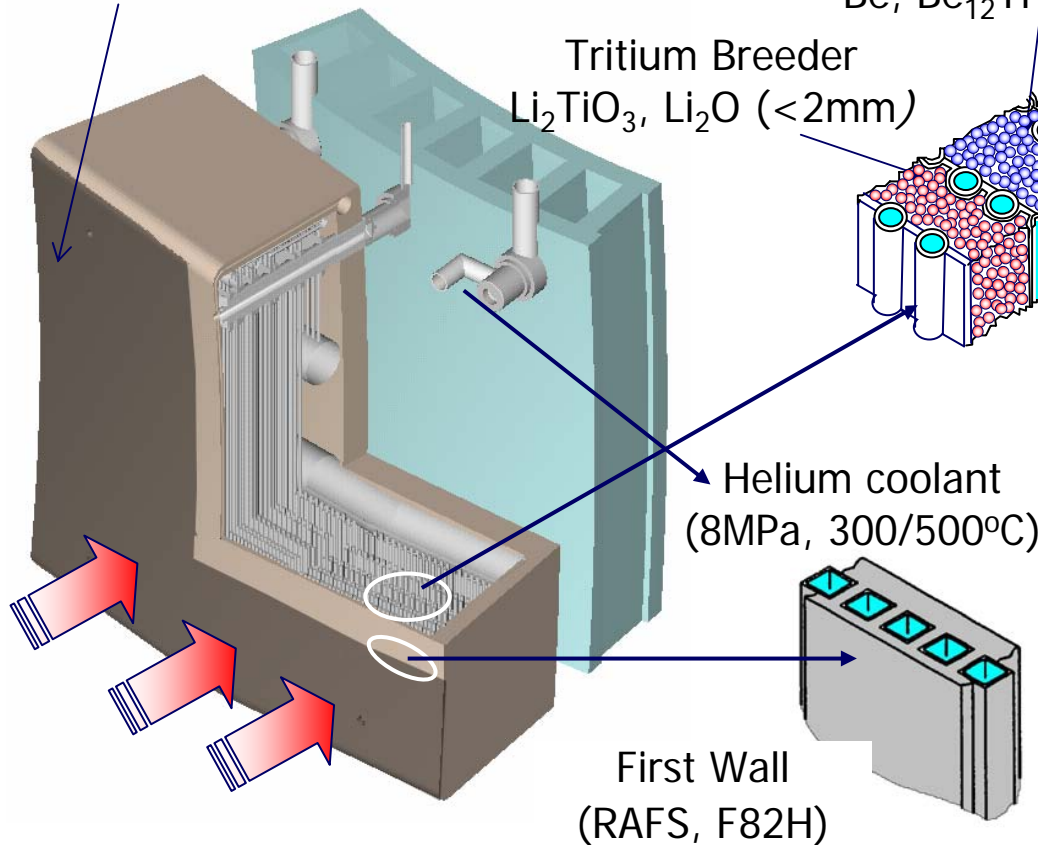
- ❑ First wall and ferritic steel structure cooled with helium
- ❑ Breeding zone is self-cooled
- ❑ Structure and Breeding zone are separated by SiCf/SiC composite *flow channel inserts (FCIs)* that
  - ❖ Provide thermal insulation to decouple PbLi bulk flow temperature from ferritic steel wall
  - ❖ Provide electrical insulation to reduce MHD pressure drop in the flowing breeding zone



*Pb-17Li exit temperature can be significantly higher than the operating temperature of the steel structure ⇒ High Efficiency*

# UCLA's work on sophisticated modeling of pebble bed behavior feeds into the design of large scale fusion blanket components

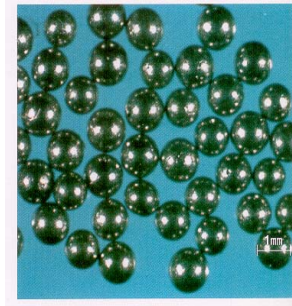
Be coating for FW protection



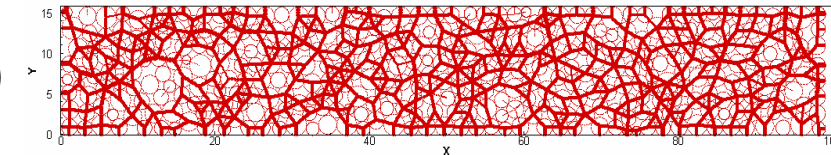
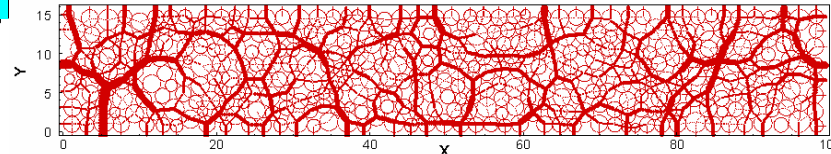
Neutron Multiplier  
 $\text{Be}, \text{Be}_{12}\text{Ti}$  (<2mm)

