

# ***Nuclear Energy: And Production of Hydrogen***

***Hydrogen Technical and  
Fuel Cell Advisory Committee (HTAC)***

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Entergy Nuclear  
December 18, 2007**



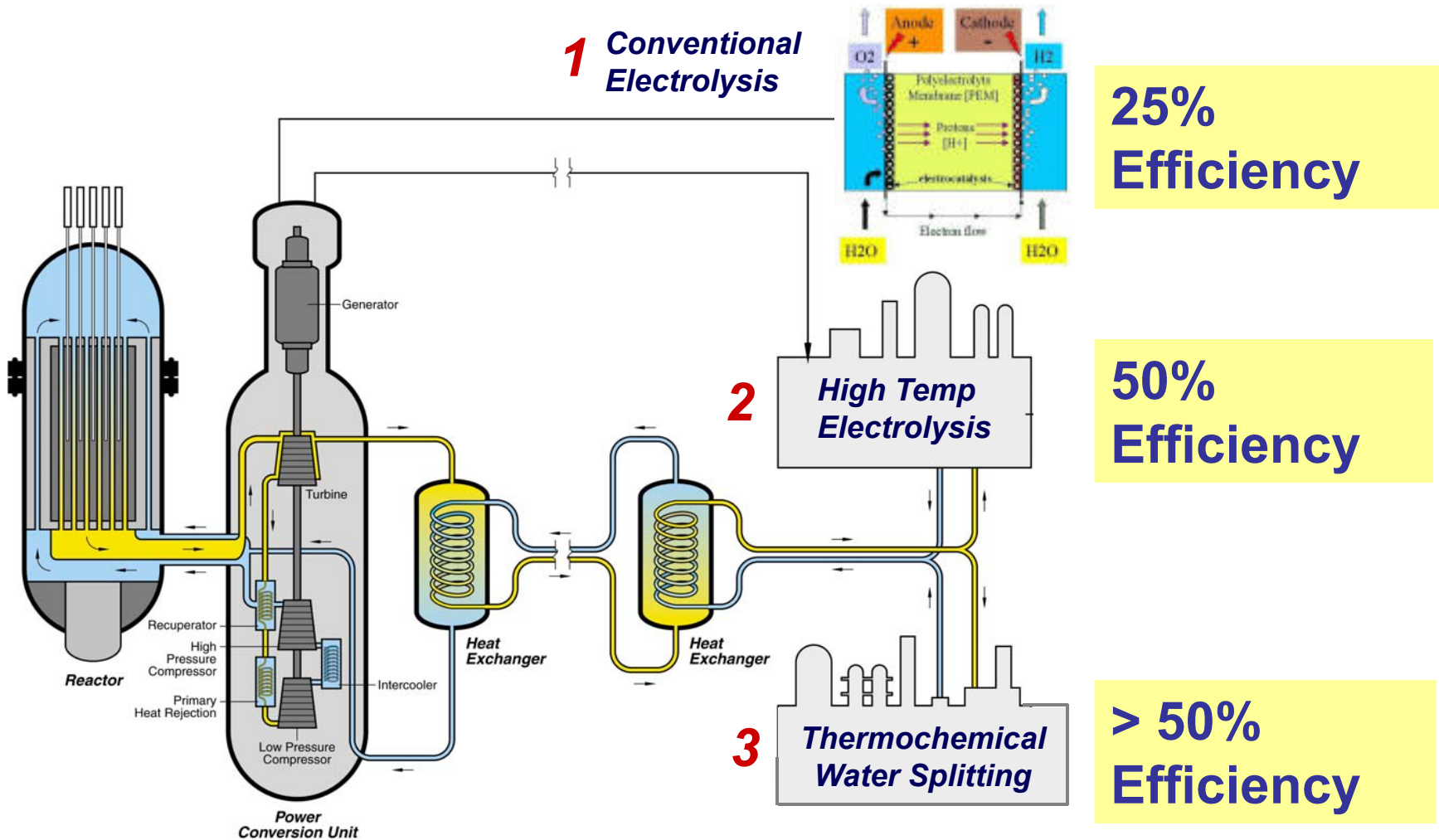
# Energy Does Not Have a Crystal Ball

*But we do know...*

- ✓ **World needs more energy**
- ✓ **Supply of oil and gas is finite**
- ✓ **Environmental regulations are stricter**
- ✓ **America needs energy security/diversity**

