



Nuclear Fission Renaissance: Opportunities for Research

Mujid S. Kazimi

Director, Center for Advanced Nuclear Energy Systems
TEPCO Professor of Nuclear Engineering
Professor of Mechanical Engineering
Kazimi@mit.edu, tel 1-617-253-4206

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MIT Center for Advanced Nuclear Energy Systems




Center For Advanced Nuclear Energy Systems

<i>Research Programs</i>			
Advanced Power Reactors	Nuclear Fuel Cycle Economics and Policy	Nuclear Systems Performance Management	Nuclear Energy and Sustainability
<i>Education Programs</i>		<i>National & International Collaborations</i>	
<p>Professional Courses</p> <ul style="list-style-type: none"> - Nuclear Plant Safety - Reactor Technology for Power Plant Executives – with INPO - Risk-Informed Operational Decision Making - Materials Degradation Management – now EPRI 	<p>Symposium Series</p> <ul style="list-style-type: none"> - High Burnup LWR Fuel - Nuclear Energy and the Hydrogen Economy - Simulation of Fuel Cycle - Next Generation Reactor - Innovative Nuclear Systems - Rethinking the Fuel Cycle - Supercrit. CO2 Power Cycle - Directions for Breakthrough Research 	<ul style="list-style-type: none"> * Battelle Energy Alliance for INL management * Nuclear Regulatory Commission for Adv. React. • EPRI/ENI Waste Manage. * TEPCO on BWR advanced technology * CEA on fuel cycle issues * INET-Tsinghua Univ. on gas reactors 	





Looking for the next technology

- *High power density fuel for PWRs and BWRs*
 - *Annular Fuel for PWRs (DOE, proposed for KAERI)*
 - *Slim Fuel for BWRs (TEPCO)*
 - *Cross Shaped Fuel for BWRs (TEPCO)*
 - *Ceramic cladding materials for high temperature water reactors (W, proposed for EPRI)*
 - *The use of nuclear energy to enhance economics of liquid fuels*
 - *Design of a nuclear system to heat up oil fields. (proposed for ENI)*
 - *design of a hydrogen production system using a medium temperature reactor (MIST)*
 - *Fuel Cycle Options for An Expanding Nuclear Energy (EPRI/NEI)*
 - *Assessment of Uranium resource magnitude and cost*
 - *Physics of actinide burning designs for LWRs, Gas Reactors and Fast reactors.*
 - *Fuel Cycle System Simulation Code Assessment - CAFCA, others*
 - *Economics of separation and manufacturing of actinide fuels*
 - *MIT reactor redesign for higher power with LEU (DOE-ANL)*
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Ceramic SiC as a Clad for LWR Fuel

A project involving MIT, Westinghouse, Gamma Engineering, and ORNL

Objective is to enable high power density, higher burnup, and higher water exit temperatures as a means to improve future LWR economics

	Zr	SiC
Long-term Service Temperature	~750°C	-1700°C
Cross-Section	~193 mb	~148 mb
Thermal Conductivity	33 watt/m/°K	5 watt/m/°K
17% Steam Corrosion in 400 sec	<1200°C	-1900°C
BWR water corrosion @360°C@ 32 days (recision rate)	1 micron	<0.1 micron

