REVIVAL OF NUCLEAR ENERGY OPTION

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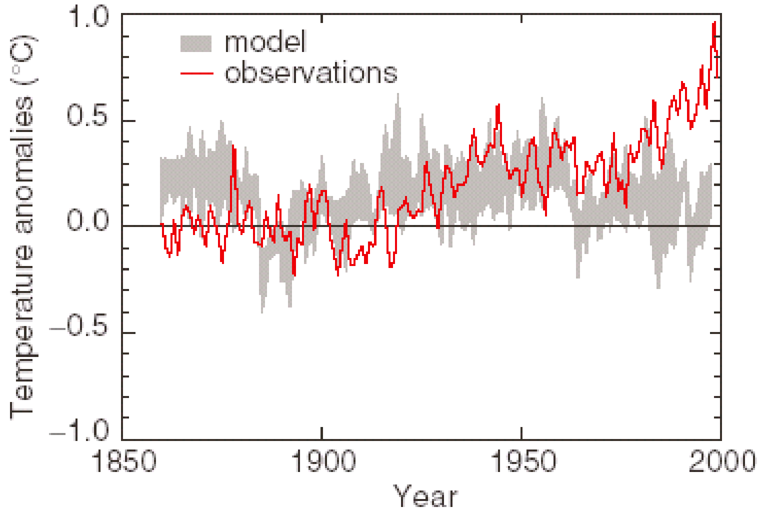
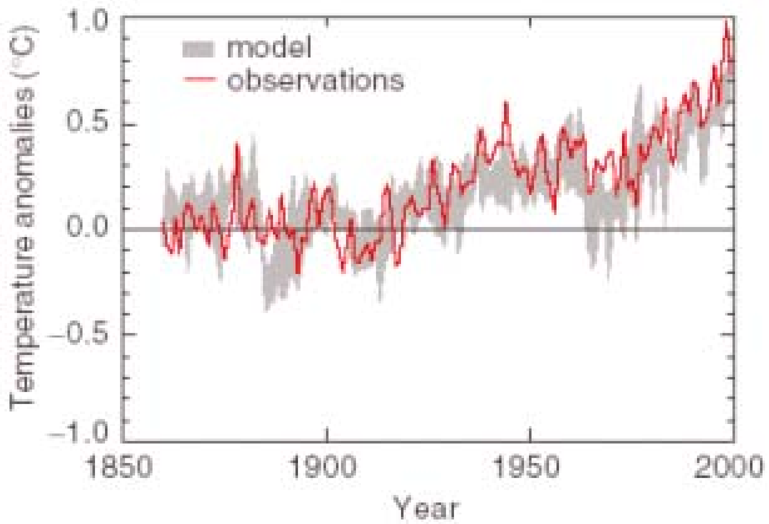
SUSTAINABLE SOCIETY of the 21th Century?

- We cannot have SUSTAINABLE SOCIETY without SUSTANIABLE ENERGY which is based on SUSTAINABLE NUCLEAR ENERGY!
- We need Nuclear Energy - to provide an abundant, reliable, affordable, clean, and secure source of energy for our nation and the world.
- Definition of SUSTAINABLE ENERGY:
- "A living harmony between the equitable availability of energy services to all people and the preservation of the earth for future generations." MIT "Sustainable Energy - Choosing Among Options"

Can we predict?

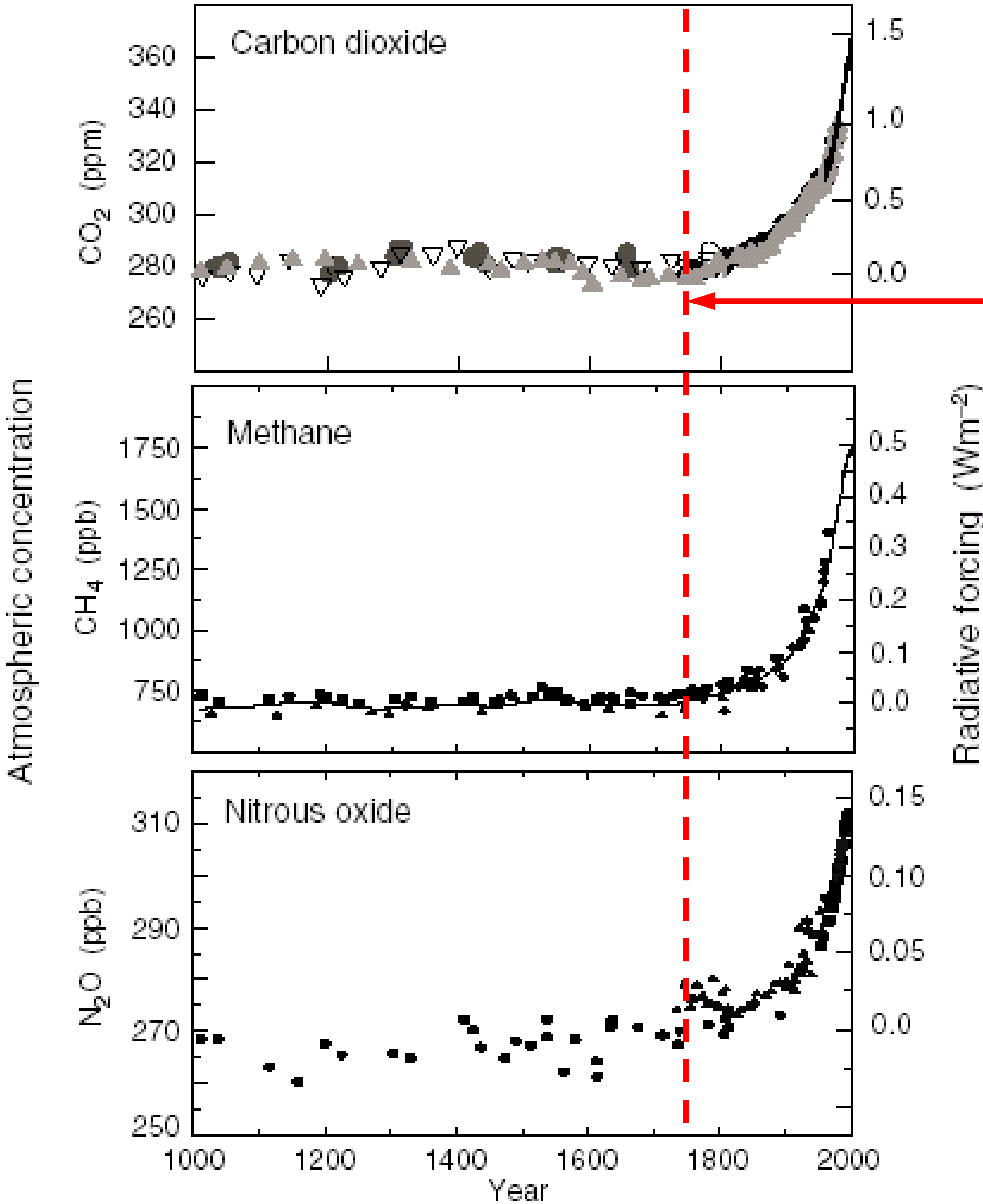


Climate change due to natural causes (solar variations, volcanoes, etc.)



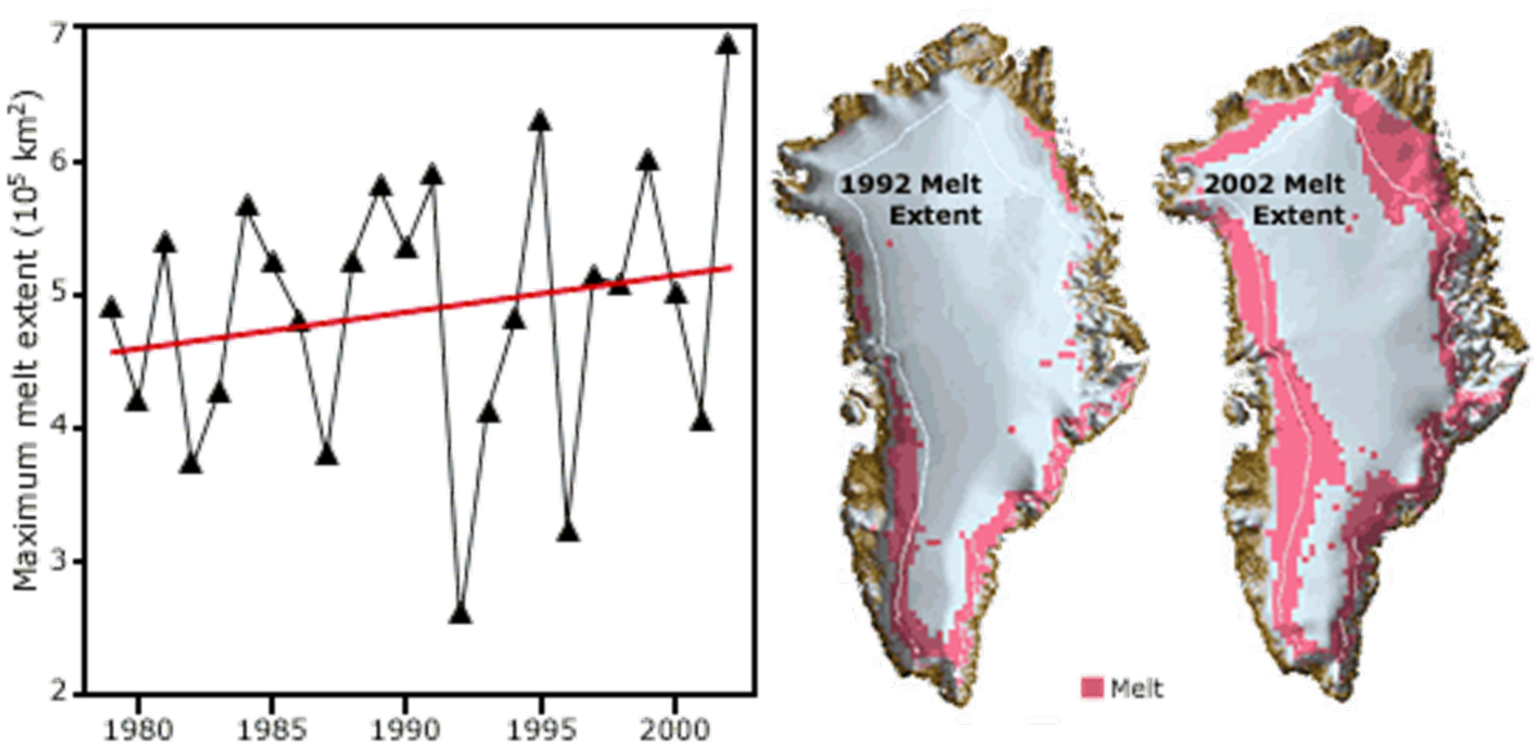
Climate change due to natural causes and human generated greenhouse gases