**Future of Nuclear and Hydrogen energy are promising**

# Getting H<sub>2</sub> From Nuclear Energy

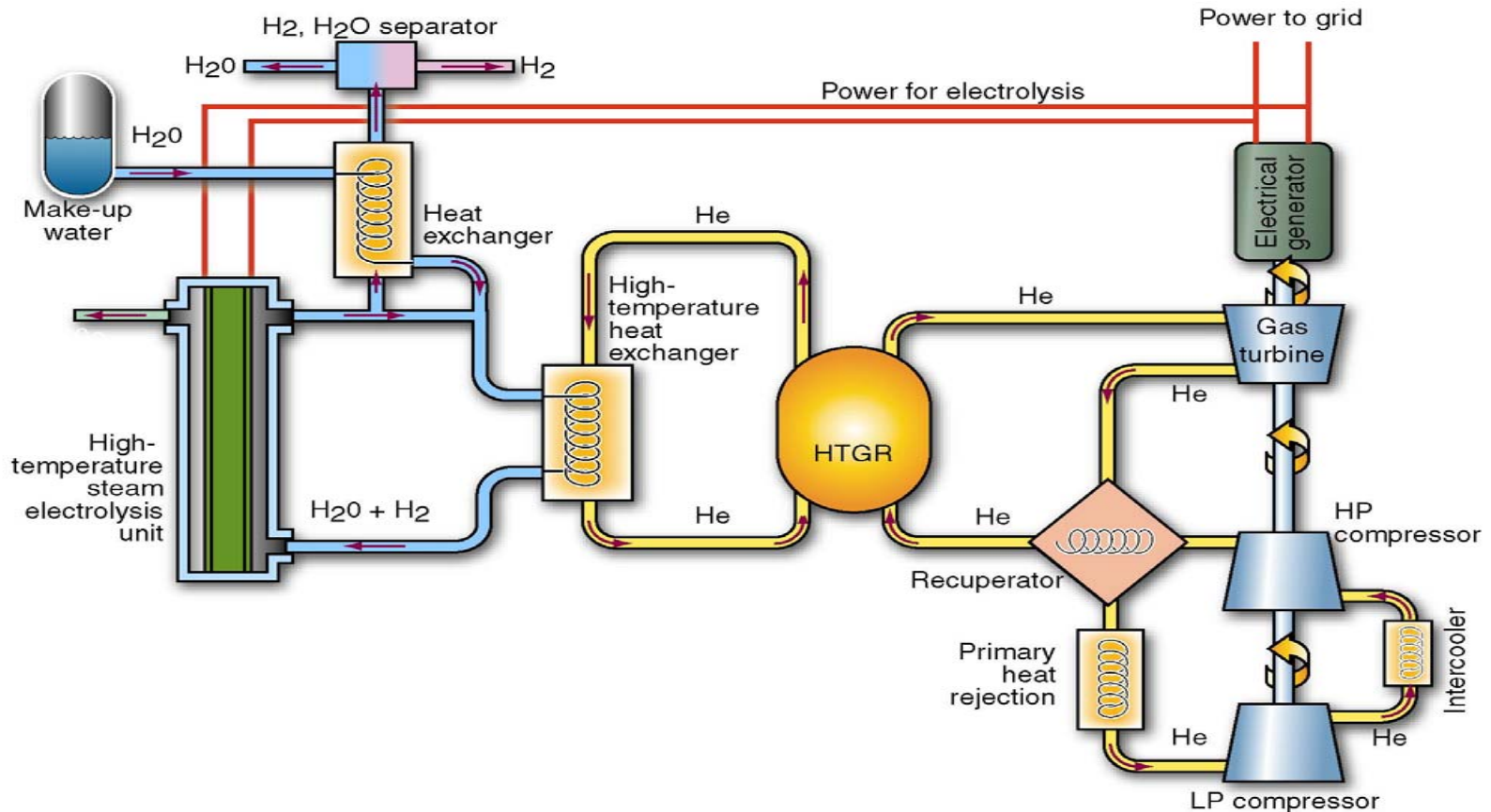


# High Temperature Electrolysis



Based on Solid Oxide Fuel Cell (SOFC) technology

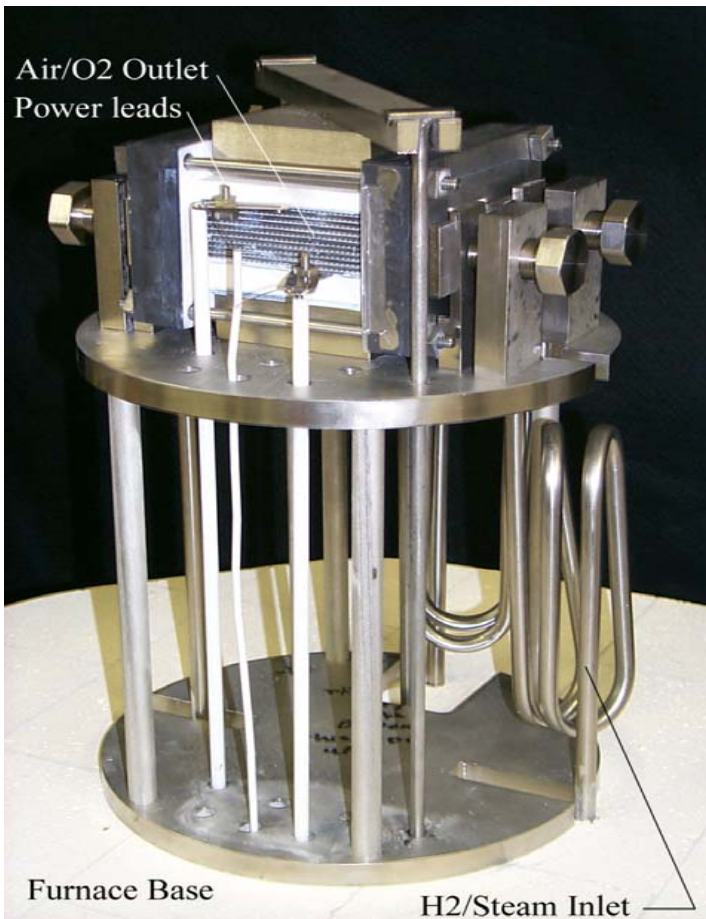
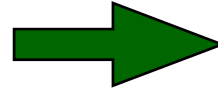
- Solid Oxide Electrolysis Cell (SOEC)  $\Rightarrow$  Basically A SOFC Operating In Reverse
- Uses Thermal Energy to Reduce Electrical Energy Requirements



# High Temperature Electrolysis at INL

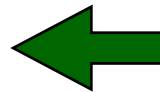
## “Button Cell” Experiments Completed (2003)

- Characterized Basic Operating Properties



## “Planar Stack” Experiments Underway

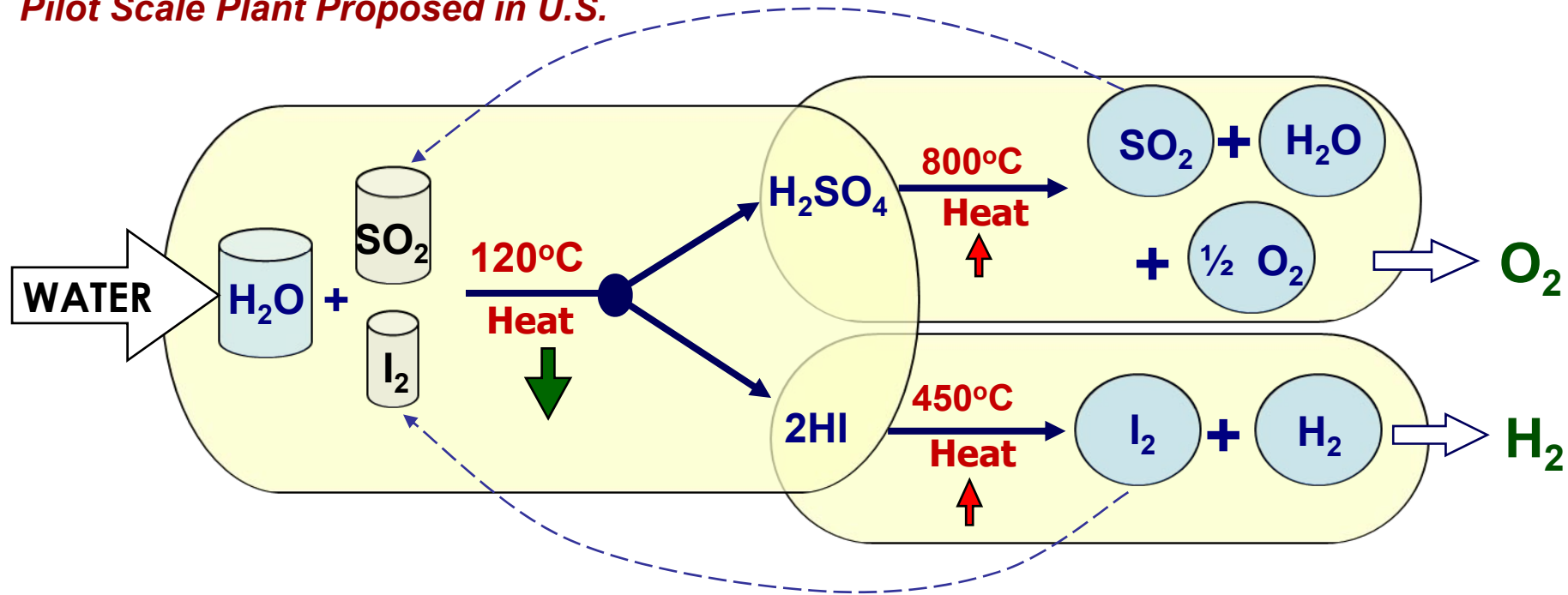
- 10-cell Stack Tested – October 2004
  - Temps  $\Rightarrow$  800°C - 900°C
  - H<sub>2</sub> Production Rates  $\Rightarrow$  50 L/hr – 115 L/hr
- 18-cell Stack Being Constructed



# Thermochemical Water Splitting

## Sulfur Iodine - "SI" Process (Most Advanced)

- Development Work in Japan, France, & U.S.
- Lab Tests in Japan (50 L/hr)
- Pilot Scale Plant Proposed in U.S.