1. Good performance during irradiation
 - Gap changes slowly with time, even during a transient due to low creep below 1000 °C. Large margin to dissociation at 2000 °C
 - Relevant clad properties do not degrade with time, temperature, or radiation (after initial conductivity reduction)
 2. Very low operating and accident corrosion rates
 - Estimated <10% Zr corrosion rate in BWR conditions
 - UO₂/SiC interaction not an issue
 - SiC/steam/air corrosion rates 10⁻⁶ to 10⁻⁷ of Zr corrosion rates
 - Reduced hydrogen production during severe accidents
 3. Potential for allowing high clad temperature during transients, thus eliminating Critical Heat Flux issues
 4. Reduced cladding neutron absorption cross sections
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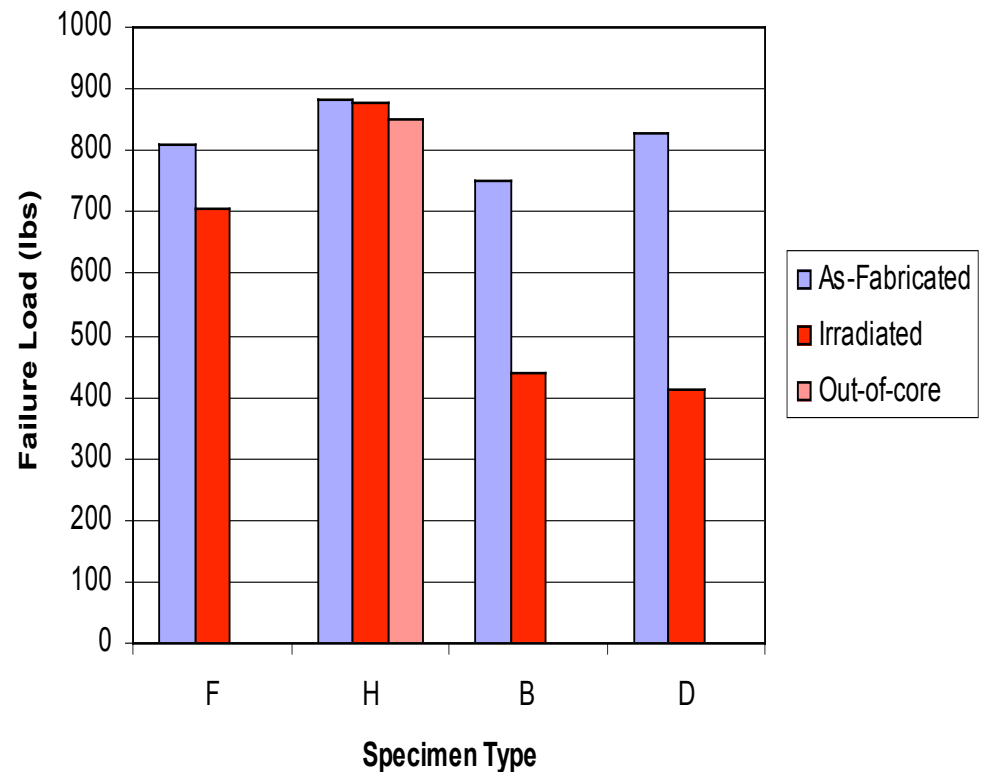
Gamma/NovaTech Winding Architectures

- Bamboo-A
 - 2 Layers
 - 3 Layers
 - Thick at Inter-Weaves
 - Inter-weaves Align Axially
- Bamboo-C
 - 2 Layers
 - 3 Layers
 - Thick at Inter-Weaves
 - Inter-weaves Align Circumferentially
- Max Interweave
 - 2 Layers
 - 3 Layers
 - Thick at Inter-Weaves
 - Inter-weaves Distributed



Summary of MITR Irradiation Testing

- Specimens under PWR coolant conditions (300 C, 10 MPa, 20 cc/kg H₂, 800 ppm B, 2.2 ppm Li)
- Initial exposure of 24 in-core samples and 15 above-core samples for 68 EFP Days, 4 months elapsed time, with interim examination of sample subset (see figure)
- Weighing and visual inspection at MIT, mechanical property testing at ORNL
- Second exposure of 12 new and 12 continued samples for 156 EFP Days ended October 9. Examination is now beginning.