Concentration of Greenhouse gases

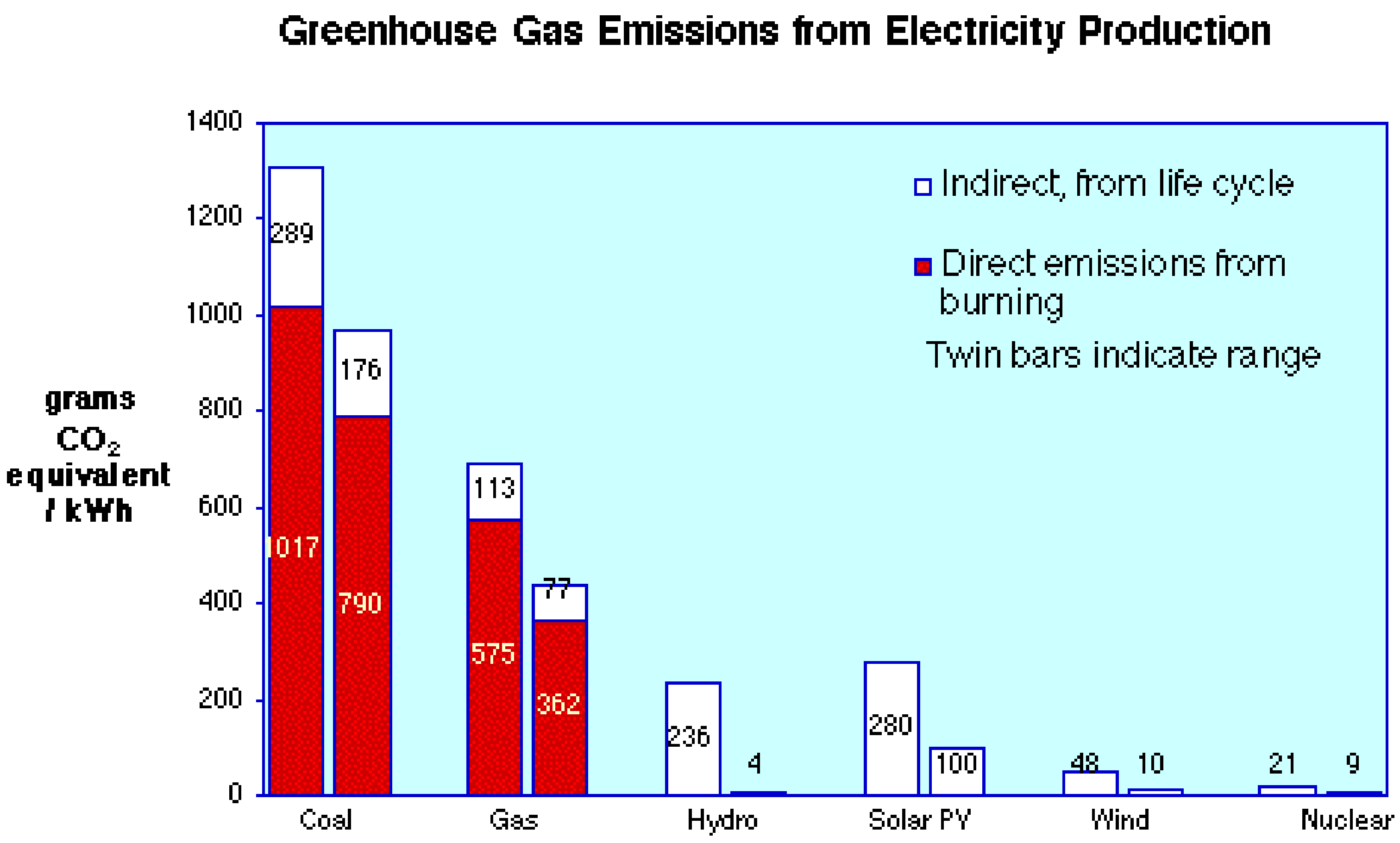


1750, the beginning of the industrial revolution

Greenland is melting



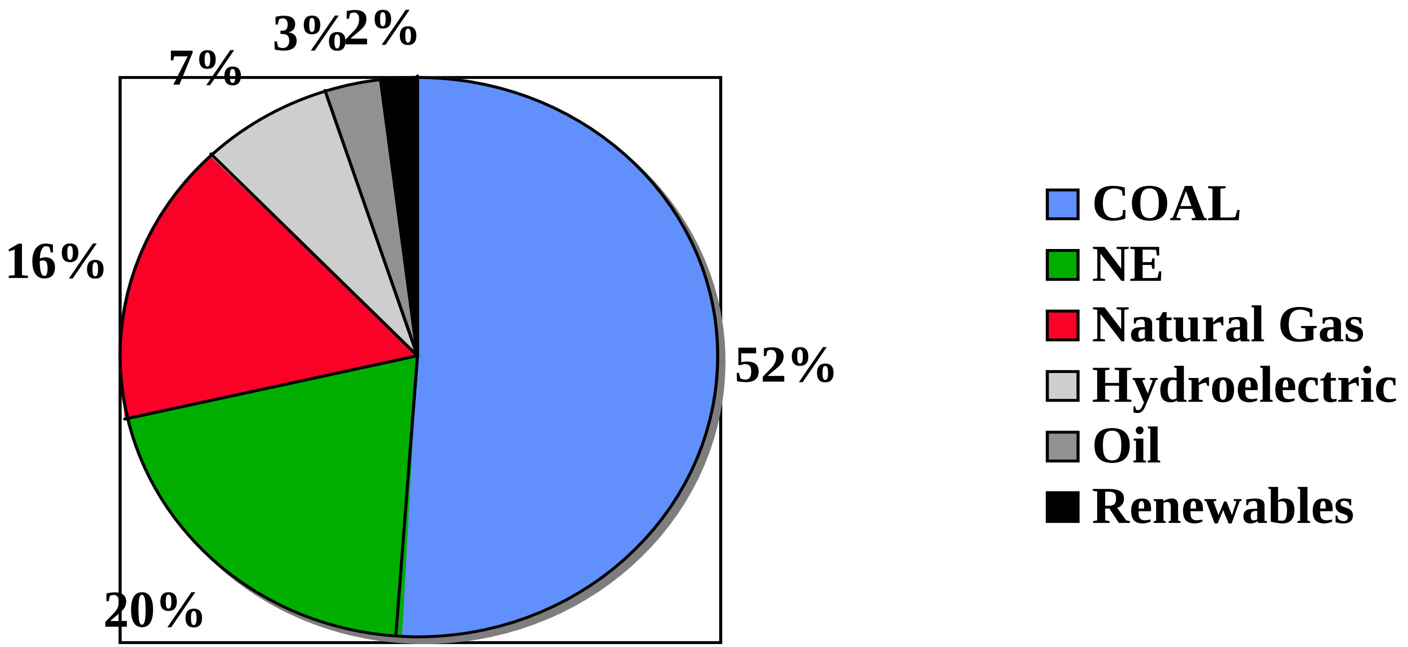
Life-cycle analysis considers construction as well as fuel consumption



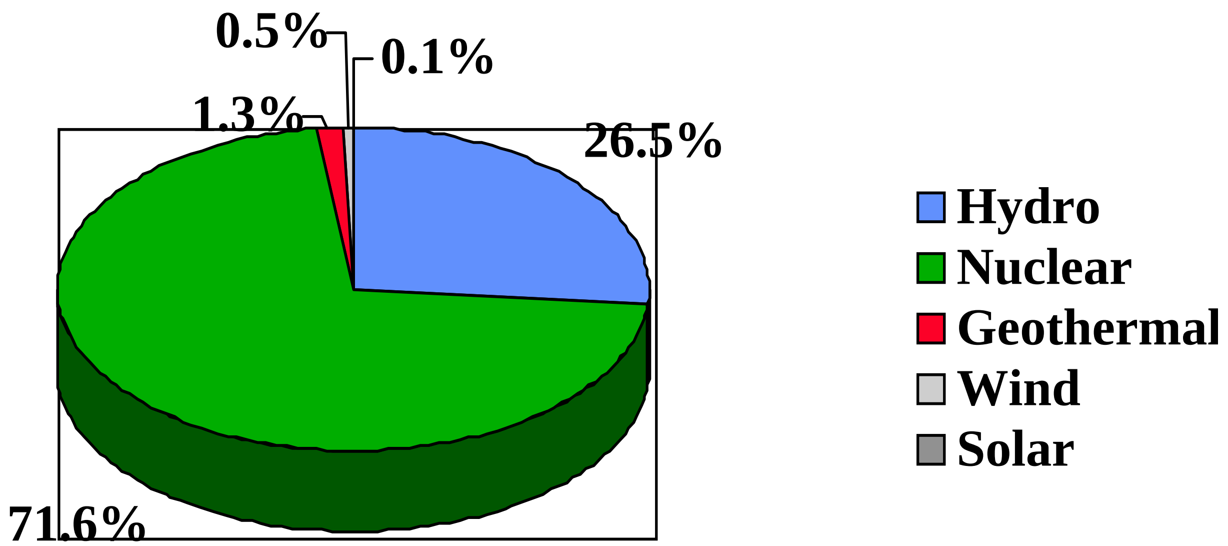
Source: IAEA 2000

Where does U.S. electricity comes from?