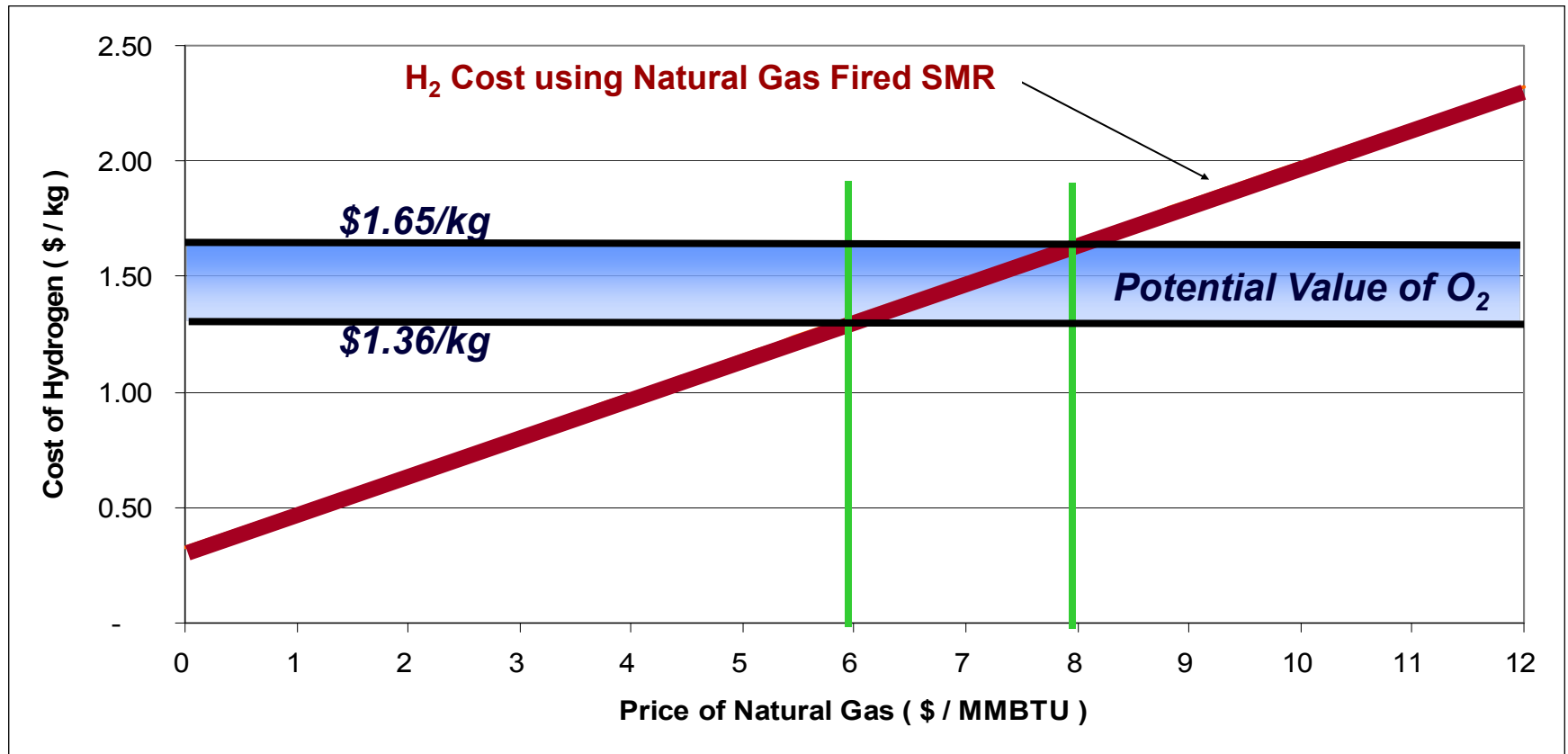


Efficiencies 47%- 53%

$600 \text{ MW}_{\text{Th}}$  Module  $\Rightarrow$   $\sim 200$  Tons / Day

# Nuclear H<sub>2</sub> – Commercially Viable?

## Comparative Economics - - Based on SRNL Study



Source: SRNL

# Centralized Nuclear H<sub>2</sub> Production

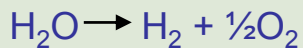
## Centralized Nuclear H<sub>2</sub> Production Plant



Heat  
⇒



Thermochemical  
Water-Splitting



Modular  
Helium  
Reactor



**(4) 600 MW<sub>th</sub> Units**  
**SI Process (52% Eff. HHV)**  
**760 Tons/Day**

**\$1.65/kg**

High Capacity  
Pipeline



Industrial H<sub>2</sub> Users

**\$1.86/kg**

Hydrogen  
Fueled  
Future



Distributed  
Power      Transport  
Fuel



H<sub>2</sub> Storage

**\$0.05/kg**

**\$0.16/kg**

Source: *SRNL*



# The Freedom Reactor™

## Modular Construction

- 288 MWe / Unit - - 4 Units / Site
- ~200 Tons/Day H<sub>2</sub> Production/Unit
- Below Grade Silo & Terrorist Hardened
- Construction Time < 3 years

## Low Capital & Operating Cost

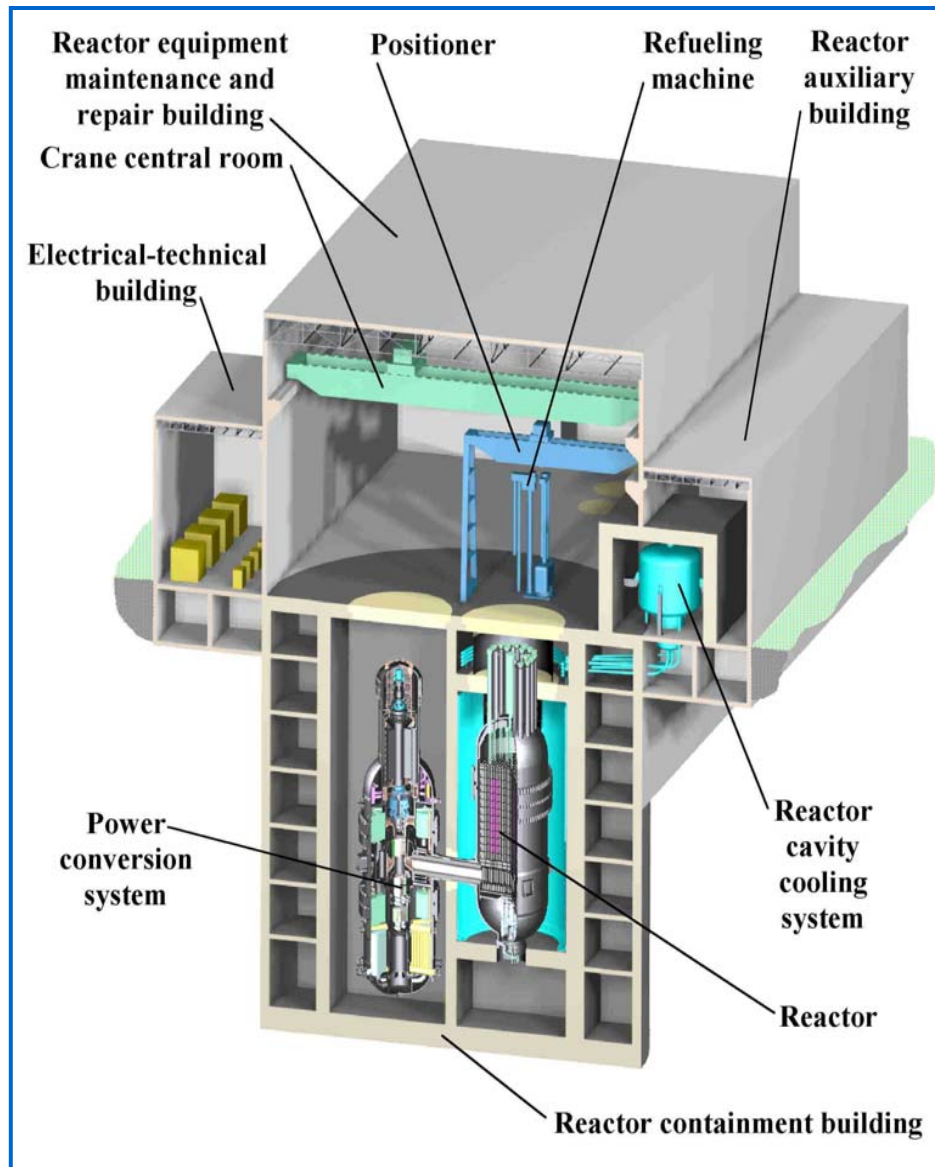
- Capital Cost ~ \$1000 - \$1417 /kW
- Low Staffing Levels
- Low Decommissioning Costs