Several samples showed promise,
But not all



Expanding to new sciences


- **Nanotechnology**

- *Solid surfaces*
- *manufacturing of actinide fuels*
- *Nanofluids in radiation environments*
- *Improve efficiency of energy conversion*

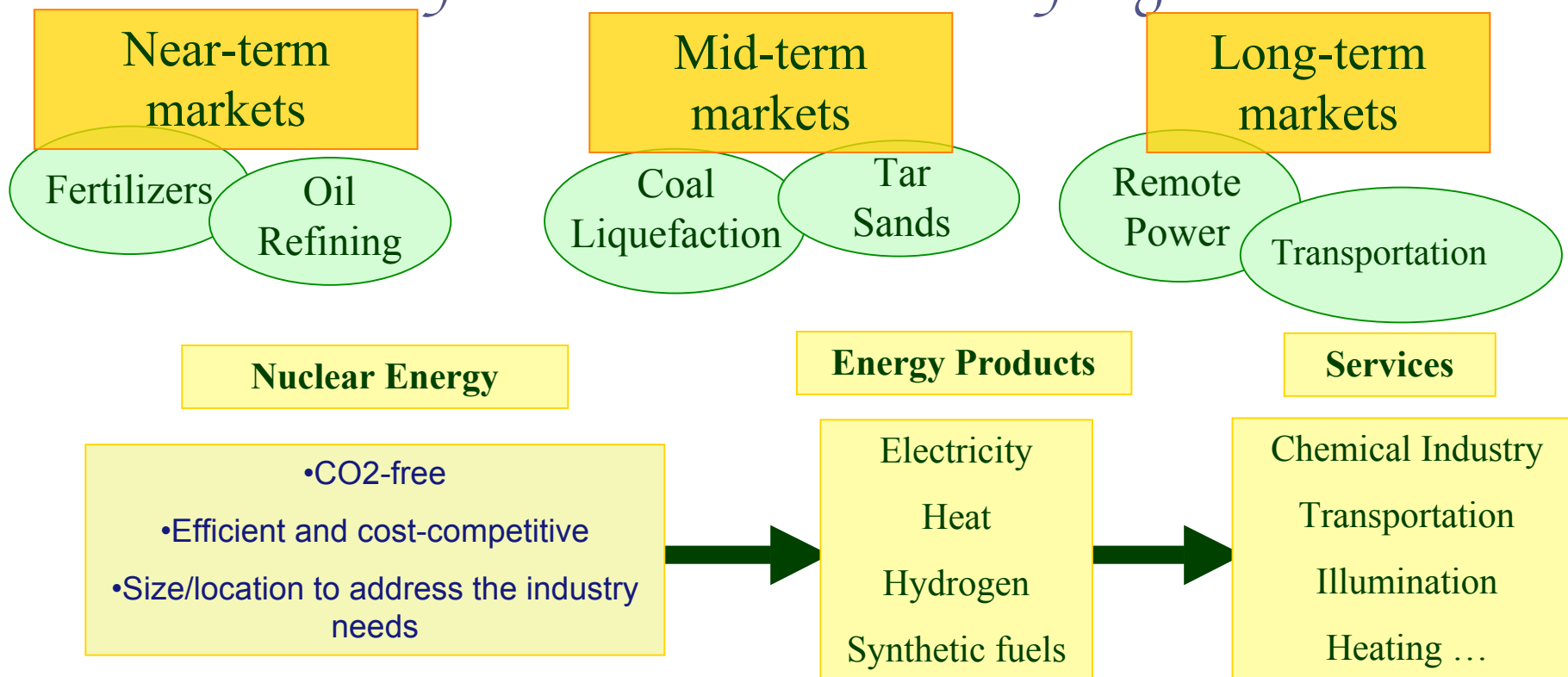
- **Simulation/Computation**

- *Connecting the atomic scale to the macroengineering*
- *Reducing design development time and effort*
- *Understanding the impact of fuel cycle options*

- **Electrochemistry**

- *Reducing the costly corrosion rates*
 - *Boosting the performance of solid oxide electrolyzers*
 - *Boosting the performance of catalysts in separation processes*
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Why nuclear For Heat and Hydrogen?