Source: NEI

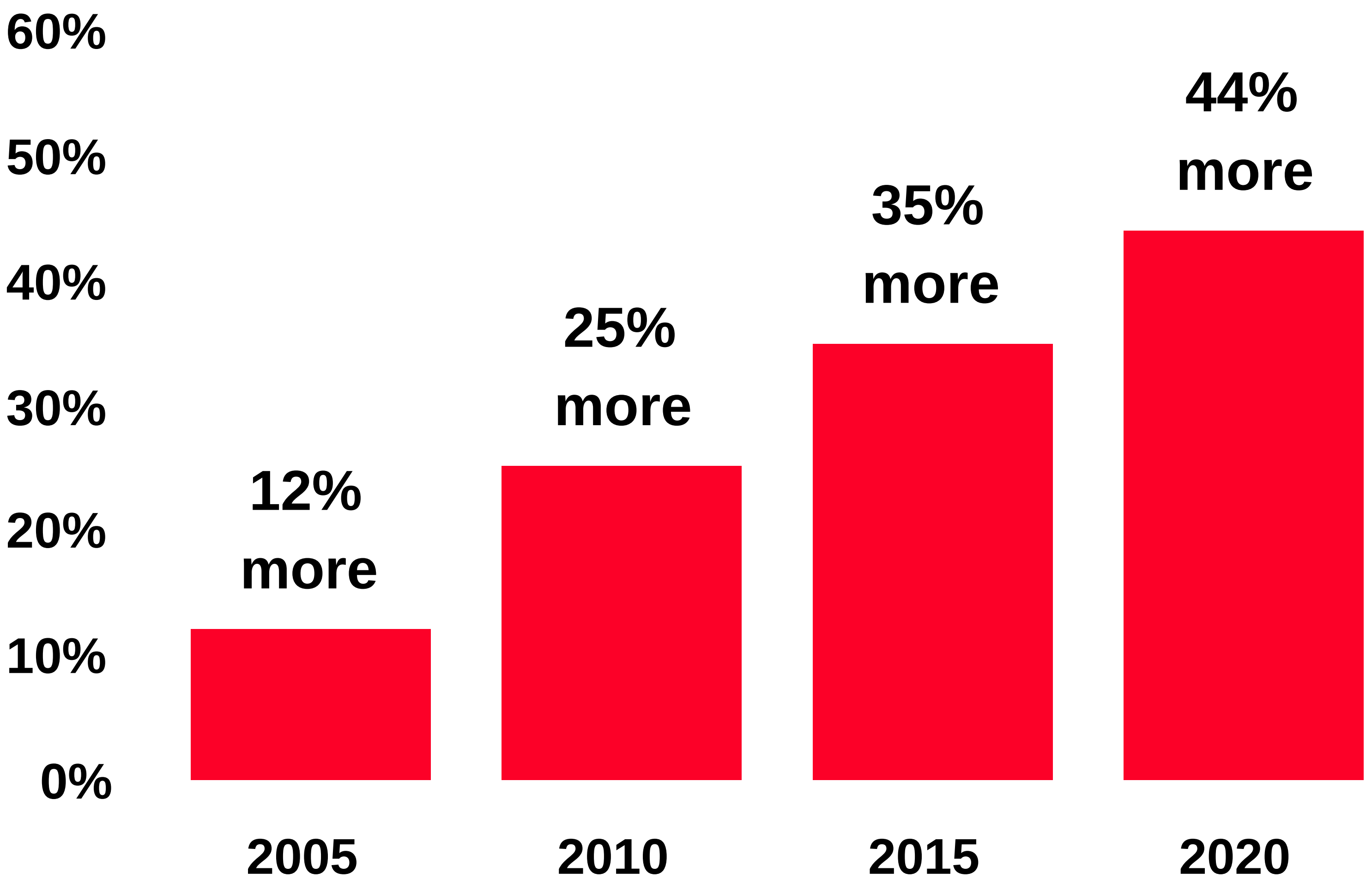


U.S. Sources of Emission-Free Generation (2000)



Source: EIA

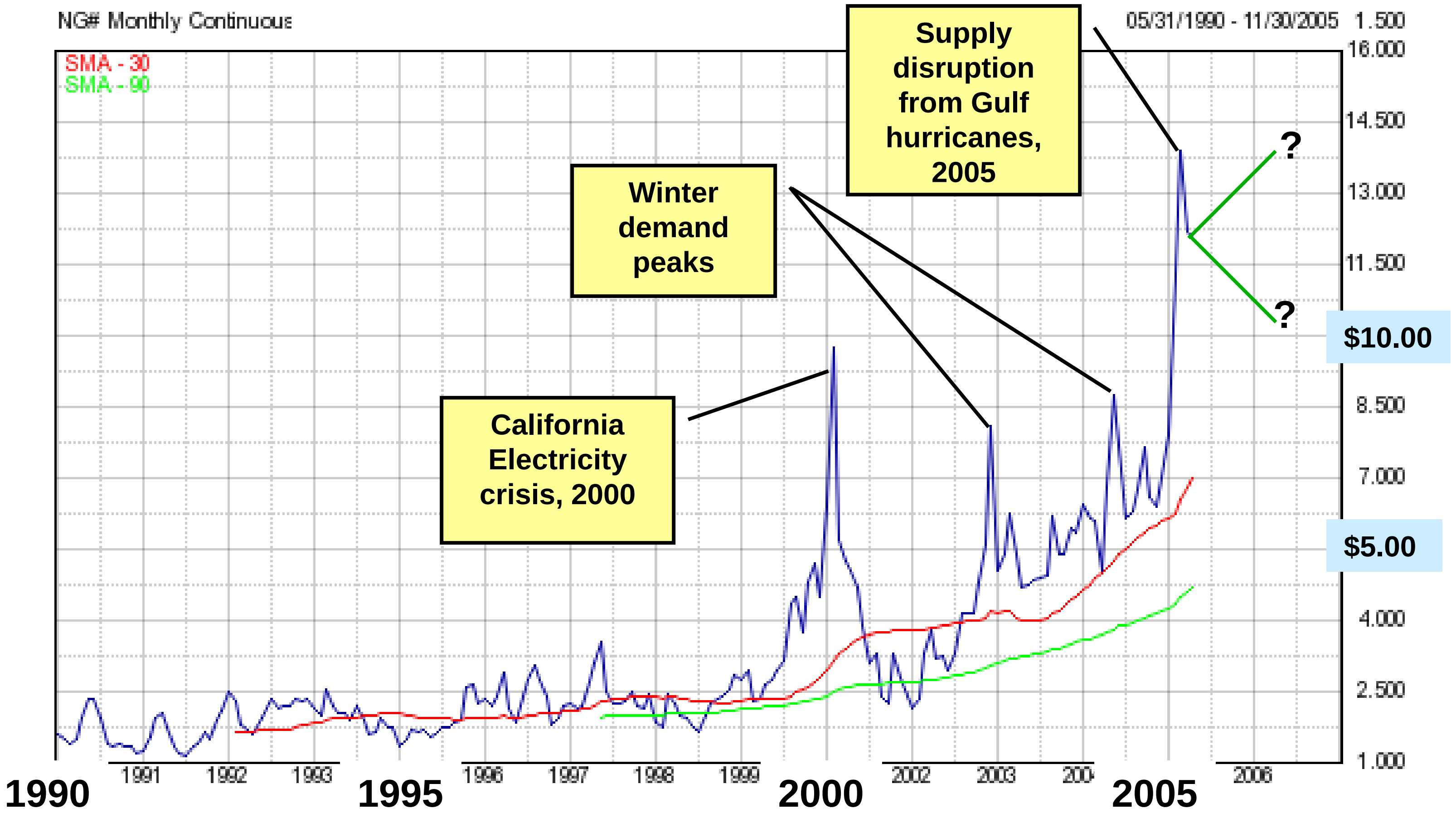
By 2020, U.S. Electricity Needs Will Increase by 44%



Source: U.S. Department of Energy

NYMEX Natural Gas 1990 – 2005

Recent natural gas price volatility and level creates openings for nuclear and coal.



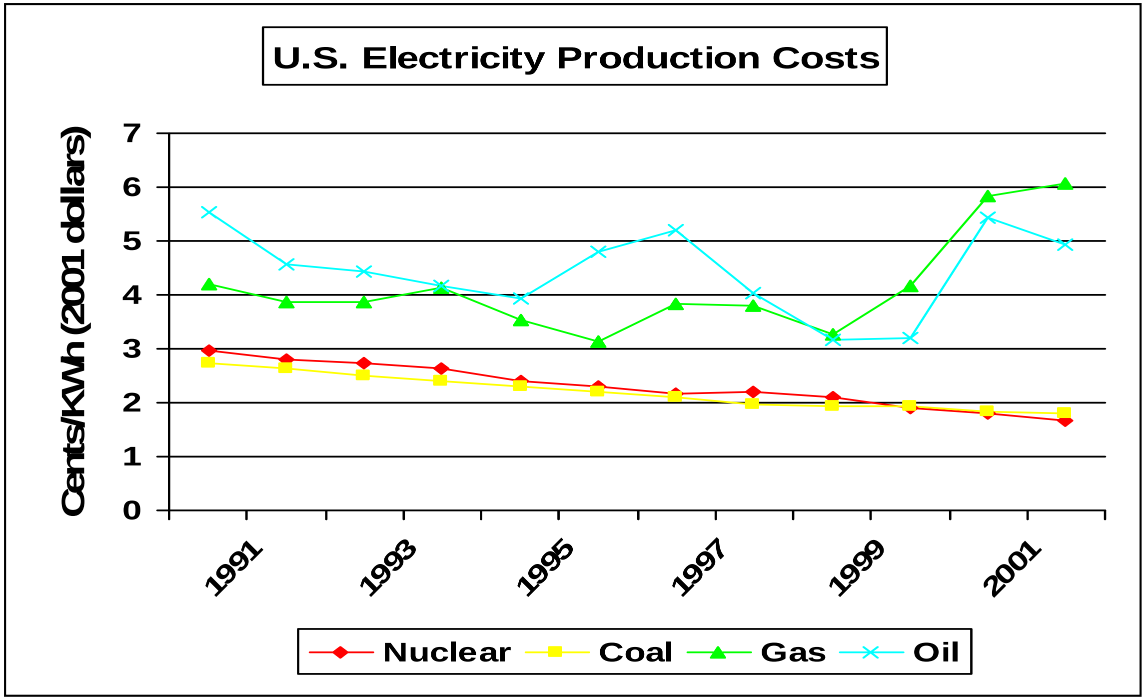
http://www.ccstrade.com/quotes/historical/monthly.xsp

Why Is Nuclear Energy Important?