## Proven Nuclear Technology Base

- 40 Years - Gas Reactor Experience
- U.S. & International

## Safety

- Passive cooling
- Meltdown Proof
- Proliferation Resistant

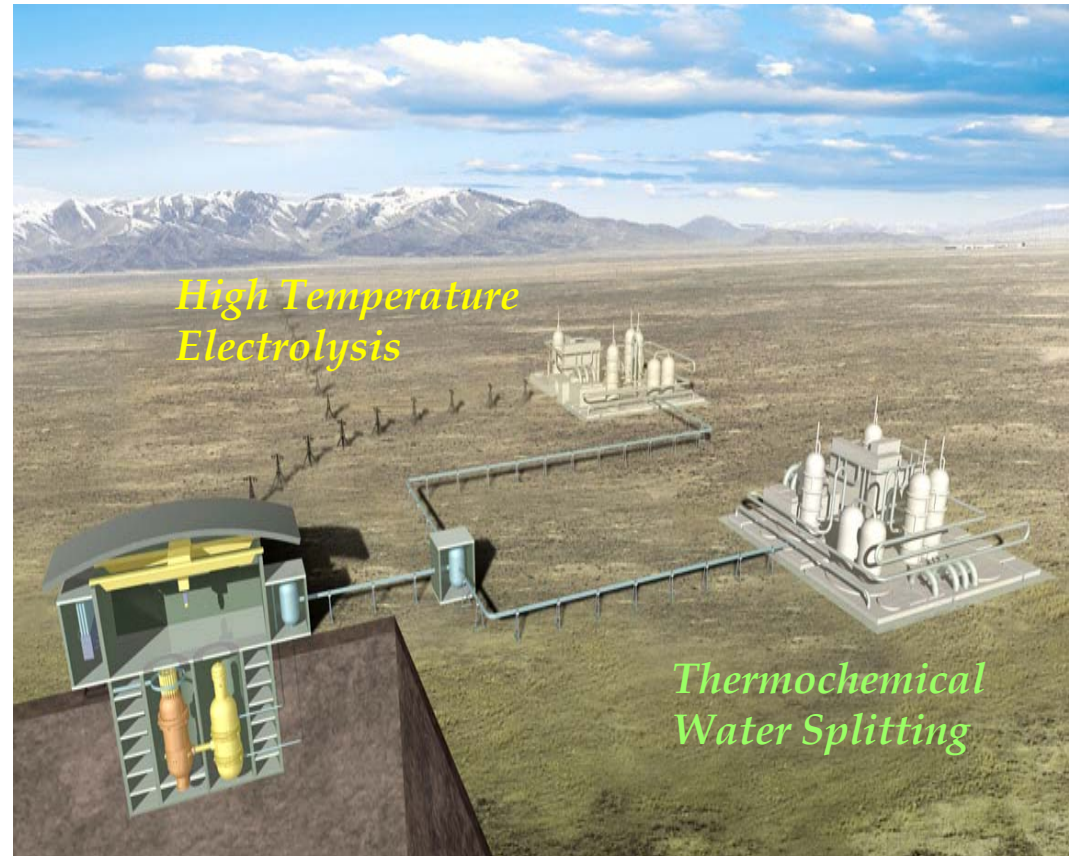


# The Next Generation Nuclear Plant

The Energy Policy Act includes \$1 billion for the Next Generation Nuclear Plant at Idaho National Lab

## Need demonstration at INL

- Prove design, construction
- Produce electricity and hydrogen
- Validate costs, operations
- Show other benefits – waste reduction, fuel flexibility



# The Nuclear-H2 Nexus

- High volume with low cost
- Does not pollute the air
- Stable, domestic fuel

*..... If the hydrogen economy emerges in the transportation sector as I believe it will, then nuclear power generation will have to play a paramount part in its evolution.*

*... Hydrogen is the currency of an energy system. To create the currency, hydrogen, primary power must be utilized. The most likely candidate to produce the power is nuclear.*

**Dr. Geoffrey Ballard, founder of the fuel cell and  
Scientific American's 2002 Business Leader of the Year**

# ***Myths & Truths Of Nuclear Energy***

# Nuclear Myths: Safety

## Myth

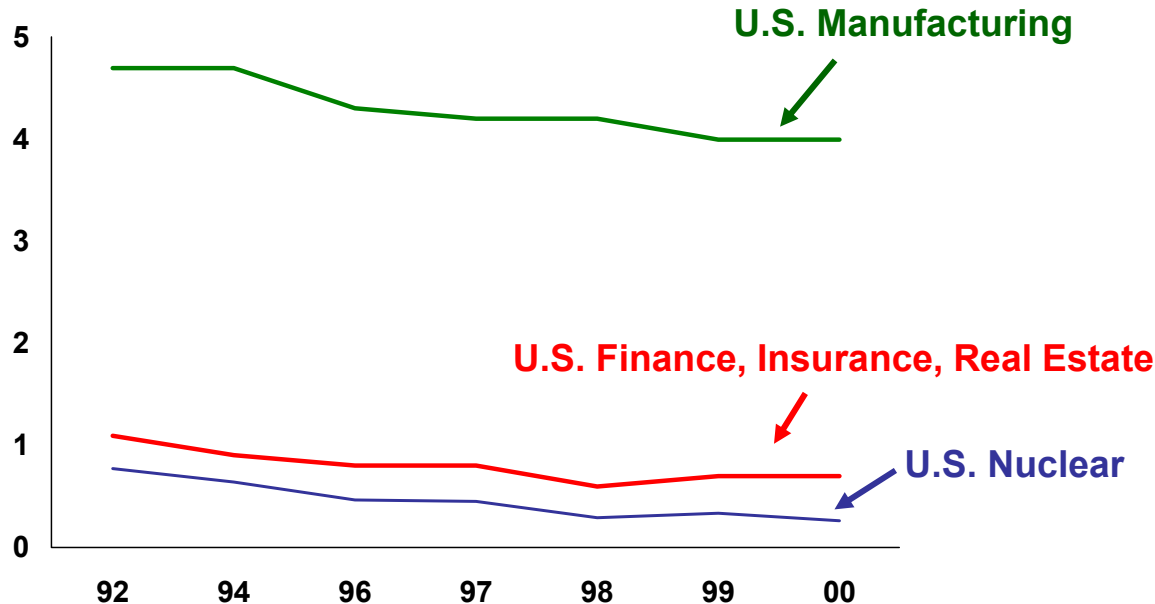
**Nuclear energy is not safe**

## Truth

**Nuclear energy is as safe or safer than any other form of energy available**

### OSHA Accident Rates

Accidents per 200,000 worker-hours



U.S. Bureau of Labor Statistics, NEI

***No member of the public has ever been killed or injured in 40 years of nuclear energy in the U.S.***

**It's safer to work in a nuclear plant than in an office**

# Nuclear Myths: Chernobyl

## Myth

**A Chernobyl here would kill thousands of Americans**

## Truth

**Chernobyl-type accident could not happen in the U.S.**

- **Chernobyl design would not be permitted in U.S.**
  - *U.S. reactors have containment structures; Chernobyl did not*
- **56 died at the time of the accident - all were on-site plant and emergency workers**
- **UN study estimates ~ 4,000 thyroid cancers are expected to occur, but few deaths**
  - *Thyroid cancer is one of most curable with survival rate of 99%*
  - *No evidence of increase in leukemia or other cancers*

