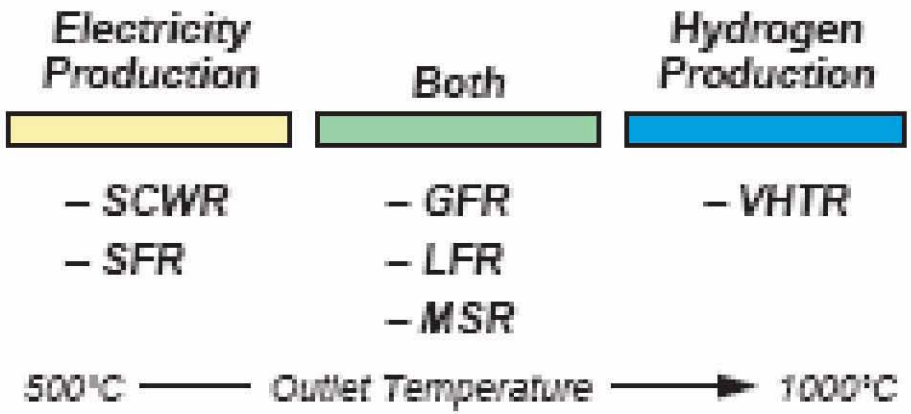
22.39 Integration of Reactor Design, Operations, and Safety

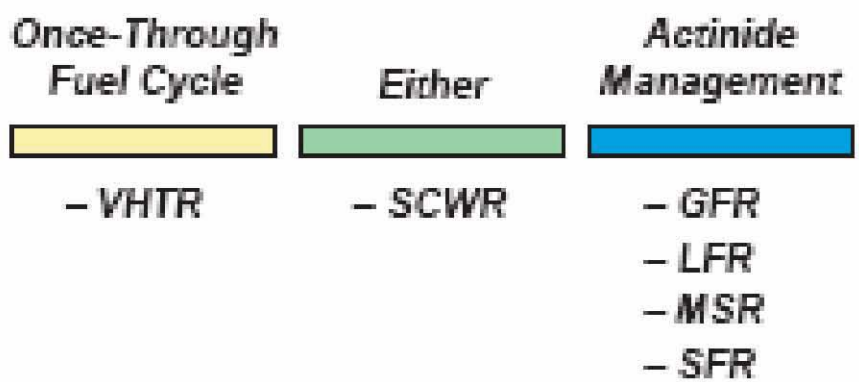
Lecture 1: Nuclear Energy System Strategies

Sept. 6, 2006

Prof. Neil Todreas
MIT

Missions and Economics for Generation IV





A Technology Roadmap for Generation IV Nuclear Energy Systems, US DOE GIF-002-00, p. 17, Dec. 2002

Near Term Deployment and Generation IV Concepts

	Outlet Temperature	Pressure
Thermal Spectrum		
VHTR	1000 C	7 MPa
SCWR	510 C	25 MPa
MSR	700 C (850 C)	< 0.1 psi
Fast Spectrum		
GFR	850 C	7 MPa (He) 20 MPa (CO_2)
LFR	~ 550 C; 800 C	0.1 MPa
SFR	530 C – 550 C	0.1 MPa
Near Term Deployment		
PWR	324 C	15.5 MPa
BWR	288 C	7.17 MPa

US Nuclear Strategy to 2050 (with Horizon to 2100) Example Strategies (Not a Complete List)

Strategy	Reactors	Electricity	Waste	Hydrogen
1	ALWRs	LWR	Yucca Mountain (open and expand)	Low Temperature Electrolysis
2	ALWRs--CONFU	LWR	Thermal Transmutation of Actinides	Low Temperature Electrolysis
3	ALWRs--SFR	SFR cost reduction	Fast Transmutation of Actinides	High Temperature Electrolysis
4	ALWRs--GFR	GFR cost effectiveness	Fast Transmutation of Actinides	High Temperature Electrolysis
5	ALWRs – VHTR -- GFR	GFR and VHTR cost effectiveness	Fast Transmutation of Actinides	Very High Temperature Hydrogen Processes
6 etc.	Etc. with LFR, MSR, SCWR			

Note: CONFU's are thermal LWRs with partial fertile free cores which can transmute actinides