- **Nuclear energy enables:**
  - **Air quality improvement**
  - **Carbon emission reduction**
  - **Waste reduction**
  - **Proliferation risk reduction**
  - **Increased energy security and independence**

Nuclear energy is affordable

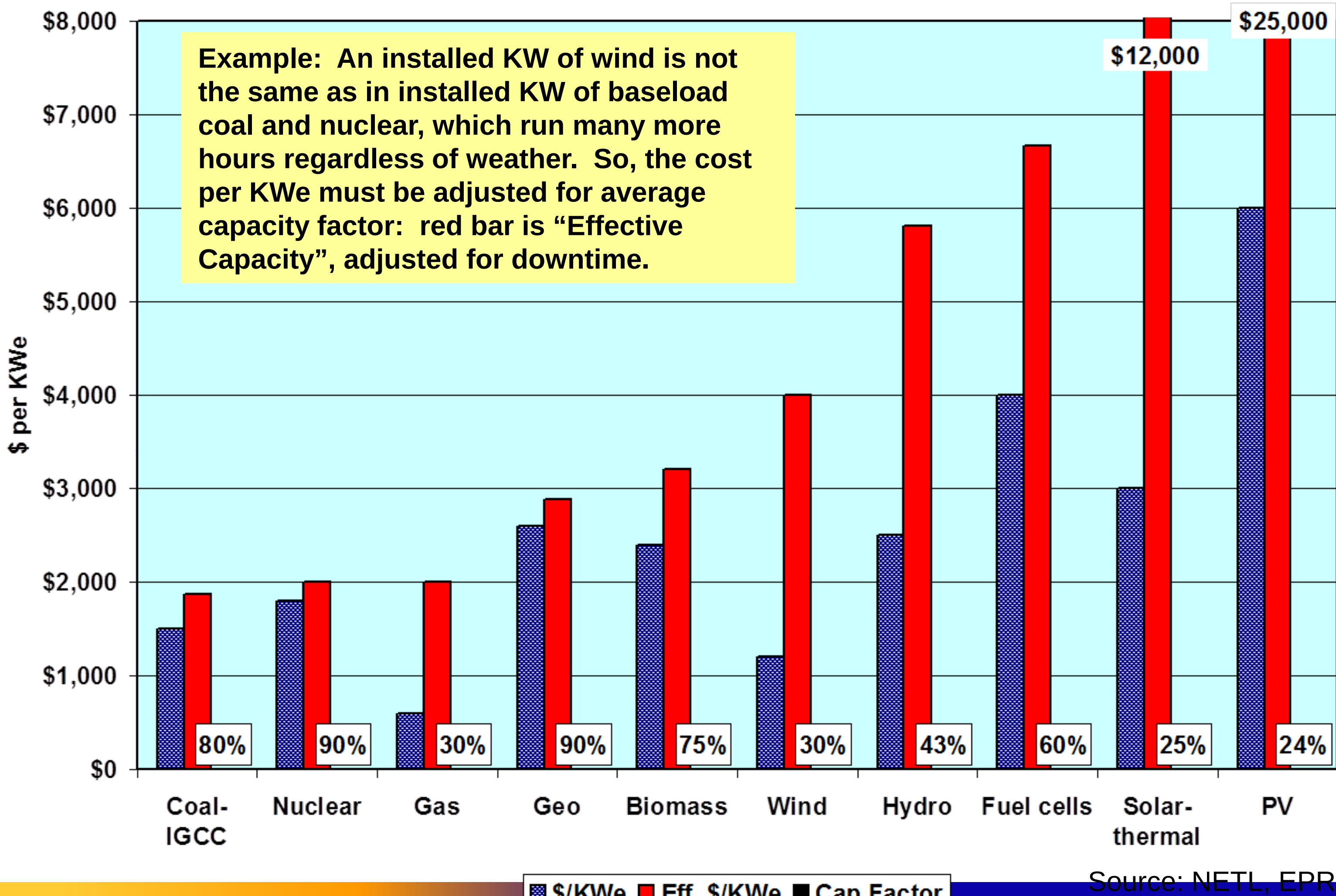
- Currently operating U.S. nuclear power plants have achieved low operating costs and are attractive in today's market
- We are designing new plants that can be built faster and at less cost than today's reactors (less than $1500/kW)



Source: Central Research Institute of Electric Power Industry, Japan 2000

Real Cost of Power Sources Affected by Capacity Factor

- Fuel costs, weather affect downtime of some sources, which impacts investment.



Source: NETL, EPRI

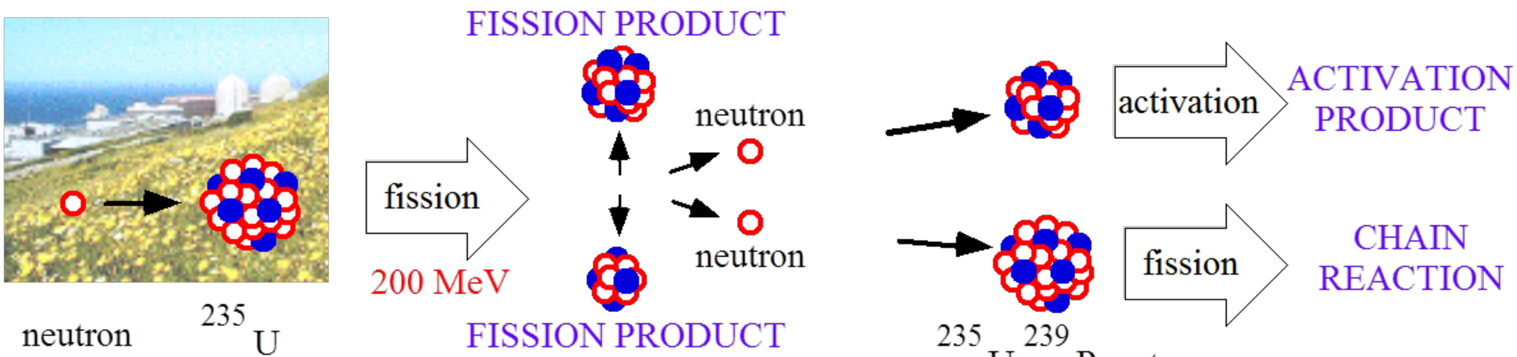
Sources of Electricity in California (1999)

Fuel Type	GWh	%
Coal	51,460	19.8
Large Hydro	52,082	20.1
Natural Gas	80,497	31.0
Nuclear	42,030	16.2
Other (Oil,Diesel)	1,671	0.6
Eligible Renewables	31,625	12.2
Geothermal	12,786	4.9
Solar	954	0.4
Wind	3,850	1.5
Total	259,365	100

Electricity from NPPs in California

Name of Plant	Capacity (MW)	In Service	Owner
Diablo Canyon			
Unit 1	1,073	1985	PG&E
Unit 2	1,087	1986	PG&E
San Onofre			
Unit 1	436	1968-92	SCE/SDG&E
Unit 2	1,070	1983	Same
Unit 3	1,080	1984	Same
Humbolt Bay			
Unit 3	65	1963-76	PG&E
Rancho Seco	913	1975-89	SMUD
Vallecitos	30	1957-67	PG&E/GE

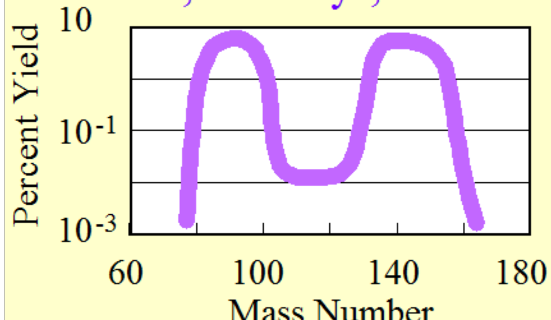
Energy from Nuclear Fission



- **Fission Fuel Energy Density: 8.2 x 10^{13} J/kg**
- **Fuel Consumed by 1000-MW_e Plant: 3.2 kg/day**
- **Waste:**

Fission Prod. (3.2 kg/day)

^{90}Sr, 30 yr; ^{137}Cs, 30 yr; ^{99}Tc, $2x10^5$ yr; etc.



Activation Products

Fuel → Transuranics, longer half lives (^{239}Pu, 24,000 yr; ^{237}Np, $2x10^6$ yr; etc.)

Structures → Moderate half lives, low-level waste (^{60}Co, 5 yr)

Coolants → Low (water) to moderate (metals) half lives

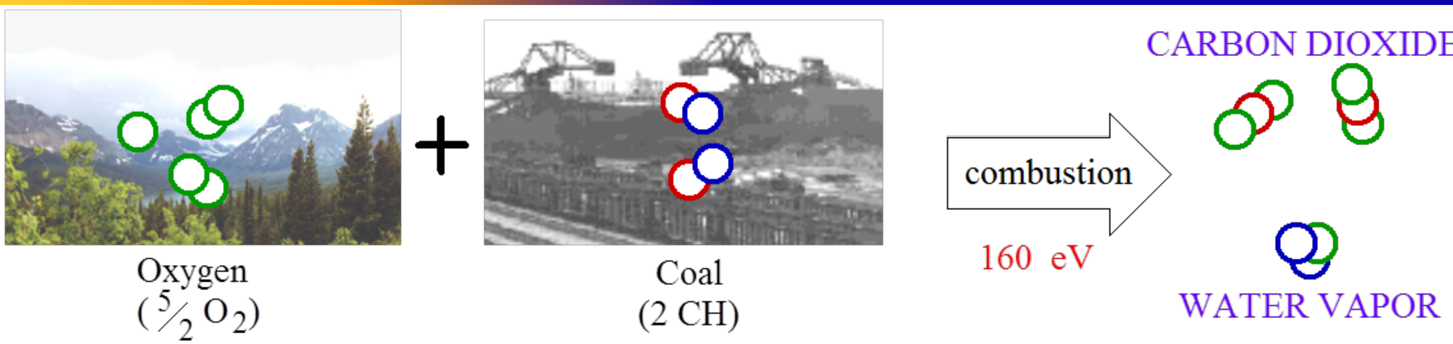
Transmutation → Convert from long to short half life

Mining

Radon from mill tails if not capped

Construction materials

Energy from Fossil Fuels



- **Fossil Fuel (Coal) Energy Density: 2.9 x 10^7 J/kg**
- **Fuel Consumed by 1000-MW_e Plant: 7,300,000 kg/day**
- **Waste:**

<u>Coal Combustion Products</u>

NO_x → High temperature combustion

SO_x → Sulfur in coal (0.4% - 5%)

Ash → (5% - 25% of coal mass)

CO_2 → Global warming

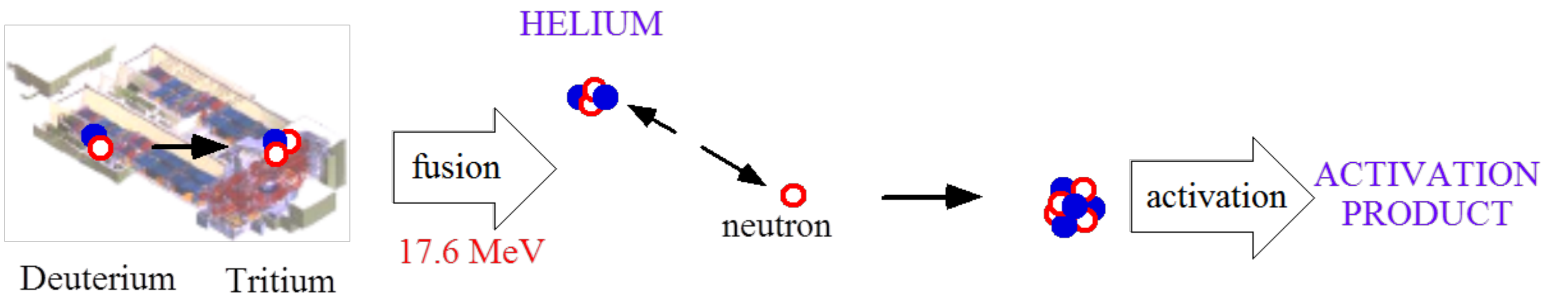
<u>Mining</u>

Leachates/ dust from mining

Construction materials

1999 Global Coal Consumption: 3 billion tons

Energy from Nuclear Fusion



- **Fusion Fuel Energy Density:** **3.4×10^{14} J/kg**
- **Fuel Consumed by 1000-MW_e Plant: 0.6 kg/day**
- **Waste:**