**Chernobyl death toll has been greatly overstated**

# Nuclear Myths: Aging Plants

## Myth

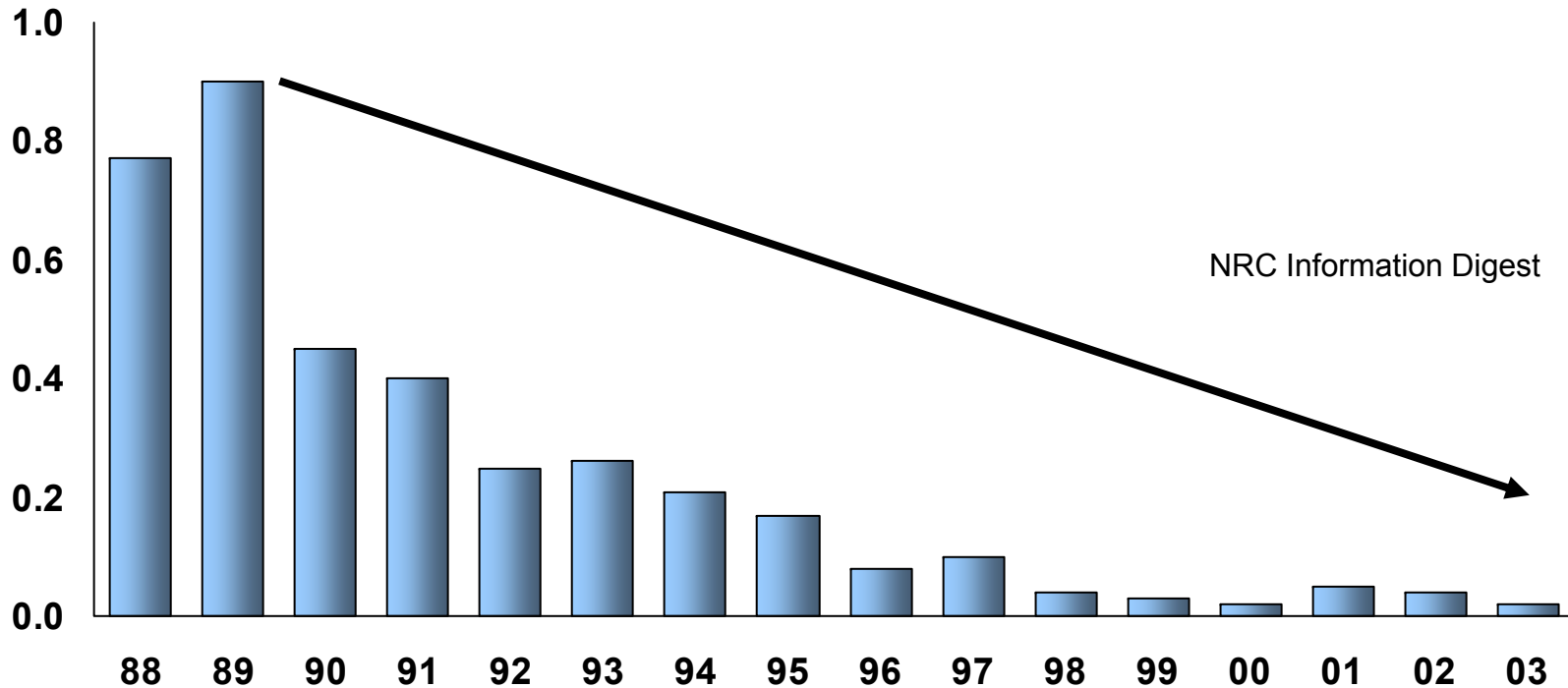
As nuclear plants age, they become more risky

## Truth

Safety and reliability of nuclear plants have improved over time

### NRC Significant Events

Annual industry average per plant



**NRC reportable events are virtually zero**

# Nuclear Myths: Cancer

## Myth

**Nuclear energy plants  
cause cancer**

## Truth

**No increased risk of cancer  
for people living near  
nuclear energy plants**

- **Nuclear plant workers have LOWER mortality than Americans overall**
    - *35% lower for all cancers*
    - *66% lower for all non-cancer deaths*
  - **Americans receive significantly more radiation from natural sources than from nuclear energy plants**
    - *Average resident gets 360 millirem a year from natural sources*
    - *Average nuclear energy plant worker receives 160 millirem a year*
    - *The limit at plant fence is 5 millirem a year*
- Nuclear Energy Institute*

**“(There is) no general increased risk of death from cancer for people living in 197 U.S. counties containing or closely adjacent to 62 nuclear energy facilities.”**

*National Cancer Institute Report,  
Journal of the American Medical Association, 1991*



# Nuclear Myths: Terrorist Targets

## Myth

**Nuclear energy plants are terrorist targets**

## Truth

**Not attractive targets due to strong security and reinforced structures**

- Nuclear energy plants have the highest security in American industry
    - *Well-armed, trained security forces*
    - *Strong physical security barriers*
    - *Continuous link to Department of Homeland Security and local law enforcement*
  - Established response procedures and contingency plans
- “[Nuclear power plants] are probably our best-defended targets. There is more security around nuclear power plants than anything else we’ve got. Its infrastructure, especially against these kinds of terrorist threats, is extremely good.”* John Hamre, President, Center for Strategic & International Studies

**Other industrial facilities are far more susceptible**

# Nuclear Myths: Nuclear Weapons

## Myth

**Nuclear energy will cause a proliferation of nuclear weapons**

## Truth

**Commercial plants do not have bomb-grade materials**

- **Weapons grade uranium 235 must be highly enriched**
  - *Nuclear fuel is only 5% pure uranium 235*
- **It is difficult and expensive to enrich uranium**
  - *Requires large nationalized industrial complexes*
- **It is difficult and expensive to obtain plutonium from spent fuel**
  - *Spent fuel is highly radioactive*
- **It is not easy to divert spent fuel for other purposes**
  - *Britain, France, Japan, Russia are reprocessing their fuel*
  - *Plutonium can be recycled into new fuel - best way to dispose of it*