Tritium Breeder  
 $\text{Li}_2\text{TiO}_3, \text{Li}_2\text{O}$  (<2mm)

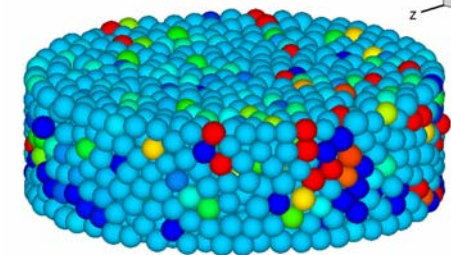
Be pebble



$\text{Li}_2\text{O}$  ceramic breeder



*Force distribution at breeder particle contacts before (top) and after (bottom) onset of creep deformation*



*3-D computer model of a pebble bed*

**Surface Heat Flux:  $1 \text{ MW/m}^2$**   
**Neutron Wall Load:  $5 \text{ MW/m}^2 (1.5 \times 10^{15} \text{ n/cm}^2 \text{ s})$**

Hydrogen Engineering Research Consortium  
(HERC) <http://herc.ucla.edu>

## Participating Faculty and Projects

V. I. Manousiouthakis (Director): H<sub>2</sub> production methods

V. K. Dhir: Heat transfer enhancement in FC cars

J. Liao: Biological H<sub>2</sub> production through metabolic engineering

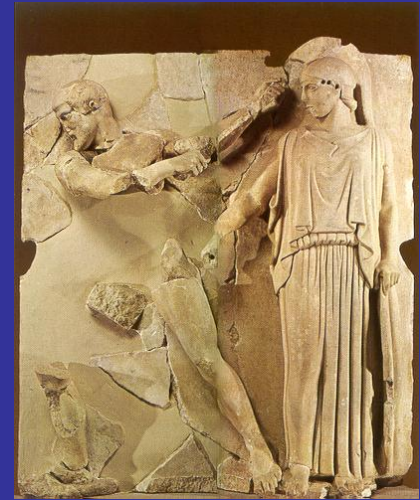
G. Orkoulas: H<sub>2</sub> storage

L. Pilon: Photo-biological H<sub>2</sub> production and CO<sub>2</sub> sequestration

S. Senkan: Catalytic conversion of ethanol to H<sub>2</sub>

W. Van Vorst, V. Manousiouthakis: H<sub>2</sub> car prototyping

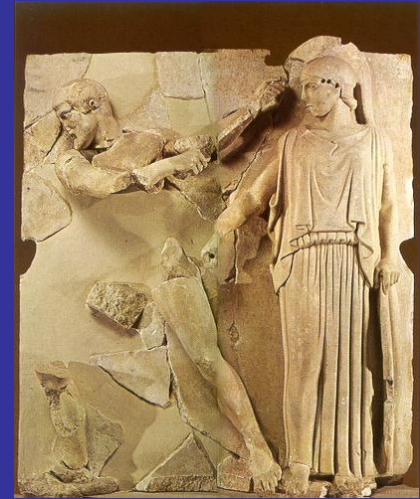
**Systems Engineering Laboratory UCLA**



HERCules  
cleaning  
Augeas'  
stables, with  
water, under the  
guidance of  
Athena



Hydrogen Engineering Research Consortium  
(HERC) <http://herc.ucla.edu>



## HERC Hydrogen Infrastructure Elements

2 DaimlerChrysler Hydrogen Vehicles

Laboratory Bench experiments on hydrogen production  
and fuel cell use

Hydrogen Fueling Station to be built on UCLA campus  
(Completion 2007)