<u>Activation Products</u>

Structures → Moderate half lives, depends strongly on material selection (low atomic mass better)

Coolants → Short half lives (low atomic mass)

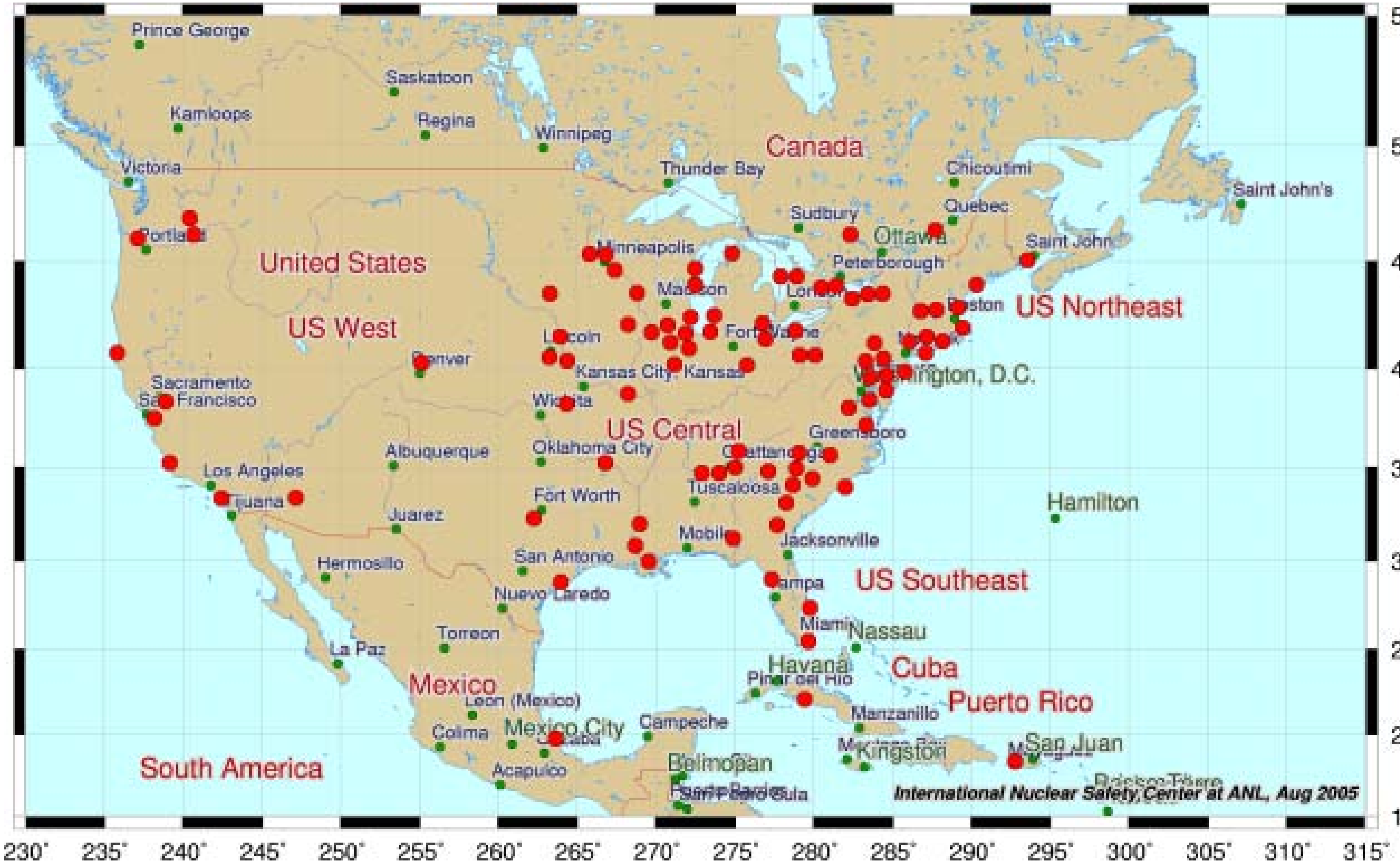
Blanket → $n + {}^{6}Li \rightarrow 4He + T$

$n + {}^{m}M \rightarrow 2n + {}^{m-1}M$

<u>Mining</u>

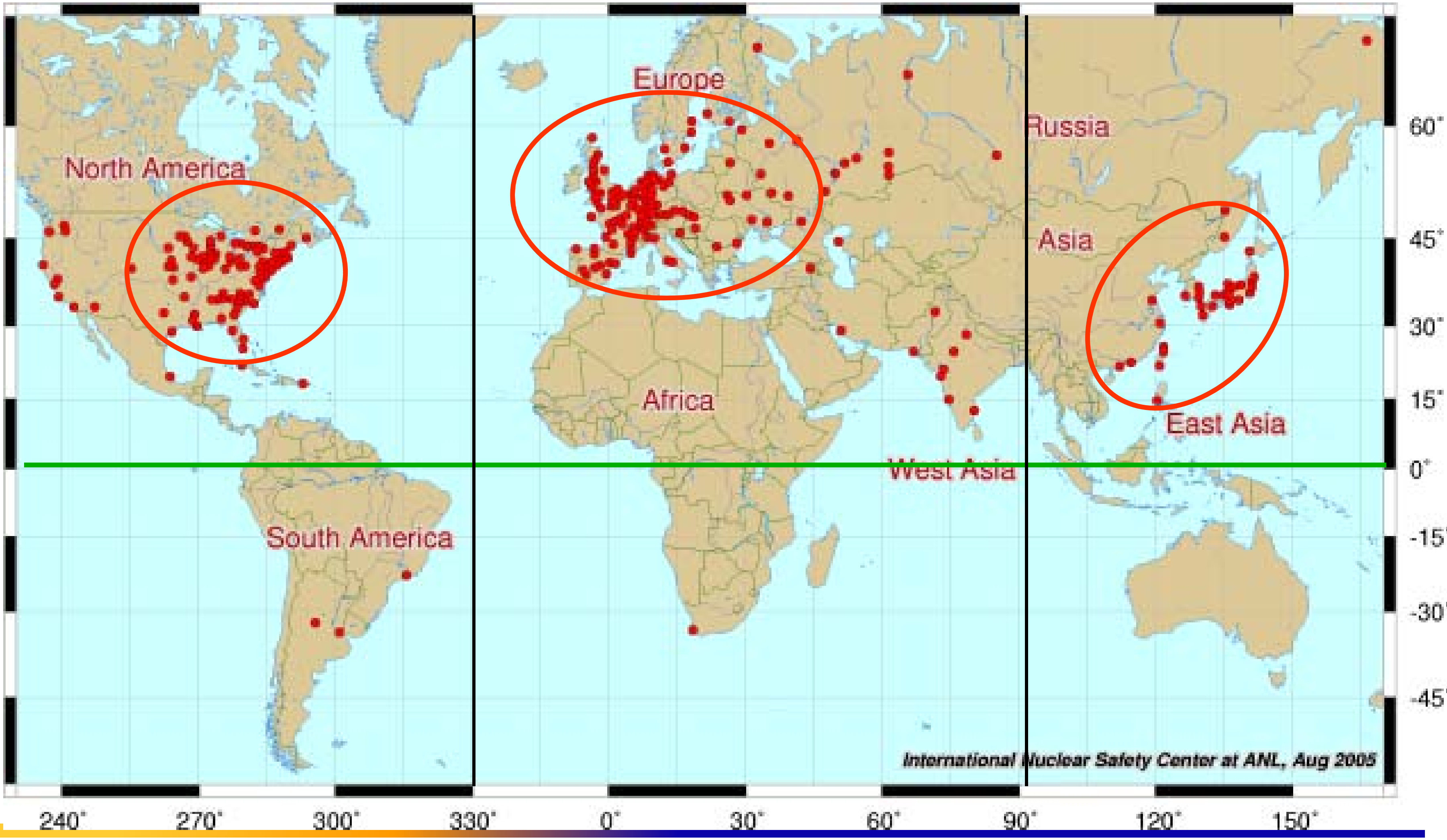
Construction materials

North American Nuclear Power: 110,000 MWe in 2005
103 Nuclear Power Plants in the USA



Nuclear Power Plants Worldwide (400 NPP): 365,000 MWe in 2005

- Nuclear power historically has been an OECD advanced economy power source.



Previous Barriers Are Now Current Opportunities

Shifts on a number of key issues improve the prospects for nuclear power:

Then (1970s-80s)

- Greenfield sites face opposition after TMI (1979); license renewals not under consideration
- High interest rates (12-15%)
- Uncertain regulatory approval with separate construction, operation licensing
- Varying plant designs; no CAD
- Uranium fuel prices at 2x-3x current price levels
- Low capacity factors (<60%)
- Regulated gas prices
- No resolution on SNF disposal
- Concern about urban air pollution, not greenhouse gases

Now – 2010

- ★ Next reactors only on current sites in supportive communities (~18-24), and often where reactors were renewed.
- Interest rates down to ~5-8%
- ★ Combined "Construction and Operating License" (COL) being defined by NRC (not tested in court)
- Pre-certified designs with CAD/CAM and 4-D modeling
- Low U-fuel prices below $10/MWh
- Capacity factors >90% since 2001
- Highly volatile gas prices >$6/mBtu
- Congressional approval for Yucca Mountain licensing phase **(July 2002)**
- ★ Global concern about GHG levels

★ Deal-breaker issue, now leaning favorable

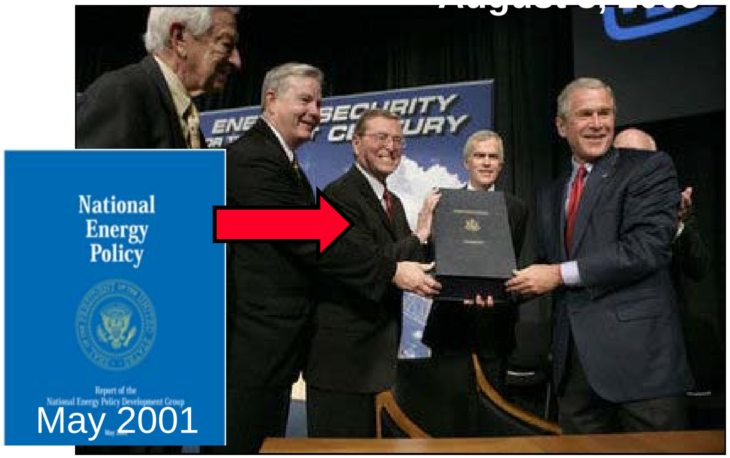
Plans for New NPP Construction

- France - 80 % electricity from NPP, will continue with construction of new NPPs, will built the first GEN IV NPP by 2020
- Japan - 30 % electricity from NPPs
- Russia - plans 30-40 new NPPs by 2030
- China - plans 30 new NPPs by 2020
- India - plans to built more NPPs
- UK - discussion about going back to NE