**It is easier to enrich natural uranium**

# Nuclear Myths: High Operating Cost

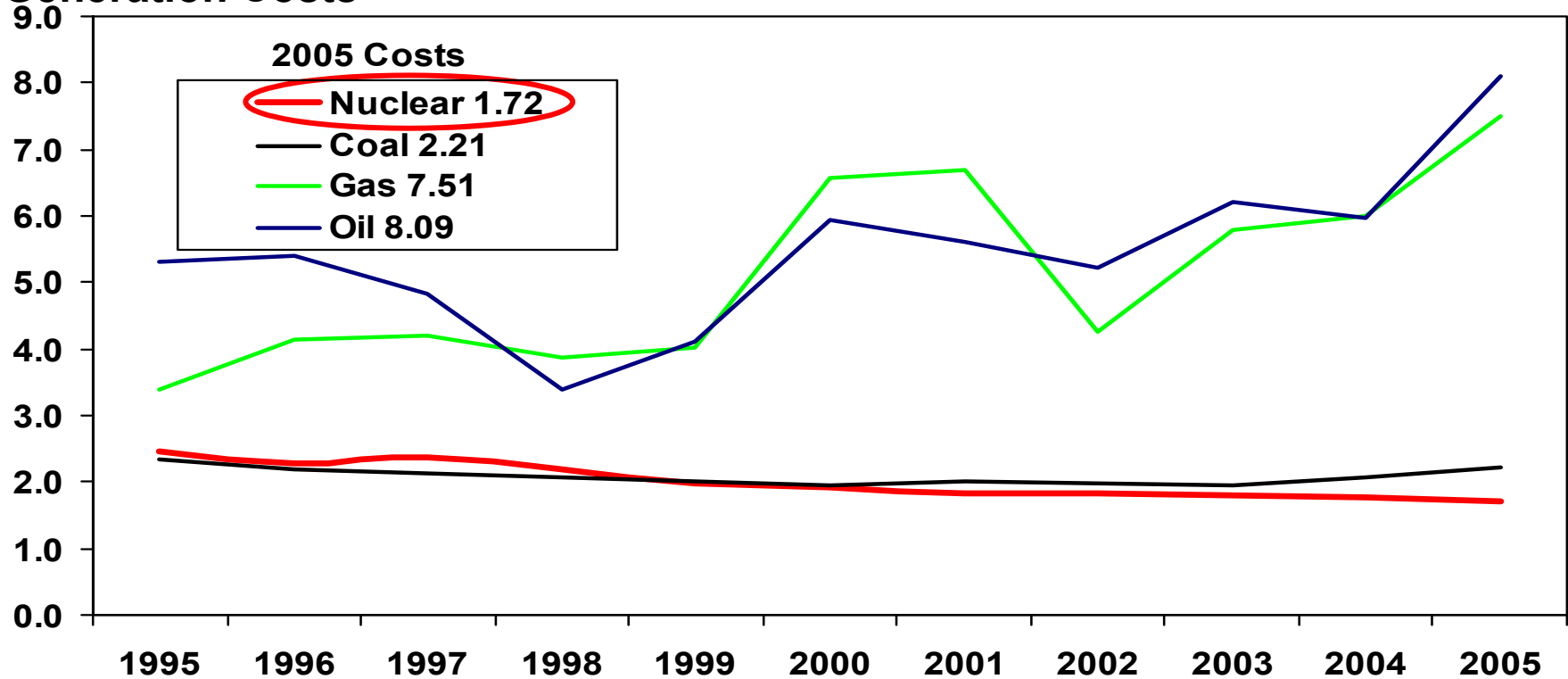
## Myth

Nuclear energy is too costly

## Truth

Nuclear is very competitive with other generation

### Generation Costs



Nuclear Energy Institute

**Nuclear is the lowest of all (except hydro)**

# Nuclear Myths: New Plants Cost Prohibitive

## Myth

**New nuclear is too expensive, not competitive with fossil**

## Truth

**MIT shows nuclear energy is very competitive**

| <b>New Nuclear (LWR)</b>   | <b>Opportunity</b>  | <b>\$/MWh</b> | <b>\$67</b> |
|----------------------------|---------------------|---------------|-------------|
| Reduce construction cost   | \$2000 to \$1500/KW | -12           | 55          |
| Reduce construction time   | 5 to 4 years        | -2            | 53          |
| Reduce O&M, including fuel | \$15 to \$13/MWh    | -2            | 51          |
| Reduce cost of capital     | 15% to 12% equity   | -9            | 42          |
| Increase capacity factor   | 85% to 90%          | -2            | <b>40</b>   |

| <b>Carbon Tax Effect</b>       | <b>\$0/ton</b> | <b>\$50/ton</b> | <b>\$100/ton</b> | <b>\$200/ton</b> |
|--------------------------------|----------------|-----------------|------------------|------------------|
| Pulverized Coal                | 42             | 54              | 66               | 90               |
| CCGT (Low Gas \$3.77/ MCF)     | 38             | 43              | 48               | 59               |
| CCGT (Moderate Gas \$4.42/MCF) | 41             | 47              | 52               | 62               |
| CCGT (High Gas \$6.72/ MCF)    | 56             | 61              | 67               | 77               |

*The Future of Nuclear Energy, MIT*

**Nuclear is competitive with no carbon restrictions, and very competitive with carbon restrictions**

# Nuclear Myths: Low Reliability

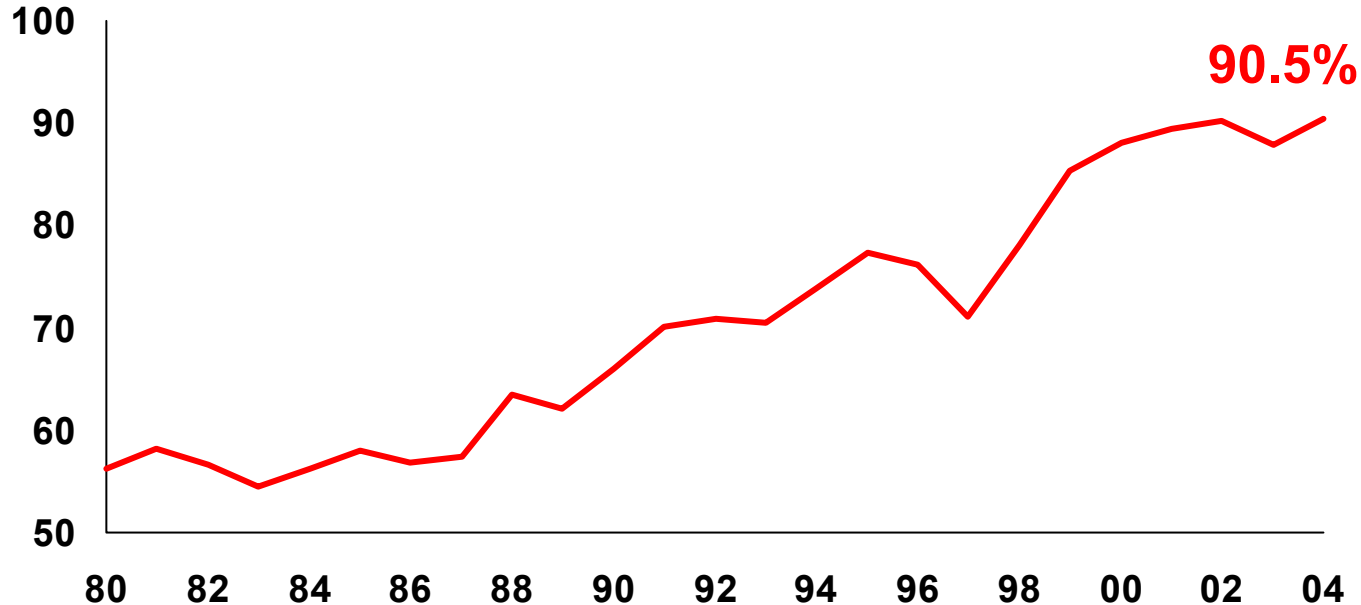
## Myth

**Nuclear energy is not reliable**

## Truth

**U.S. nuclear generation is the most reliable**

**Capacity Factor at 103 Plants**  
80-04; %



*Nuclear Energy Institute*

**Capacity factor increase at 103 plants in the last 15 years is equivalent to building 26 new 1,000MW plants**

# Nuclear Myths: Environment

## Myth

**Nuclear energy is bad for the environment**

## Truth

**Nuclear energy is improving the environment**

- **U.S. nuclear energy plants avoided tons of emissions in 2004**
  - *3.43 million tons of sulfur dioxide*
  - *1.11 million tons of nitrogen oxide*
  - *700 million tons of carbon dioxide*
- **U.S. nuclear energy plants avoided carbon emissions equal to 94% of U.S. auto emissions (138 million cars)**
- **World wide, 440 nuclear energy plants save more than twice the Kyoto Accord carbon targets annually**