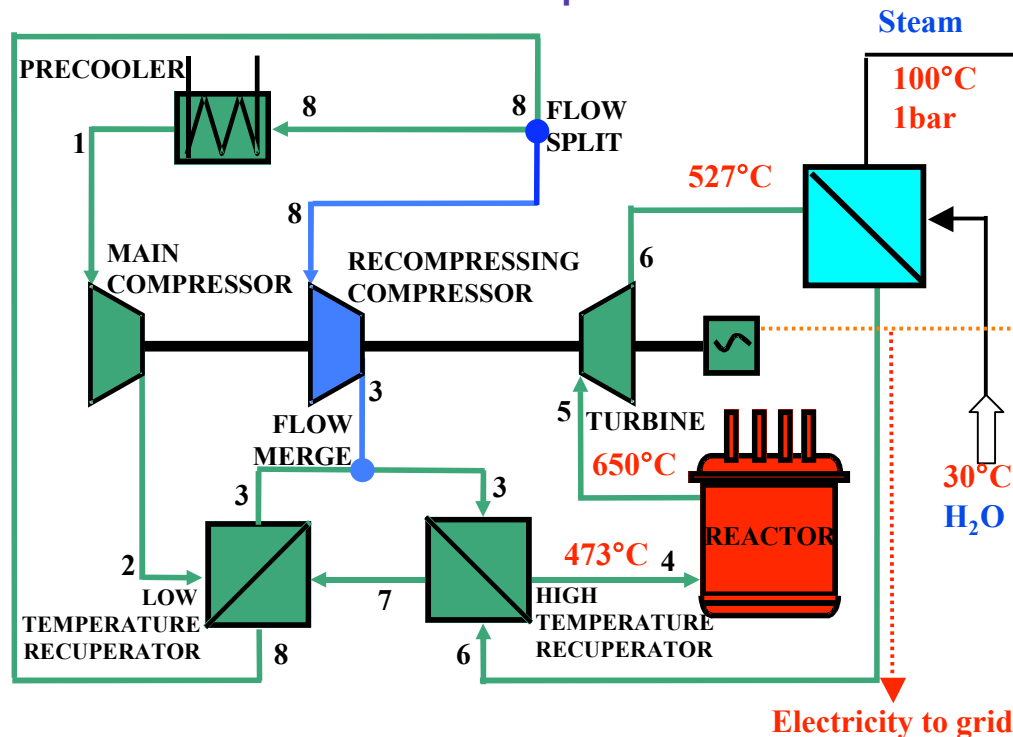


- * The use of heat and/or hydrogen from nuclear energy in place of natural gas
 - ✓ Reduces carbon emissions,
 - ✓ Provides a hedge against natural gas price fluctuations, and
 - ✓ Prolongs the availability of natural gas for other applications
- * Oil industry should benefit from an advanced technology to aid in oil production and refining without requiring a large network of transportation infrastructure.

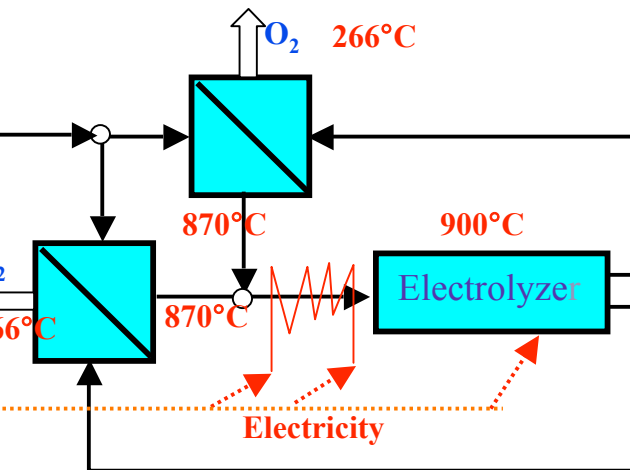
Can economic H₂ be made with medium temp.?

Nuclear plant

SCO₂-GFR and AGR were evaluated.
But FSR or SCWR are also possible.



Electrochemical plant



Key enabling features:

- Recover heat from H₂ and O₂
- Ohmic heating helps keep cell hot

- Yes and at very attractive efficiencies – 45% at 650°C
- IHX material problem eliminated (T=525°C)
- Materials problem for heat transport eliminated (steam line at 200 °C)
- Reactor operates between 475 and 650 °C and only electrochemical plant runs at 900 °C