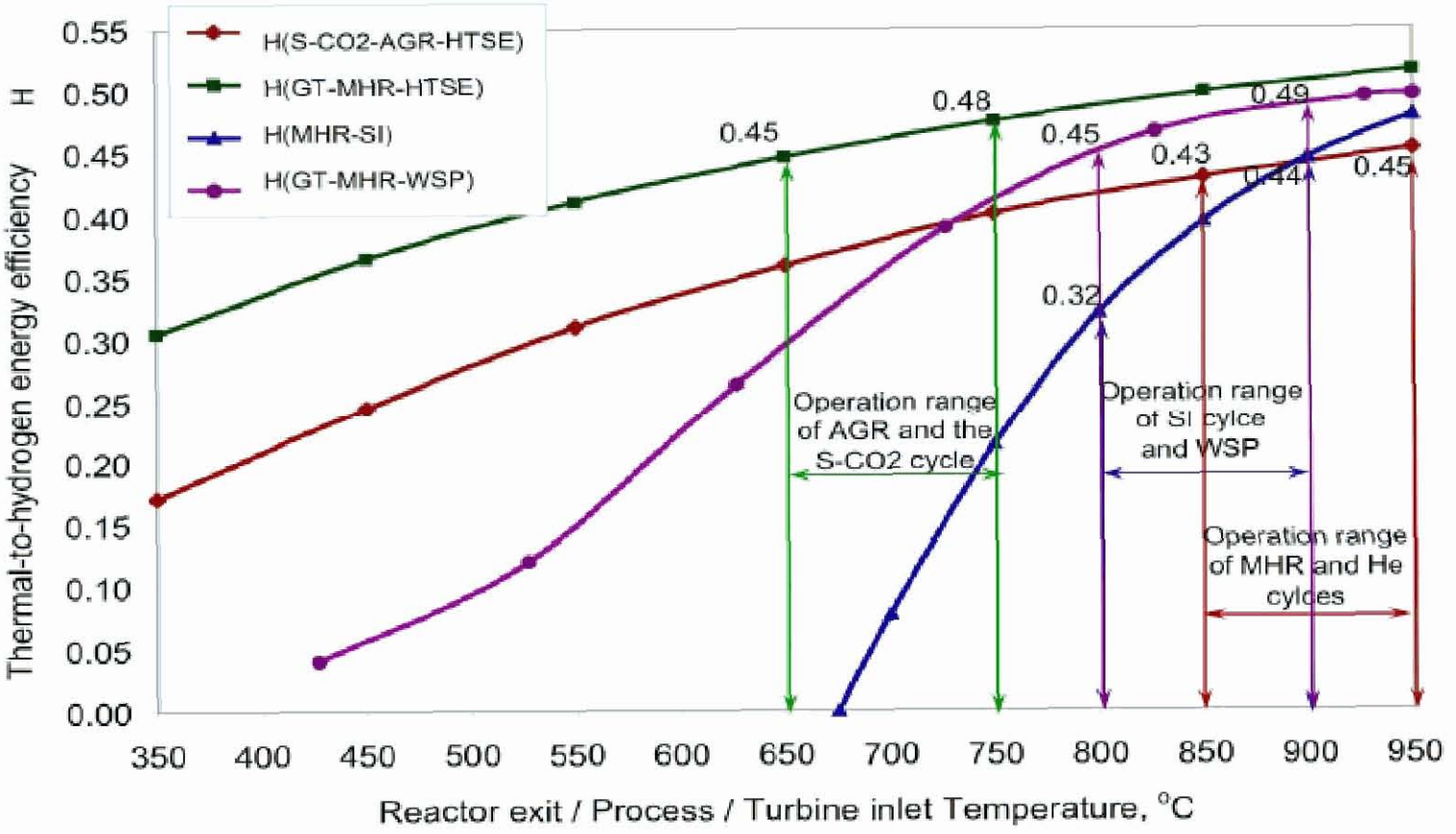
Advanced Reactor Technology Candidates for Hydrogen Production

Advanced Reactor Technology	T_{outlet} (°C)	η_{th} (%)
Helium Gas Cooled Reactor, GT-MHR	850-950	45-48
Supercritical CO_2 Cycle with i.e. S-AGR	650-750	47-51
Super Critical Water Reactor, SCWR	400-600	38-45
Advanced Light Water Reactors, ALWR	285-320	32-34
Advanced High Temperature Reactor, AHTR	750-1000	NE
Lead Bismuth Cooled Reactor, HMCR	540-570	NE