*Nuclear Energy Institute*

**Nuclear power reduces air pollution and greenhouse gases by displacing other generation**

# Nuclear Myths: Greenhouse Gases

## Myth

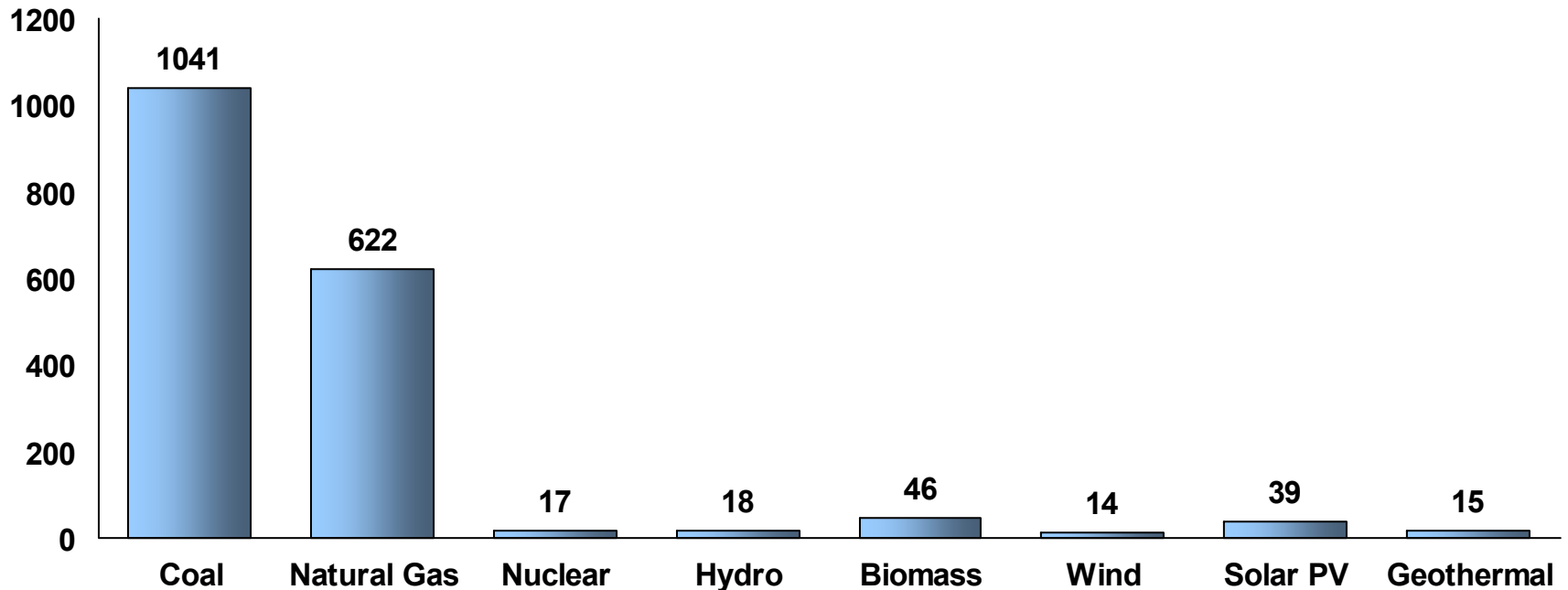
**Nuclear emits significant greenhouse gases**

## Truth

**Nuclear emits very little greenhouse gasses**

### Life Cycle CO<sub>2</sub> Emissions Analyses

Tonnes CO<sub>2</sub>-equiv/GW<sub>e</sub>h



"Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis," Paul J. Meier, University of Wisconsin-Madison, August, 2002

**Nuclear energy is on par with renewables**

# Nuclear Myths: Nuclear Waste

## Myth

There is no solution to nuclear waste

## Truth

Deep geologic repository is a very good solution

## Yucca Mountain

- Technically sound
  - 1,000' below ground
  - Repository in solid rock
  - 1,000' above water table
- Remote location on Nevada Test Range
- Current repository in NM-Waste Isolation Project (WIP)



Spent nuclear fuel in one remote location is appropriate solution



# Nuclear Myths: Massive Amounts of Waste

## Myth

There are huge volumes of nuclear waste

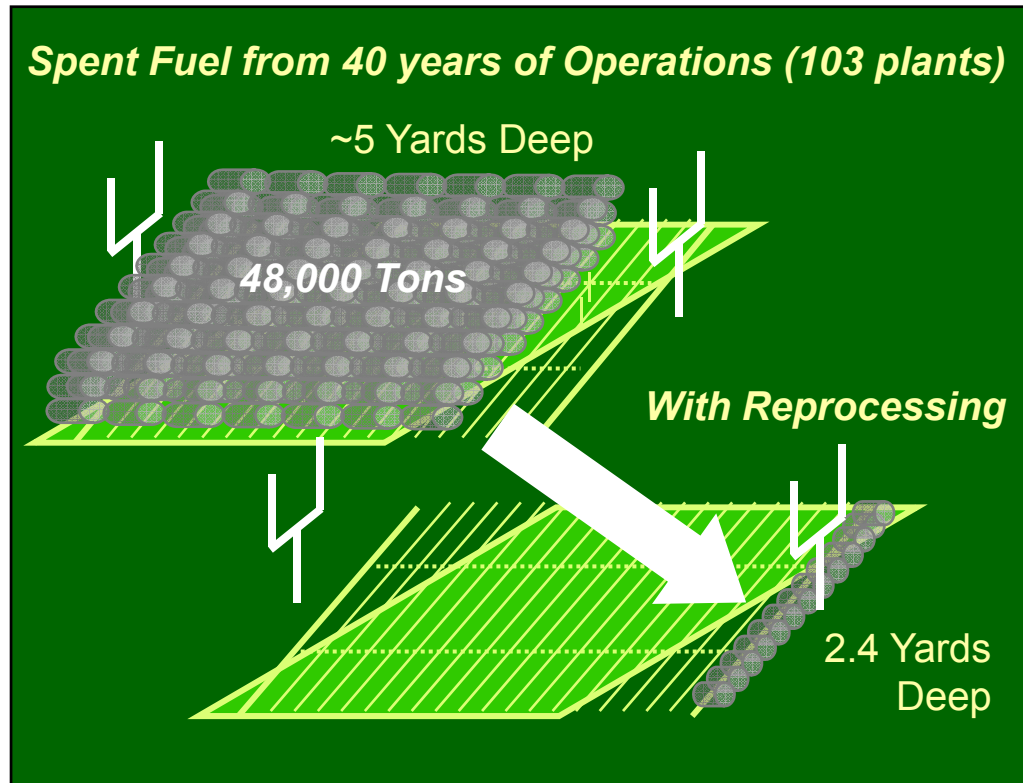
You could stack all spent fuel from 40 years of operations (103 plants) on a football field about 5 yards deep

- Reprocessing would reduce waste to one end zone
  - Vastly decreases volume
  - Converts long-lived isotopes into short-lived ones (10,000 Years → 300 Years)
  - Extends uranium fuel
- Other countries ARE reprocessing

*Nuclear Energy Institute*

## Truth

Spent fuel is small in volume, easily managed



**U.S. should reprocess to reduce volume and reclaim the 96% fuel that is unburned in our once-through fuel cycle**

# Nuclear Myths: Waste Transportation

## Myth

**Nuclear waste cannot be transported safely**

## Truth

**Spent fuel is being shipped safely by truck and rail today**

- **3,000 shipments for 1.7 million miles in U.S. already (U.S. DOD)**
  - *No container has leaked or cracked*
  - *No radiation released*
- **Shipping container design is tested and tough**
  - *30-foot free fall to unyielding surface (120 mph head-on collision)*
  - *Puncture test is a 40-inch fall onto vertical steel rod 6" in diameter*
  - *30-minute exposure to fire (1475 °F), then submerged in 3 feet of water 8 hrs*
- **Approved transportation routes with detailed planning**
  - *Law enforcement support*
  - *Emergency response support and secure stopover facilities*

*Nuclear Energy Institute*

**Spent fuel can be and is being safely shipped**

# Nuclear Myths: Renewables

## Myth

**Renewables are better than nuclear energy**

## Truth

**Renewables are good, but nuclear energy is more economical, dependable, and uses much less land**

**Land required for emissions-free generation of 1,000 MW**

| Method       | Requirement/ Description                | Land Area (sq. miles) |
|--------------|---|-----------------------|
| Photovoltaic | 100 km <sup>2</sup> @ 10% efficiency    | 40                    |
| Wind         | 3,000 Wind Turbines @ 1 MW ea.          | 40-70                 |
| Biogas       | 60,000,000 pigs or 800,000,000 chickens | ??                    |
|              | 6,200 km <sup>2</sup> of sugar beets    | 2,400                 |
| Bioalcohol   | 7,400 km <sup>2</sup> of potatoes       | 2,800                 |
|              | 16,100 km <sup>2</sup> of corn          | 6,200                 |
|              | 272,000 km <sup>2</sup> of wheat        | 104,000               |
| Bio-oil      | 24,000 km <sup>2</sup> of rapeseed      | 9,000                 |
| Biomass      | 30,000 km <sup>2</sup> of wood          | 12,000                |
| Nuclear      | <1 km <sup>2</sup>                      | 1/3                   |