Nuclear Renaissance in the USA- 2005

- In 2004, average production cost of nuclear electricity 1.7 c/kWhr, average capacity factor 90.7%, NE presents 70% of all non-fossil energy production in USA
- The Department of Energy Nuclear Power 2010 Program, support from the Federal Government
- August 05 - New US Energy Policy Act Passed (encourages new NPP construction - production tax credits, loan guaranties and risk protection, extension of Price-Anderson Act for 20y, funding to built a demonstration HTR at INL to produce electricity and H)
- NuStart Energy Development LLC (8 utilities, two vendors GE and Westinghouse), Entergy, Dominion, Duke, Progress, Areva (French) announced 19 new Combined Construction and Operation Licenses
- Three designs: 1,000 MWe AP1000 (Westinghouse) - received final NRC design certification in Jan 2006; 1,500 MWe ESBWR (GE), and 1,600 MWe EPR (Areva-Framatome)
- Possibility of having new reactors operating by 2014
- Shortage of qualified manpower

Energy Policy Act 2005 Passes



President George W. Bush signing H.R. 6, The Energy Policy Act of 2005 at Sandia National Laboratory in Albuquerque, New Mexico, Monday, Aug. 8, 2005. On stage are Congressman Ralph Hall (R, TX), Congressman Joe Barton (R, TX), Senator Pete Domenici (R, NM) and Senator Jeff Bingaman (D, NM).

Parallel Energy Initiatives

President's Hydrogen Initiative
Freedom Car
Nuclear Power 2010
Clean Coal Power Initiative
Climate VISION
Global Nuclear Energy Partnership 2006

Focus

- Promotes energy efficiency and renewable power and fuels, hybrid vehicles and hydrogen.
- Provides incentives for power and fuels from coal gasification, and for nuclear power and upgrades of the electric grid.
- Clarifies rules for siting power infrastructure and investment.
- Calls for inventory of domestic resources.
- Offers federal financial assistance
- Addresses Climate Challenge through sound voluntary actions and acceleration of technology.
- Closed nuclear fuel cycle, reduction of SF by reprocessing, one Yucca Mountain repository

WHAT DO WE NEED?

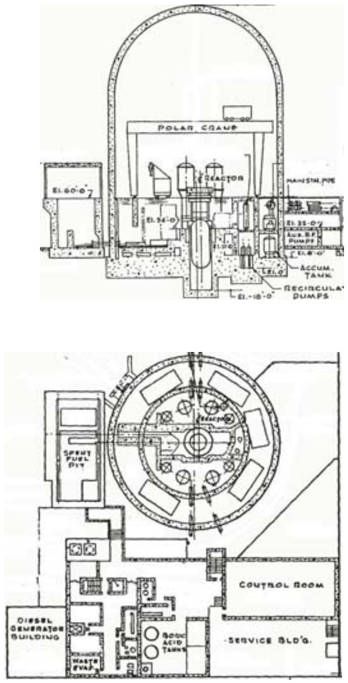
- **Advanced Nuclear Fuel Cycle**
- **Reprocessing of spent fuel**
- **Burning of Pu and minor actinides**
- **Production of electricity and hydrogen**
- **New reactor designs (GEN IV)**

WHAT DO WE NEED FOR SUSTAINABLE NUCLEAR ENERGY?

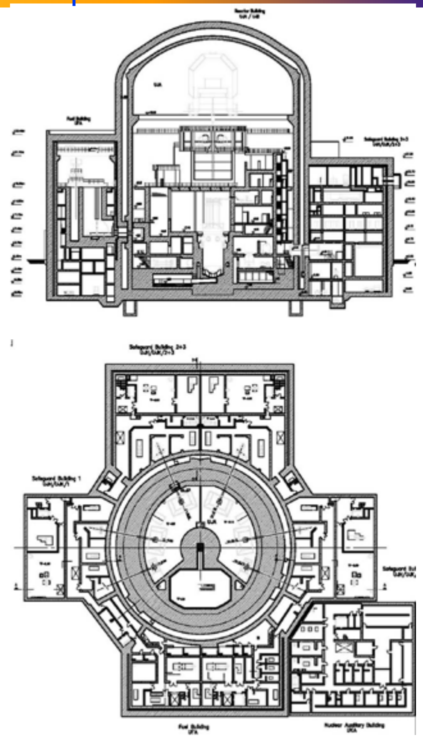
- New NPP construction with current designs (AP 1000 and ESBWR) to provide base-load emission-free energy at low cost
- Use of NE for efficient production of electricity, heat and hydrogen
- Opening of one permanent repository for retrievable spent fuel storage (spent fuel could be retrieved for reprocessing in the future)
- Development of Advanced Nuclear Fuel Cycle with reprocessing of spent fuel, and burning of Pu and minor actinides (we do not need to start reprocessing now, until we develop more efficient reprocessing system)
- Long-term: new reactor designs for optimal fuel cycle producing minimum waste

Economics will be strong influenced by design optimization to increase power while reducing structures/equipment

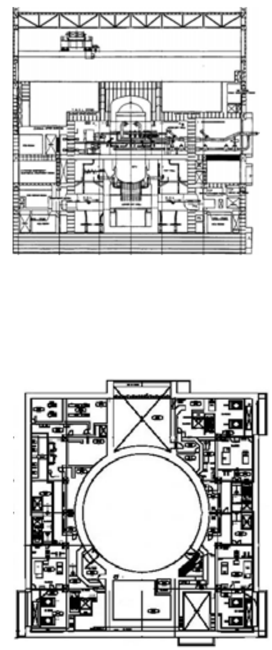
Gen II | **Gen III - Active** | **Gen III+ - Passive**



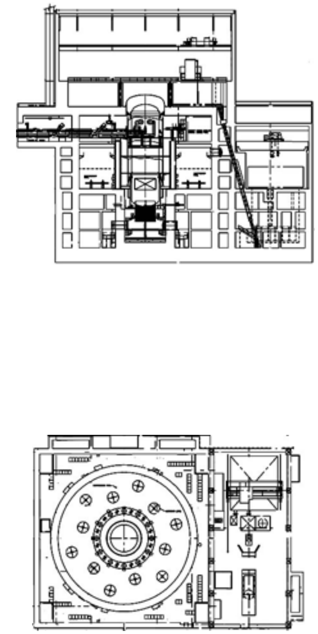
1970's PWR
1000 MWe
40 MT_{steel}/MW



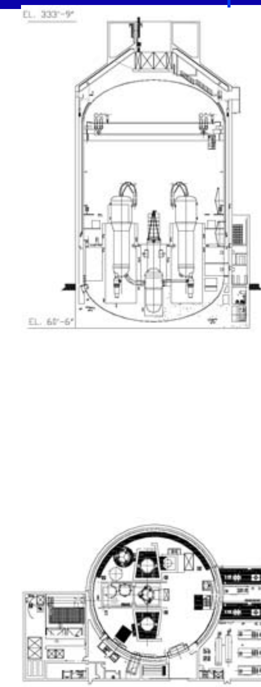
EPR
1600 MWe
49 MT_{steel}/MW



ABWR
1380 MWe
51 MT_{steel}/MW



ESBWR
1550 MWe
__ MT_{steel}/MW



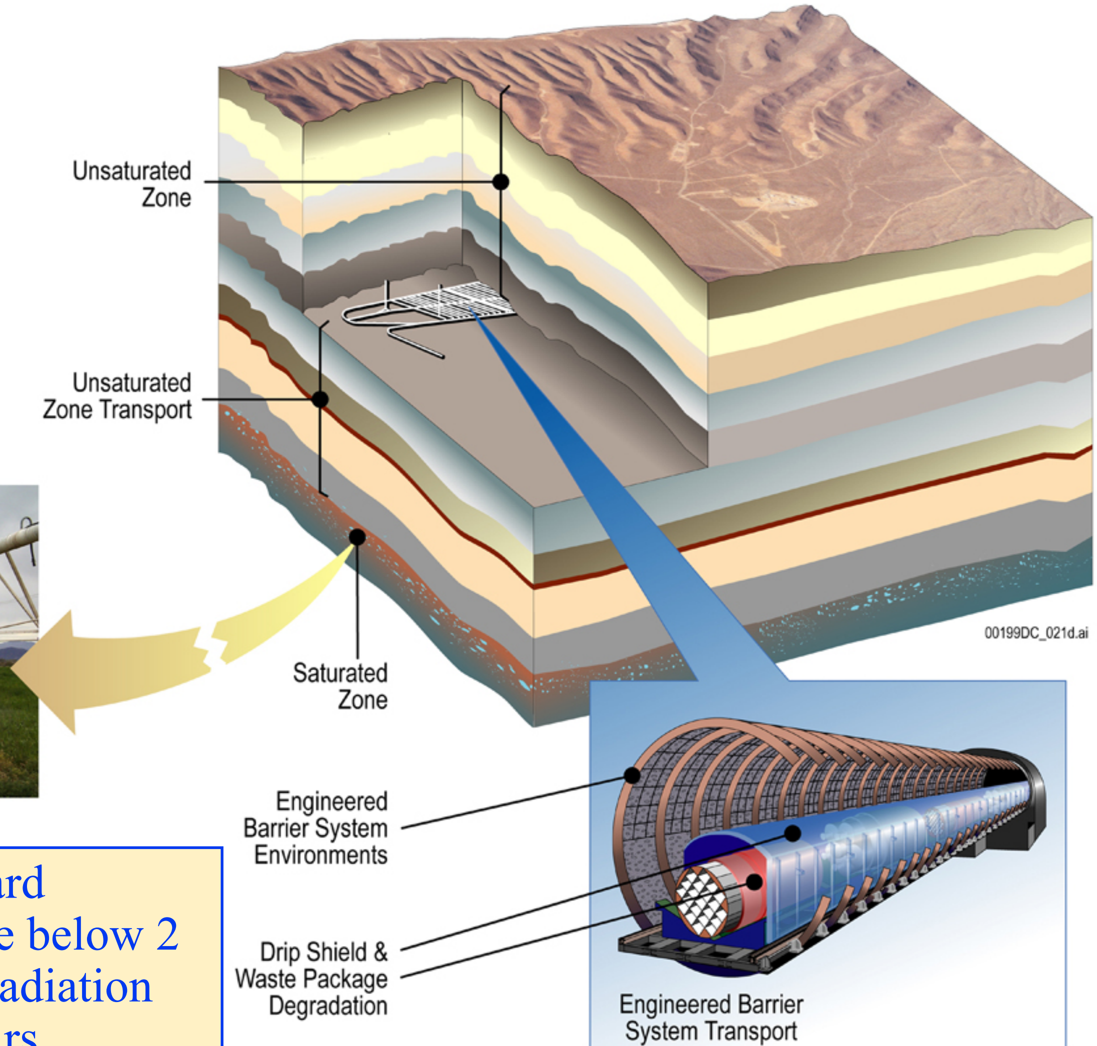
AP-1000
1090 MWe
42 MT_{steel}/MW

Large light water reactors with passive safety features will be difficult to beat for commodity electricity generation