Yildiz & Kazimi, MIT-NES-TR-001, Sept. 2003

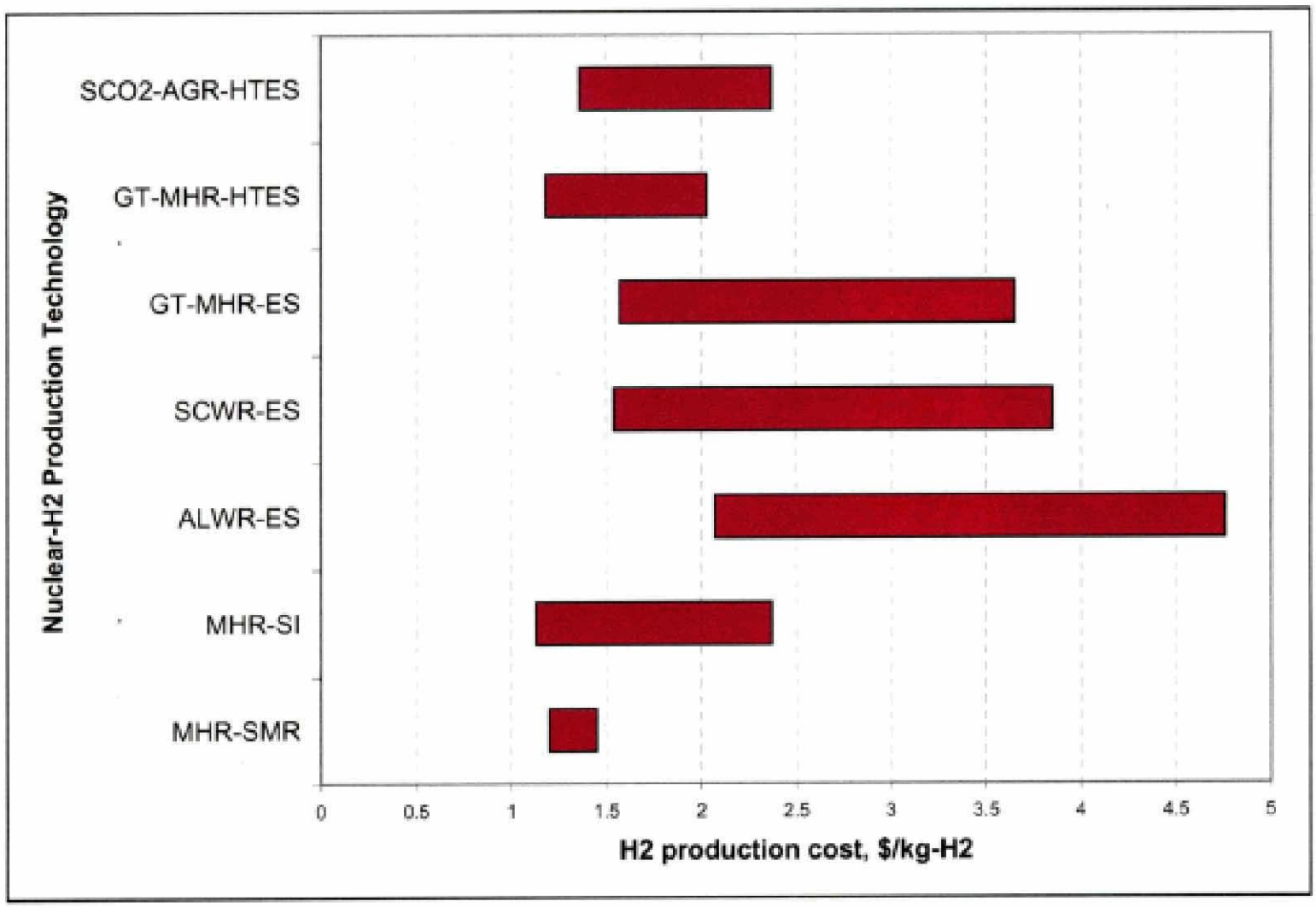
Hydrogen Production Energy Efficiency

Comparison of the thermal-to-hydrogen efficiency of the HTSE, SI and WSP related technologies as a function of temperature