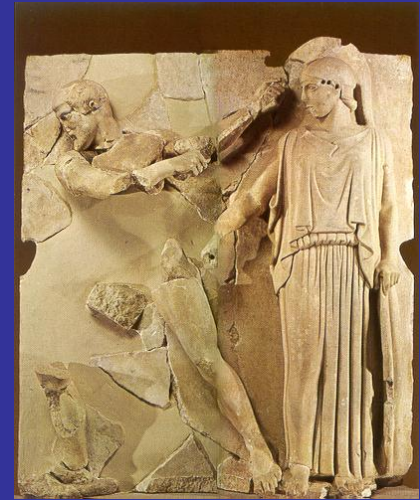


Hydrogen Engineering Research Consortium  
(HERC) <http://herc.ucla.edu>

## **HERC Upcoming Initiatives**

California British-Columbia collaboration on Hydrogen  
California Summit on Waste to Clean Energy/Hydrogen  
Proposal to Federal And State Agencies for the  
Establishment of a Hydrogen Engineering Research  
Center at UCLA

Industrial collaborators sought to team up with HERC  
Entrepreneurs sought to license UCLA H<sub>2</sub> Technology

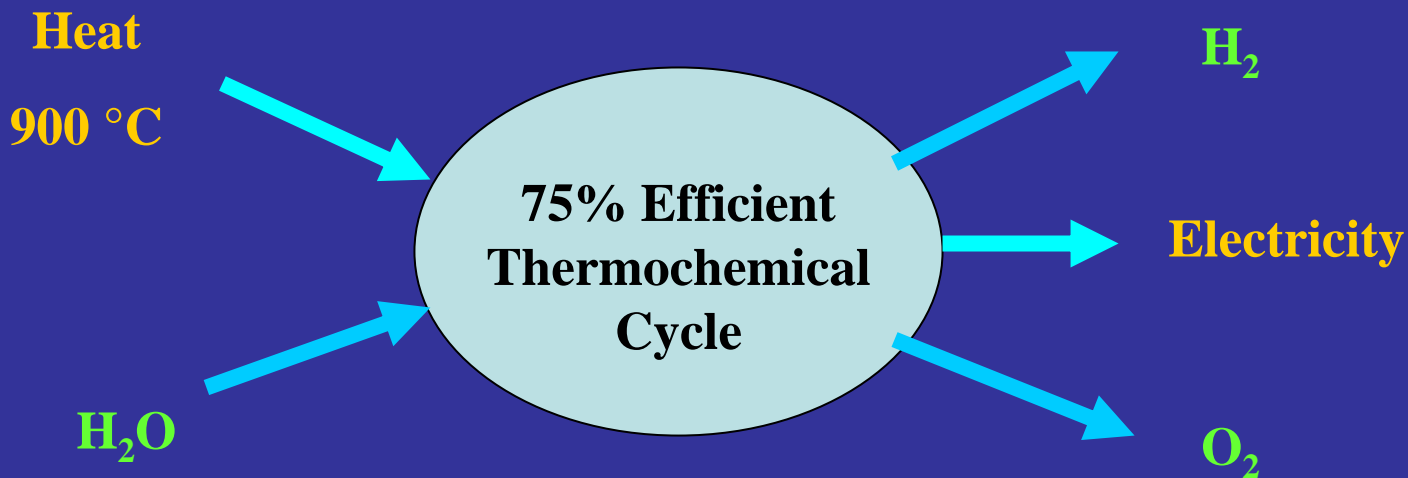


UCLA Chemical & Biomolecular Engineering Department  
DaimlerChrysler-UCLA H2 Vehicle



Systems Engineering Laboratory UCLA

# Energy to Hydrogen: Thermochemical Water Splitting Cycle



*Source: Manousiouthakis, UCLA Patent application, "Hydrogen Production by a Novel Thermochemical Water Splitting Cycle (2005)"*

# Description of Materials Thrust

In the materials for energy thrust, we work on a broad range of advanced materials. The current focus is power generation by polymer solar cells. These plastic cells potentially cost little to fabricate and are convenient to install and maintain. The other major effort is focused on new materials for energy storage, such as advanced batteries and hydrides. The current research spans from new materials to device architectures, including:

- Synthesis of new polymer semiconductors with small band gap and high carrier mobility
- Polymer blends to form bulk heterojunctions for efficient charge separation
- Polymer-inorganic hybrids to complement polymers' hole mobility with the high electron mobility of nanostructured inorganic semiconductors
- Nanostructured polymer solar cells
- Novel transparent electrode material
- Tandem cells to boost overall power conversion efficiency
- Nanostructured energy storage materials.
- Computational design of new materials for hydrogen storage
- Theory of fundamental processes in energy storage materials