**We need to recognize the limits of renewables**

# Nuclear Myths: Environmental Support

## Myth

**Environmentalists don't support nuclear energy**

## Truth

**Leading environmentalists worldwide are turning to nuclear energy**

**“Nuclear energy is the only non-greenhouse gas-emitting power source that can effectively replace fossil fuels and satisfy global demand.”**

*Patrick Moore, Founder Of Greenpeace,  
Chair and Chief Scientist of Greenspirit*

**“If we NIMBY anywhere and anytime, we should not expect the utility industry to provide electricity to everyone, everywhere, all of the time. If we believe that global warming is a real threat to our planet, then the very best way to provide baseload electricity is through emission-free nuclear power.”**

*Norris McDonald, President  
African American Environmental Assoc.*

**“Nuclear energy is the only green solution.”**

*James Lovelock, London geophysicist who developed  
the Gaia Theory on which the Greenhouse Effect is based*

**Nuclear is clean, green energy**

# Nuclear Myths: Out of Favor

## Myth

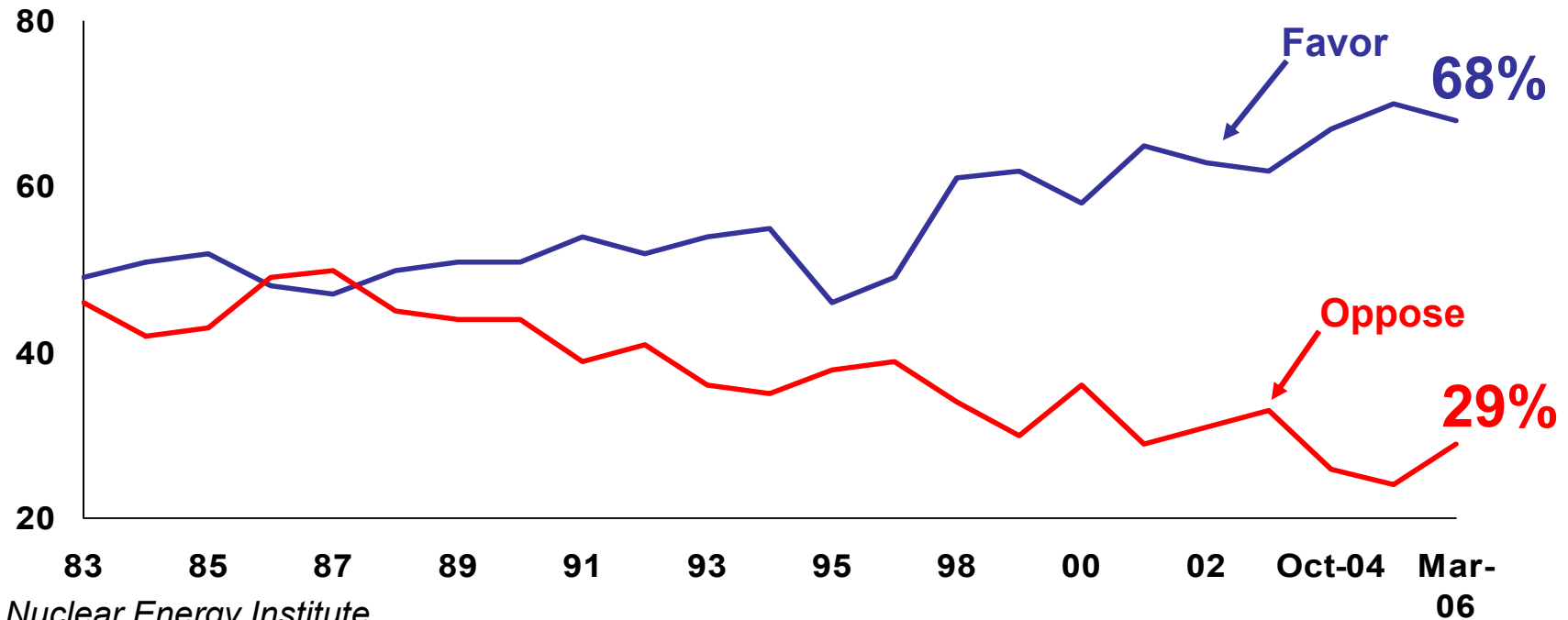
Americans don't want nuclear energy

## Truth

Americans favor nuclear energy

### Americans who favor or oppose use of nuclear energy

83-06 (Annual averages until 04); %



Nuclear Energy Institute

**There is strong nuclear energy support and it is increasing**

***What Has Changed  
Since We Built Nuclear  
Plants The First Time***

# The Industry Has Learned From the Past

## *Past failures include...*

1. Nuclear Regulation – Uncertainty post-TMI
2. Plant Design – Individual/unique designs
3. Construction – Over schedule and budget
4. Owner/Operations – Immature industry
5. Economics – Recession and high inflation

**These conditions have changed**

# 1. Nuclear Regulation

## *Then*

- **2-step process (10CFR 50)**
  - *Construction then Operating License*
- **Evolving requirements**
- **Issues raised repeatedly**
- **Few trained in process**

## *Now*

- **1-step process (10CFR 52)**
  - *Combined Construction and Operating License*
- **Stable requirements**
- **Issues raised only once**
- **Many trained in process**

**New one-step licensing significantly reduces risk**



## 2. Plant Design

### *Then*

- New un-proven designs
- Individual unique designs
  - *Numerous changes*
  - *Custom plants*
- Pre-computer engineering methods
- Analog technology

### *Now*

- Proven designs
- Standard designs
  - *Pre-certified designs*
  - *Standard, identical plants*
- Automated design processes
- Digital technology

**New standard designs enable evolutionary technology**

# 3. Construction

## *Then*

- **Multi-prime contractors**
- **Design as you construct**
- **On-site stick built**
- **Limited scheduling tools**
- **Manual document/data control**

## *Now*

- **Turnkey EPC approach**
- **Design >85% complete at start of construction**
- **Modular techniques**
- **Sophisticated scheduling software**
- **Automated document/data control**

**New construction methods minimize construction time and risk**

## 4. Owner/Operations

### *Then*

- **Small, individual owner operators**
- **Low quality standards**
- **Poor industry communications**
- **Immature industry**
  - *Primarily fossil operators*
  - *Low capacity factors*
  - *High operating costs*

### *Now*

- **Large, consolidated fleet operators**
- **High quality assurance**
- **Well connected industry (INPO/WANO)**
- **Mature industry**
  - *30+ years experience*
  - *>90% capacity factors*
  - *Low, stable cost*

**Mature industry offers proven track record**

# 5. Economics

## *Then*

- Double digit interest rates
- Local rate compacts approved after-the-fact
  - *Phased-in rate plans mitigate rate shock*
- No environmental recognition
- First of kind costs and risks
  - *Construction delays*
  - *Financial stress*

## *Now*

- Single digit interest rates
- Local rate compacts pre-approved
  - *CWIP in rate base*
  - *Stable solid fuel benefits*
- Recognized greenhouse gas benefit
- Federal incentives
  - *Risk insurance*
  - *Loan guarantees*
  - *Production tax credit*

**Energy Policy Act/local rate compacts reduce costs and risks**

# Why the Nuclear-H<sub>2</sub> Partnership?

- Large Scale, Economical H<sub>2</sub> Source
- Emissions-Free Production of H<sub>2</sub>
- Stable Fuel Costs
- Energy Security
- Preserves Natural Gas & Oil
- Helps Maintain Domestic Industry Base
- Strengthens U.S. Economy