M. Kazimi, Aug. 23, 2006, Cambridge, Massachusetts

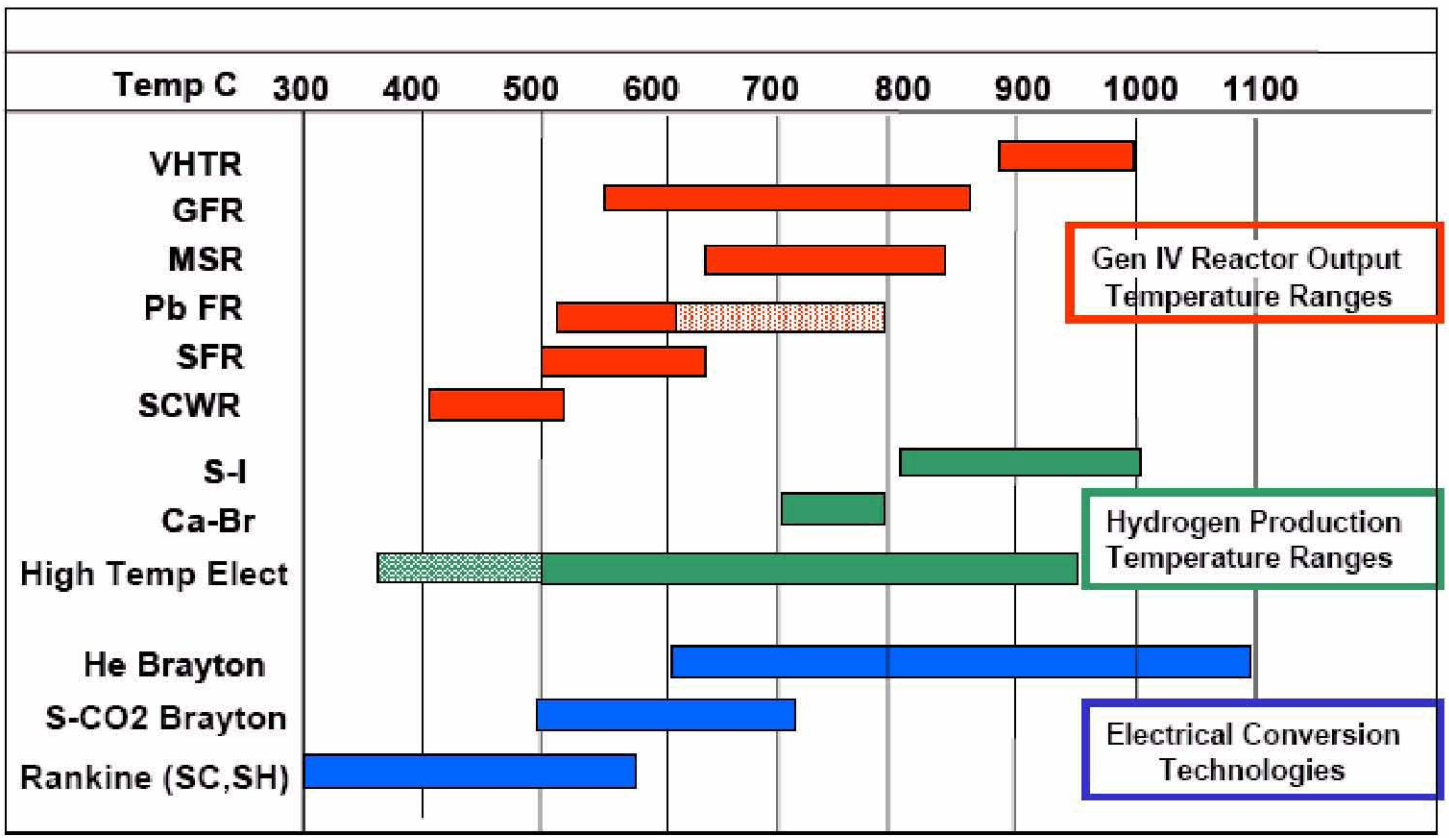
Overall Economic Results for the Alternative Nuclear Hydrogen Technologies



Yildiz & Kazimi, MIT-NES-TR 001, Sept. 2003

Generation IV Energy Conversion

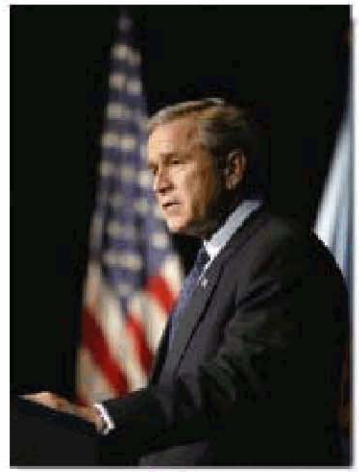
- Electrical generation - ***Gen IV Energy Conversion Program***
- Hydrogen production - ***Nuclear Hydrogen Initiative (NHI)***



Courtesy of Paul Pickard. Used with permission.

P. Pickard, 2004

What is GNEP?



This morning, I want to speak to you about one part of this initiative: our plans to expand the use of safe and clean nuclear power. Nuclear power generates large amounts of low-cost electricity without emitting air pollution or greenhouse gases.

….my Administration has announced a bold new proposal called the **Global Nuclear Energy Partnership**. Under this partnership, America will work with nations that have advanced civilian nuclear energy programs, such as France, Japan, and Russia. Together, we will develop and deploy innovative, advanced reactors and new methods to recycle spent nuclear fuel. This will allow us to produce more energy, while dramatically reducing the amount of nuclear waste and eliminating the nuclear byproducts that unstable regimes or terrorists could use to make weapons.