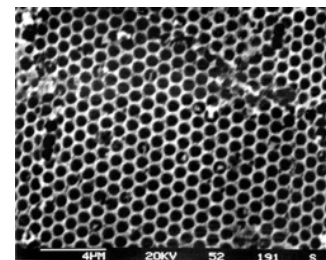


## Prof. Bruce Dunn

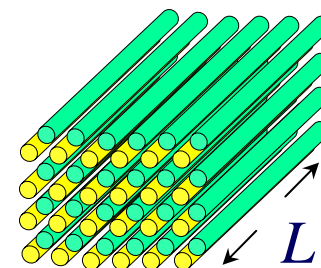
Department of Materials Science and Engineering

Research in the Dunn group involves the synthesis of inorganic and hybrid materials and characterization of their electrical, optical and electrochemical properties. One of the principal themes in the group is the synthesis and characterization of electrochemical materials and devices. Among the current research projects in the group are the creation of new materials for electrochemical energy storage, the development of novel battery structures and biofuel cells.

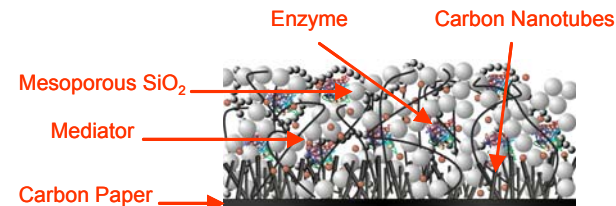
- One of our research projects involves the use of sol-gel synthesis methods to create electrochemical materials with designed chemistry and microstructure. We are interested in transition metal oxide aerogels and we have been investigating how their high surface area influences electrochemical properties. These aerogel materials exhibit properties which combine the characteristics of both batteries and capacitors, and they are able to reversibly insert a variety of monovalent and divalent ions.



- We were awarded a MURI grant to establish the enabling science and technology for creating 3-dimensional nanostructured batteries. 3-D configurations provide a means of keeping diffusion distances short leading to higher energy densities within a confined footprint area. The 3-D batteries currently being investigated are directed at powering MEMS devices.



- We have recently begun research on biofuel cells, devices which convert the chemical energy of a fuel (glucose) and oxidant (oxygen) directly to electrical energy by utilizing enzymes to catalyze oxidation and reduction reactions. Our research involves the development of an electrode nanoarchitecture in which the enzymes, mediator and carbon nanotubes (conductive component) are immobilized in a sol-gel matrix.



# Description of Professor Sungtaek Ju's Research

The Multiscale Thermosciences Laboratory (MTSL) is engaged in fundamental experimental and theoretical research activities in the characterization and synthesis of novel materials/material systems and the development of nanomanufacturing techniques. We are conducting fundamental study of nanoscale thermal transport phenomena to develop materials with superior thermal characteristics for energy and other applications. We have demonstrated nanolaminate-based super-thermal barriers that maximize the thermal protection properties without compromising mechanical or chemical characteristics. The MTSL is also conducting fundamental research into novel thermal fluids, including nanofluids and ionic liquids, to enhance the thermal performance of energy harvesting equipments and heat exchangers. Our research on nano-manufacturing is focused on the development of low-cost large-area nanoscale patterning techniques to create optical meta-materials for solar energy harvesting and related applications and nanostructured surfaces with enhanced heat transfer performance.

# CESTAR Members

Mohamed Abdou	MAE	John Mackenzie	MSE
A.V. Balakrishnan	EE	Ajit Mal	MAE
Ivan Catton	MAE	Neil Morley	MAE
Francis Chen	EE	Ming-Jiu Ni	MAE
Yoram Cohen	ChemE	Vidvuds Ozolins	MSE
Vijay Dhir	Dean / MAE	William Peebles	EE
Bruce Dunn	MSE	Qibing Pei	MSE
Jeff Eldredge	MAE	Laurent Pilon	MAE
Nasr Ghoniem	MAE	Yahya Rahmat-Samii	EE
Mark Goorsky	MSE	Richard Perrine	CEE
H. Thomas Hahn	MAE	Tom Sketchley	MAE
Robert Hicks	ChemE	Owen Smith	MAE
Chih-Ming Ho	MAE	Sergey Smolentsev	MAE
Tatsuo Itoh	EE	Jonathan Stewart	CEE
J. Woody Ju	CEE	Tsu-Chin Tsao	MAE
Sungtaek Ju	MAE	Kang Wang	EE
Ann Karagozian	MAE	Jenn-Ming Yang	MSE
John Kim	MAE	Yang Yang	MSE
Les Lackman	HSSEAS	Alice Ying	MAE
Adrienne Lavine	MAE	Mahmoud Youssef	MAE