Yucca Mountain
00199DC_043.ai

Overview of Yucca Mountain repository system

Biosphere



The current performance standard requires that maximum doses be below 2 percent of natural background radiation exposure for at least 10,000 years

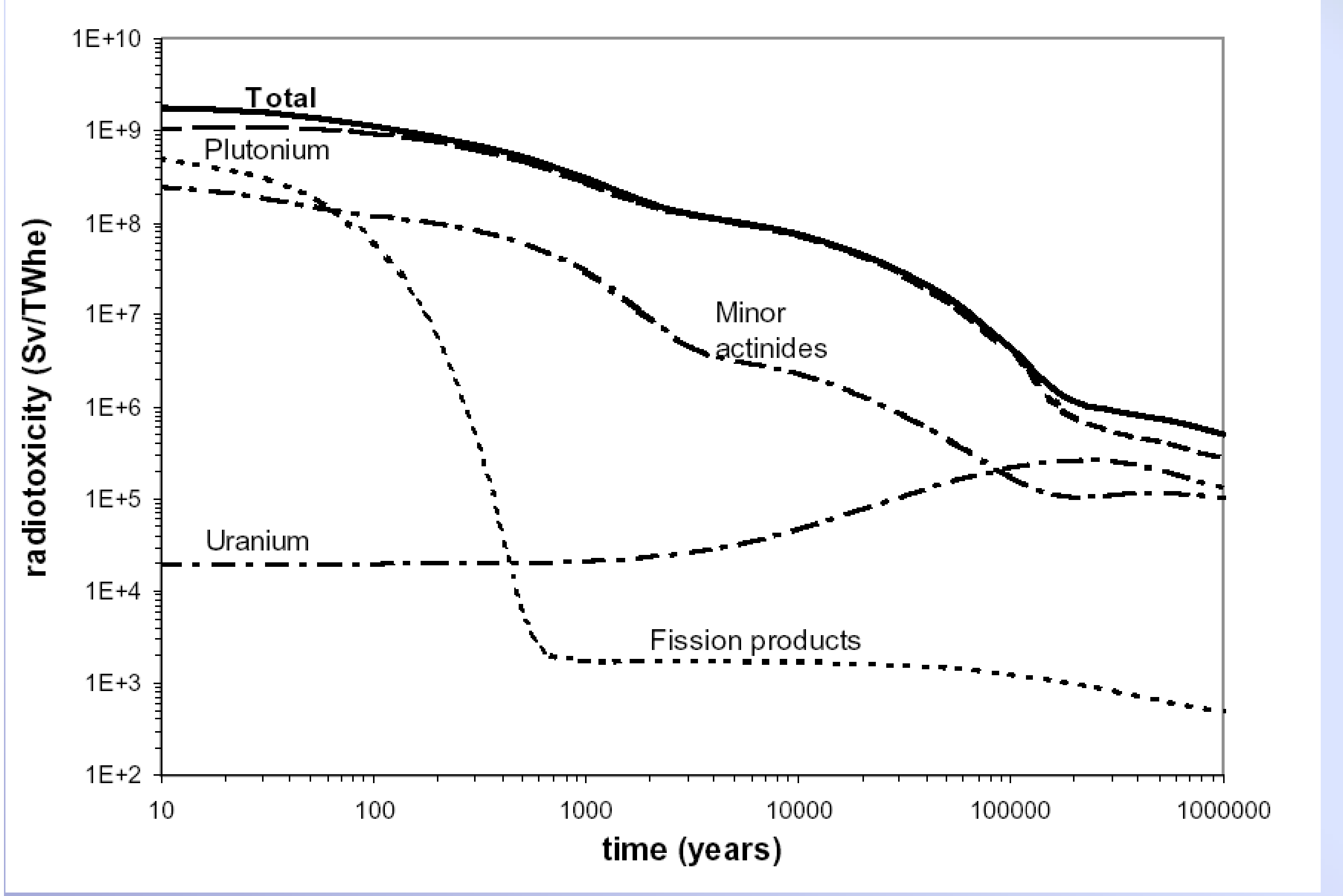
Advanced Fuel Cycle Initiative

- Reduce the long-term environmental burden of nuclear energy through more efficient disposal of waste materials
- Enhance overall nuclear fuel cycle proliferation resistance via improved technologies for spent fuel management
- Enhance energy security by extracting energy recoverable in spent fuel, avoiding uranium resource limitations
- Continue competitive fuel cycle economics and excellent safety performance of the entire nuclear fuel cycle system

Nuclear Futures		Existing License Completion	Extended License Completion	Continuing Level Energy Generation	Continuing Market Share Generation	Growing Market Share Generation
Cumulative discharged fuel in 2100 (metric ton)		100,000	120,000	250,000	600,000	1,400,000
		Existing Reactors Only		Existing and New Reactors		
Fuel Management Approach		Number of Repositories Needed at 70,000 Metric Ton Each				
No Recycle	Once-Through	2	2	4	9	20
No Recycle	Once-Through, High Burnup Fuels	2	2	3	7	17
Reprocess & Recycle	Limited Recycle, High Burnup Fuels	Recycle not applicable	Recycle not applicable	2	5	10
Reprocess & Recycle	Transitional and Sustained Recycle	Recycle not applicable	Recycle not applicable	1	1	1

04-GA50634-20

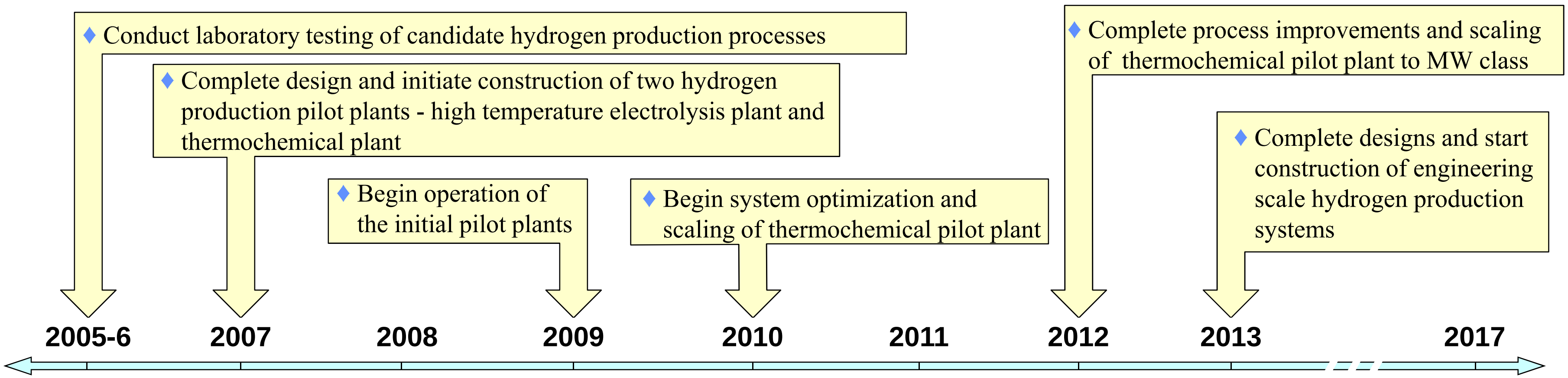
Why do we need to reprocess?

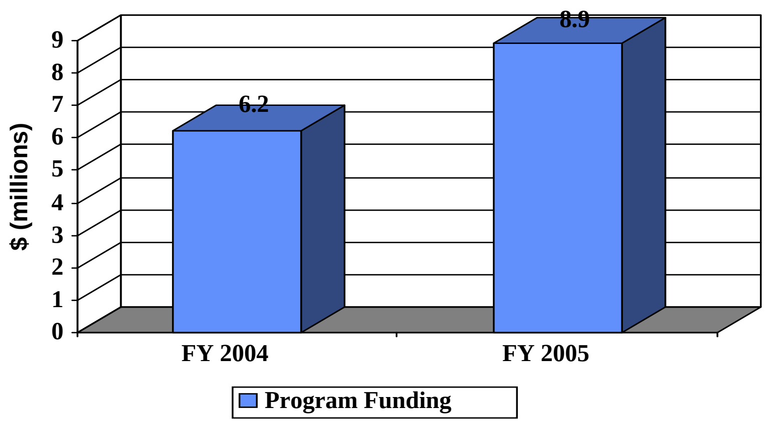


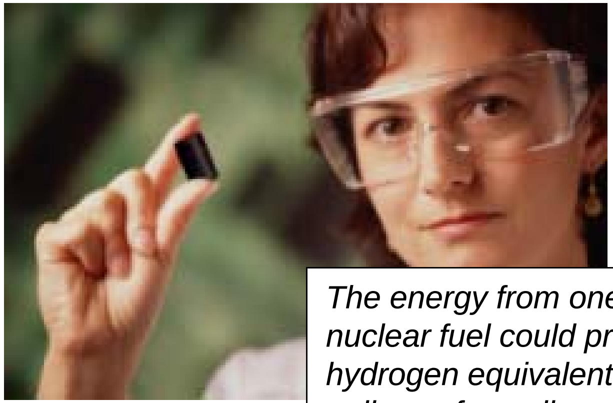
C. Madic et al., Report CEA-R-6066 (2004)

Nuclear Hydrogen Initiative

- **Established to identify and evaluate new and innovative concepts for producing hydrogen using nuclear reactors.**