President George W. Bush
Radio Address: February 18, 2006

K. Levedahl, DOE @ MIT Aug. 23, 2006

GNEP Has Three Simultaneous Goals

GNEP Goals

- Lots of Nuclear Power (1000 ~2000 GWyr by 2050)
- Take care of long – term waste problem
- Reduced Proliferation Risk

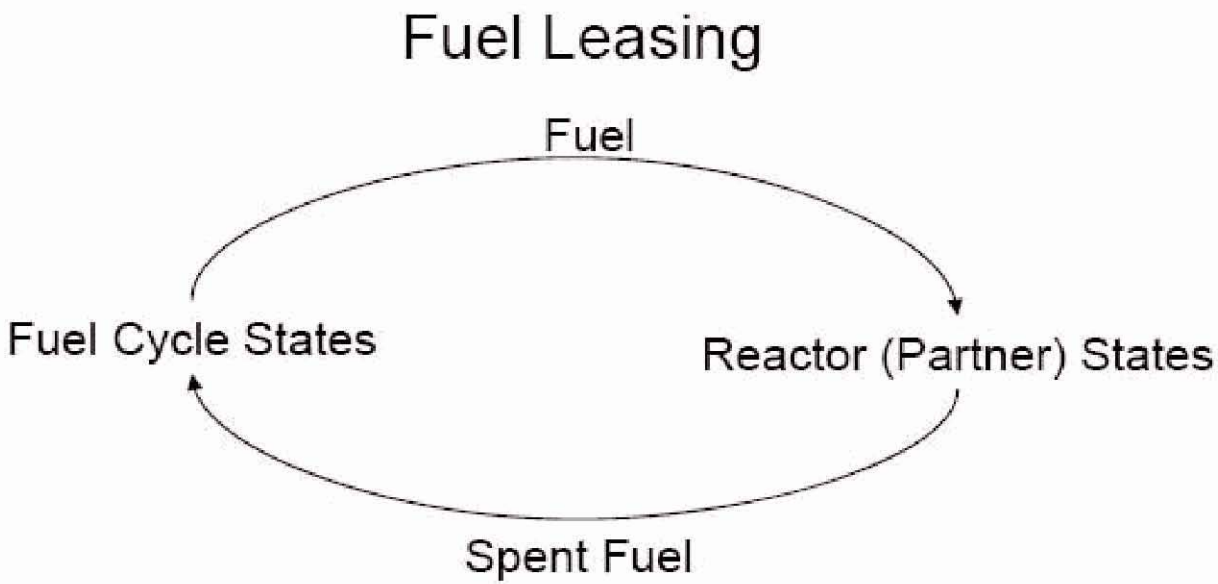
Policy change to favor recycling by "fuel cycle" states

GNEP Principles:

- Global Issues require global solutions
- Spent Fuel is an **asset** to be managed – not a waste.

K. Levedahl, DOE @ MIT Aug. 23, 2006

Key Non-proliferation Element of GNEP is Fuel Leasing



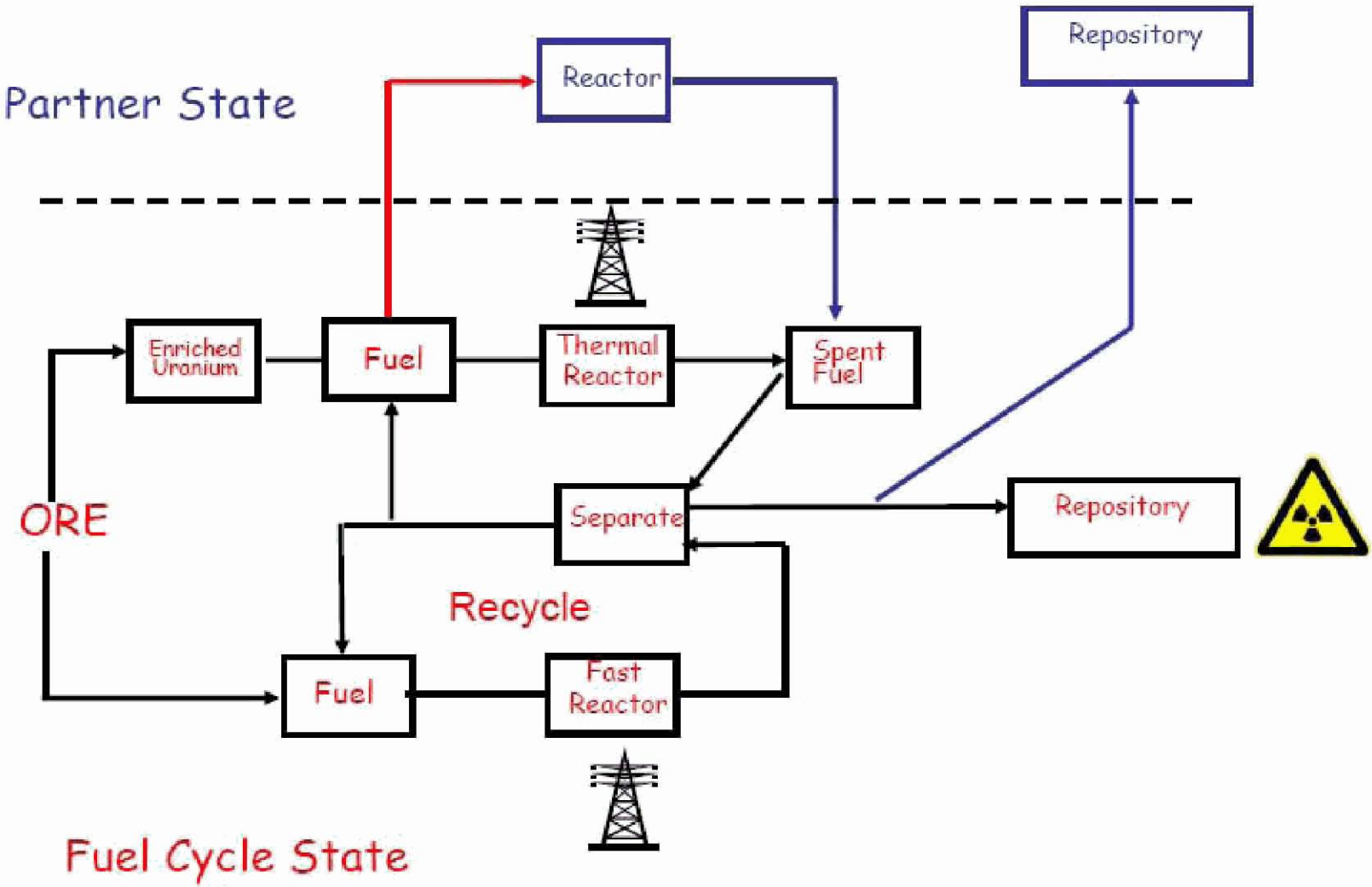
GNEP Fuel Leasing Principles:

- Encourage expansion of nuclear power
- Should make "commercial" sense
- Consistent with Nuclear Non-Proliferation Treaty

K. Levedahl, DOE @ MIT Aug. 23, 2006

Courtesy of US DOE.

Possible Fuel Leasing Configuration



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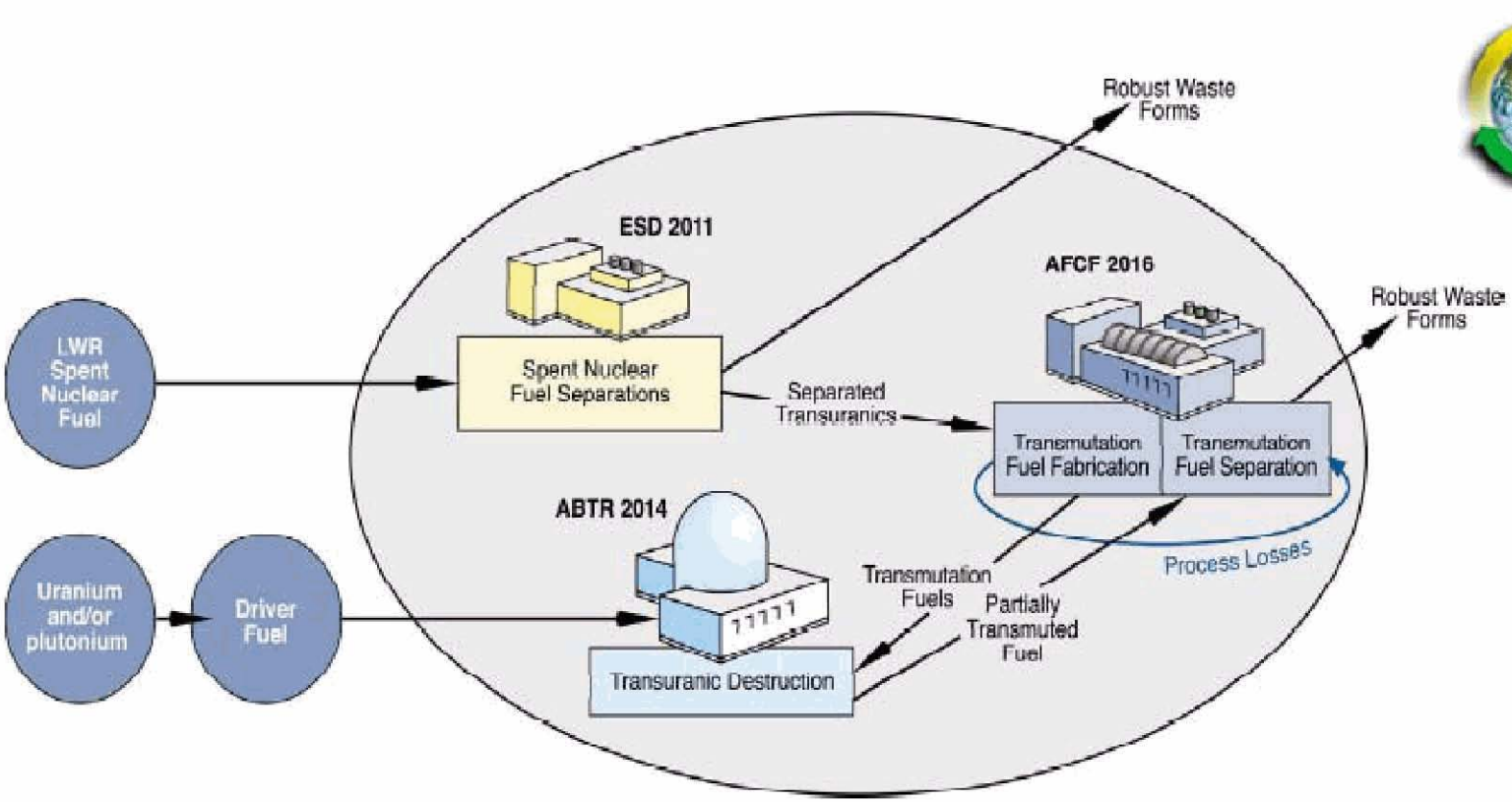
Courtesy of US DOE.

Proposed U.S. GNEP Technology Demonstration Facilities



Available for Cooperative Research

K. Levedahl, DOE @ MIT Aug. 23, 2006

Courtesy of US DOE.

GNEP Process Just Beginning

Countries Approached by U.S. to be possible Fuel Cycle States

France – active follow-up
Japan – active follow-up
United Kingdom (In midst of Government Energy Study)
Russia – active follow-up
China - follow up May 22-23, 2006

~ 100 Countries briefed at International Atomic Energy Agency

Science Attaches briefed in DC:

Russia, UK, France, China, Japan, S. Korea, Canada, Italy, Switzerland, Finland, Germany, Australia, South Africa, Netherlands, Brazil, Argentina, Indonesia, Turkey, Greece, Croatia, Norway, Nigeria, Israel, Viet Nam

Detailed Discussion with Canada, South Korea

Open to discussions with all interested states.

International Response Positive

Current National Strategies

Japan & France

Russia

Maintain LWR
Export LWR

Expand LWR
Export LWR

Interim Storage

Interim Storage (international)

Recycle PUREX/MOX

Separated Pu

Recycle PUREX

Fast Breeder Reactors

Fast Breeder Reactors

Disposition =
Spent Fuel – (U +Pu)

Disposition =
Spent Fuel –(U +Pu)

Issues:

- Disposition,
- Cost of FBR

- Infrastructure
- Disposition,
- Cost of FBR

Courtesy of US DOE.

Current National Strategies

China

Expand LWR (a lot)

Interim Storage

Recycle PUREX

↓

Fast Breeder Reactors

Disposition =
Spent Fuel –(U +Pu)

- Infrastructure
- Disposition,
- Cost of FBR

UK

Await Energy Study

In his speech at a CBI dinner last night, Blair said nuclear plants were back on the agenda "with a vengeance" in the bid to tackle climate change and dependence on unreliable fossil fuel supplies.

17th May 2006

K. Levedahl, DOE @ MIT Aug. 23, 2006
Courtesy of US DOE.

Proposed US GNEP Strategy has seven objectives

1. Expand LWR → NP-2010 / Energy Policy Act
2. Export (L)WR → Small Reactors

3. Demonstrate Recycle technology for spent fuel management
   - 3a. UREX + (spent LWR fuels) → U Cs Sr
   - 3b. Actinide fuel fabrication
   - 3c. Pyroprocessing for ABR fuels

4. Demonstrate Fast Burner Reactors

Recycle - No separated Plutonium

Little Transuranic Waste

5. Minimize Waste disposition to repository
   - Dispostion = Spent fuel w/o (U Cs Sr + Actinides)
   - 1 x Yucca Mountain sufficient for long term