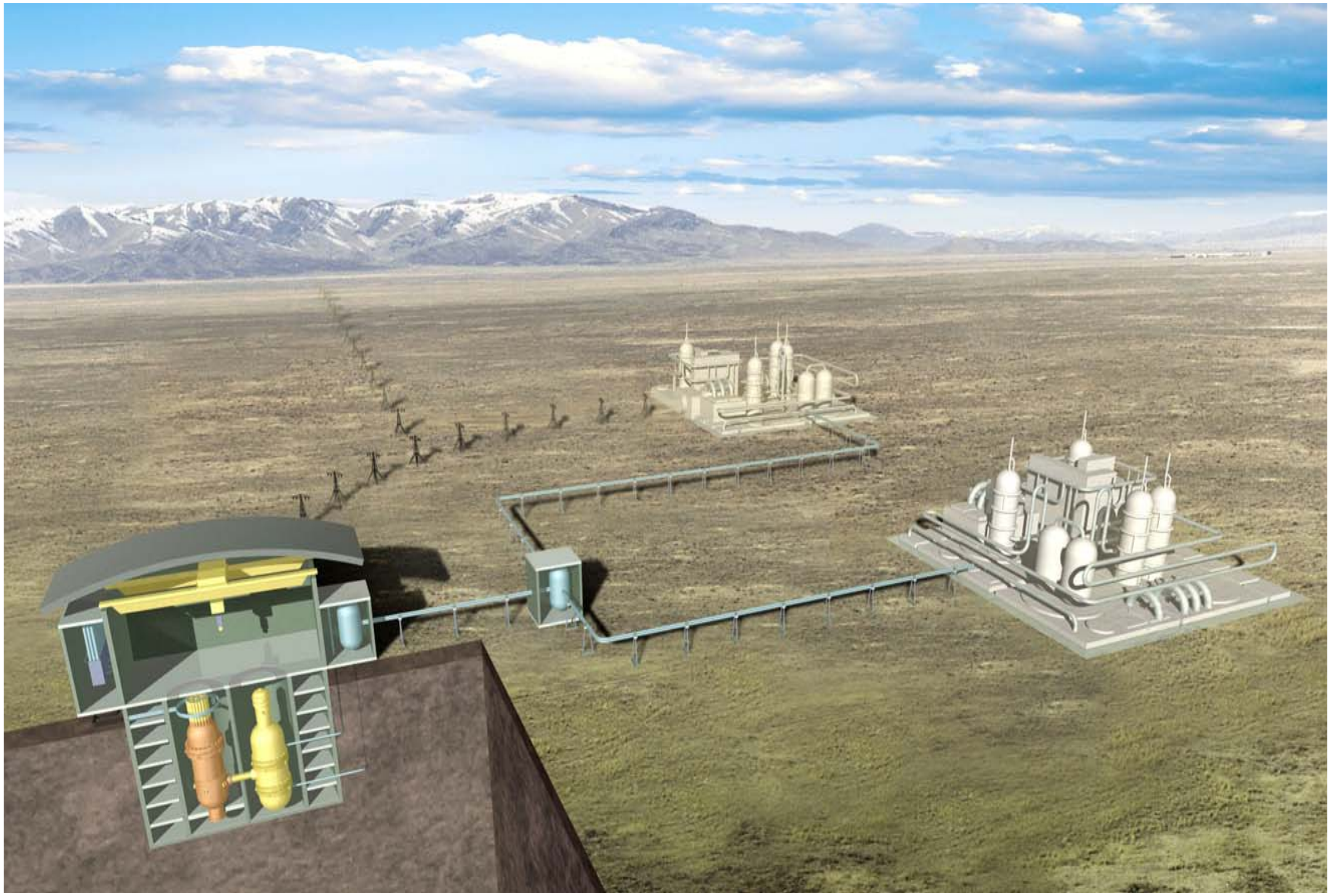




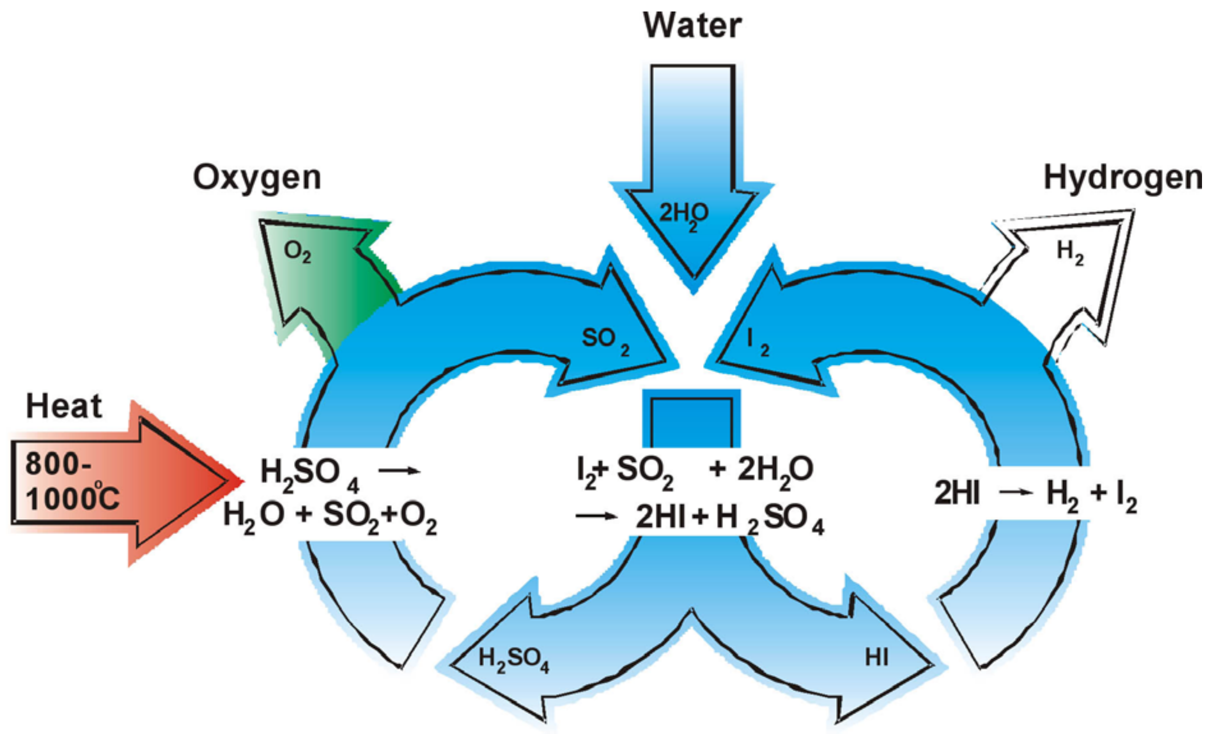


The energy from one pound of nuclear fuel could provide the hydrogen equivalent of 250,000 gallons of gasoline without any carbon emissions.

The Next Generation Nuclear Plant (NGNP) is expected to be the first Gen IV plant constructed

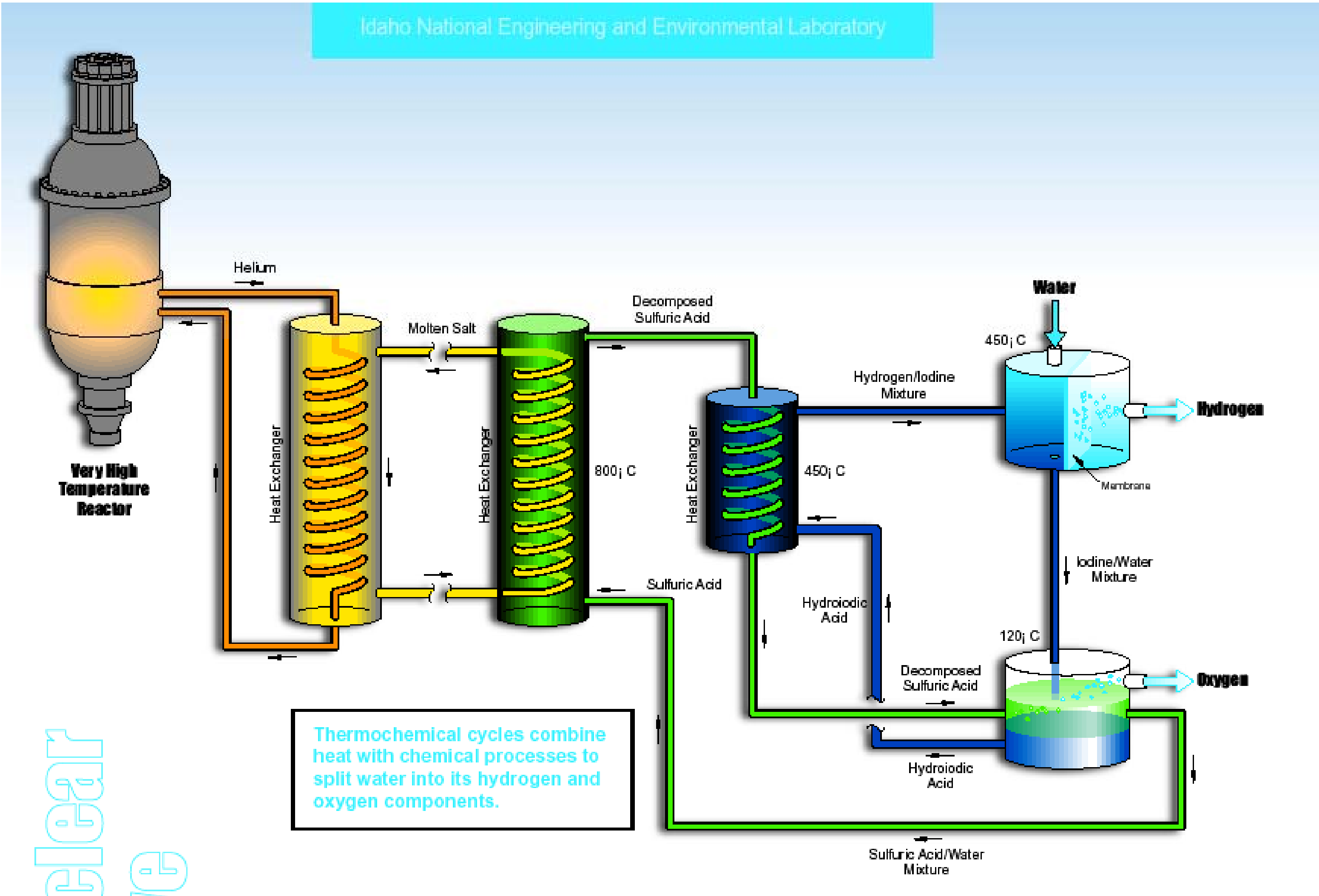


High temperature reactors can make hydrogen directly through for thermo-chemical processes



ORNL DWG 2001-102R

Producing Hydrogen - The Thermo-chemical Cycles



SUSTAINABLE NUCLEAR ENERGY

- Emission-free, safe and reliable nuclear energy systems
- Closed fuel cycle - with reprocessing of spent fuel:
  - expand the nuclear fuel supply into future centuries by recycling spent fuel to recover its energy content
  - Allow geologic repositories to accept the spent fuel of many more plant-years of NP operation through substantial reduction in the amount of spent fuel, and their decay heat
- Proliferation resistant fuel cycles
- Economical and affordable Nuclear Energy
  - New simplified modular designs
  - Production of electricity, Hydrogen, water desalination, district heating