6. Establish reliable fuel services [to "reactor states"]

7. Enhanced nuclear safeguards technologies [NNSA and IAEA roles]

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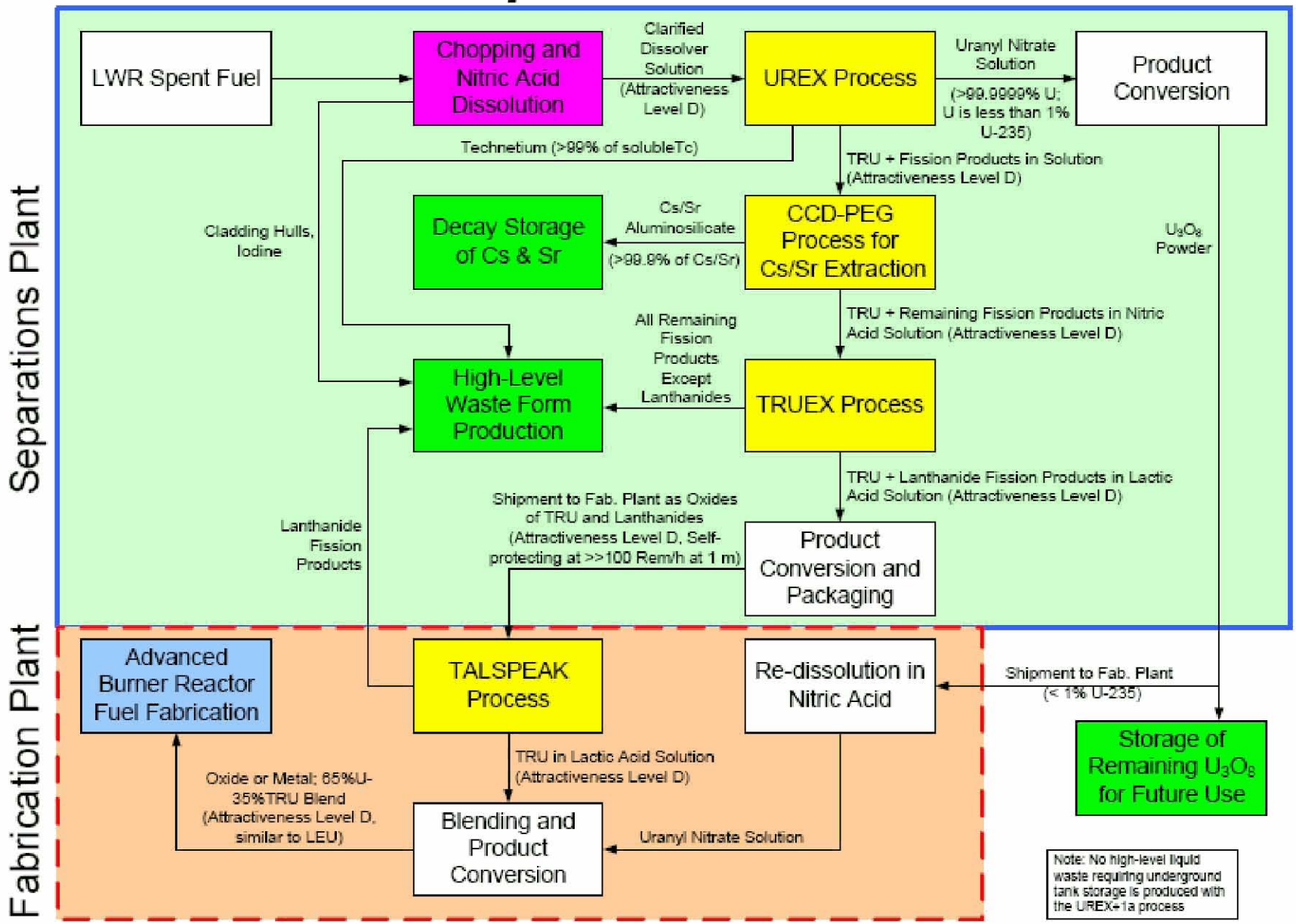
GNEP Advanced Separations: UREX+1a



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Courtesy of US DOE.

MIT Study Recommended Strategy

MIT

Expand LWR - production tax credits

Interim Storage

R&D on recycle (especially simulation)

Disposition = Spent Fuel

Yucca Mountain/Deep Bore Holes

Bottom Lines

1. Nuclear Power essential as a tool to alleviate global warning
2. Will need government support to get nuclear re-started: finance
3. **No need to recycle now ~ decades away**
4. Begin Fuel Leasing Regime

K. Levedahl, DOE @ MIT Aug. 23, 2006

Courtesy of US DOE.

Alternative NGO Nuclear Strategies

Garwin

Expand LWR

Expand Search for U
(seawater)

Interim Storage – 100 years

Research on Fast Reactors

(Likes Fuel Leasing)

Disposition:
Spent Fuel
Competitive Commercial
Mined Repositories

UCS

No Recycle
Anywhere

http://www.ucsusa.org/global_warming/

Photos of Richard Garwin and bookcover Megawatts and Megatons removed due to copyright restrictions

So, what do we do next?

Government to solve the "tragedy of the commons" that is nuclear waste:

- Is there a business model?
  - Cost of Separation
  - Transuranic Fuel
  - Cost of Burner Reactors

Proposed steps:

- GNEP technology demonstrations
- R&D including simulations