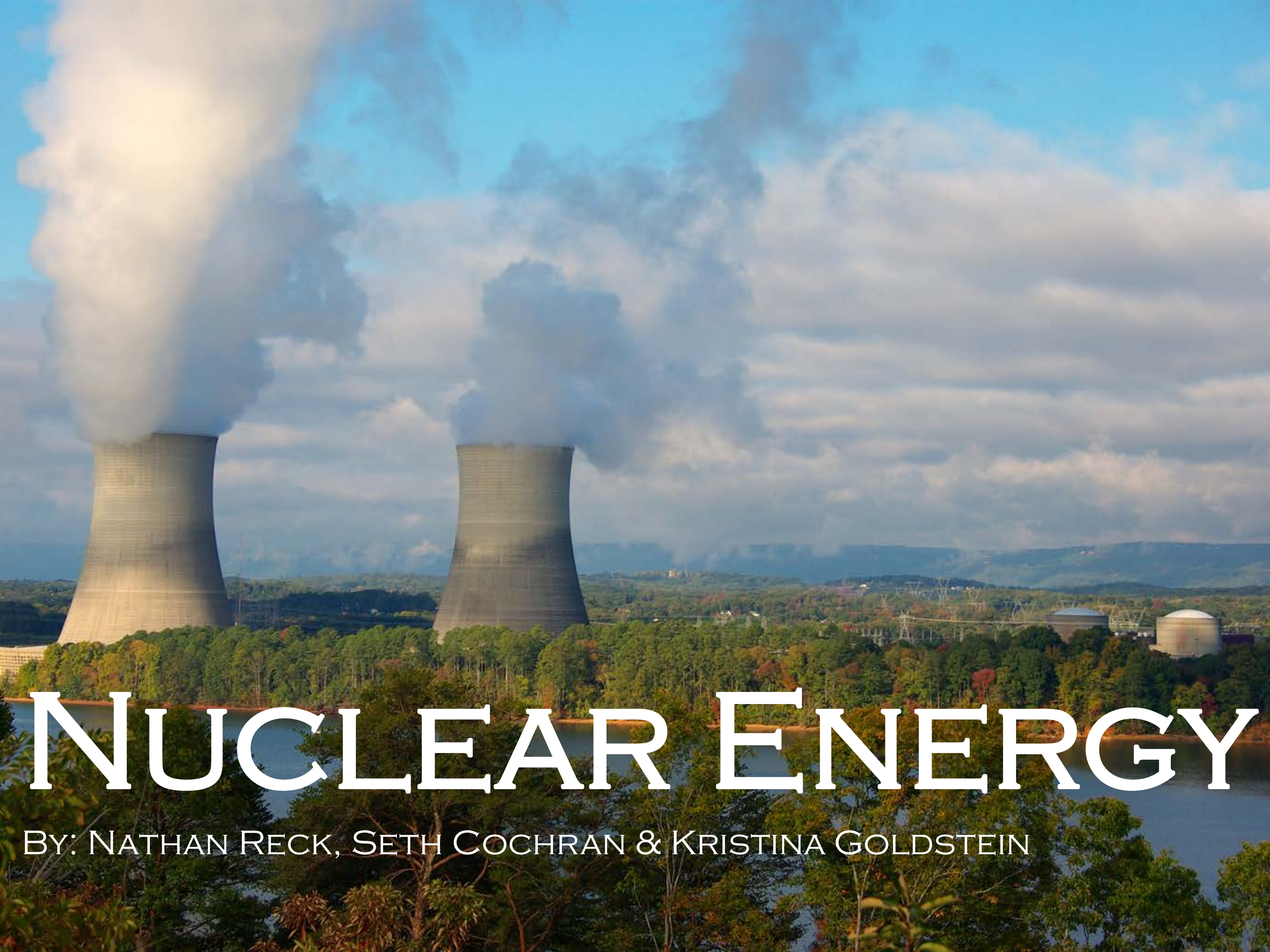


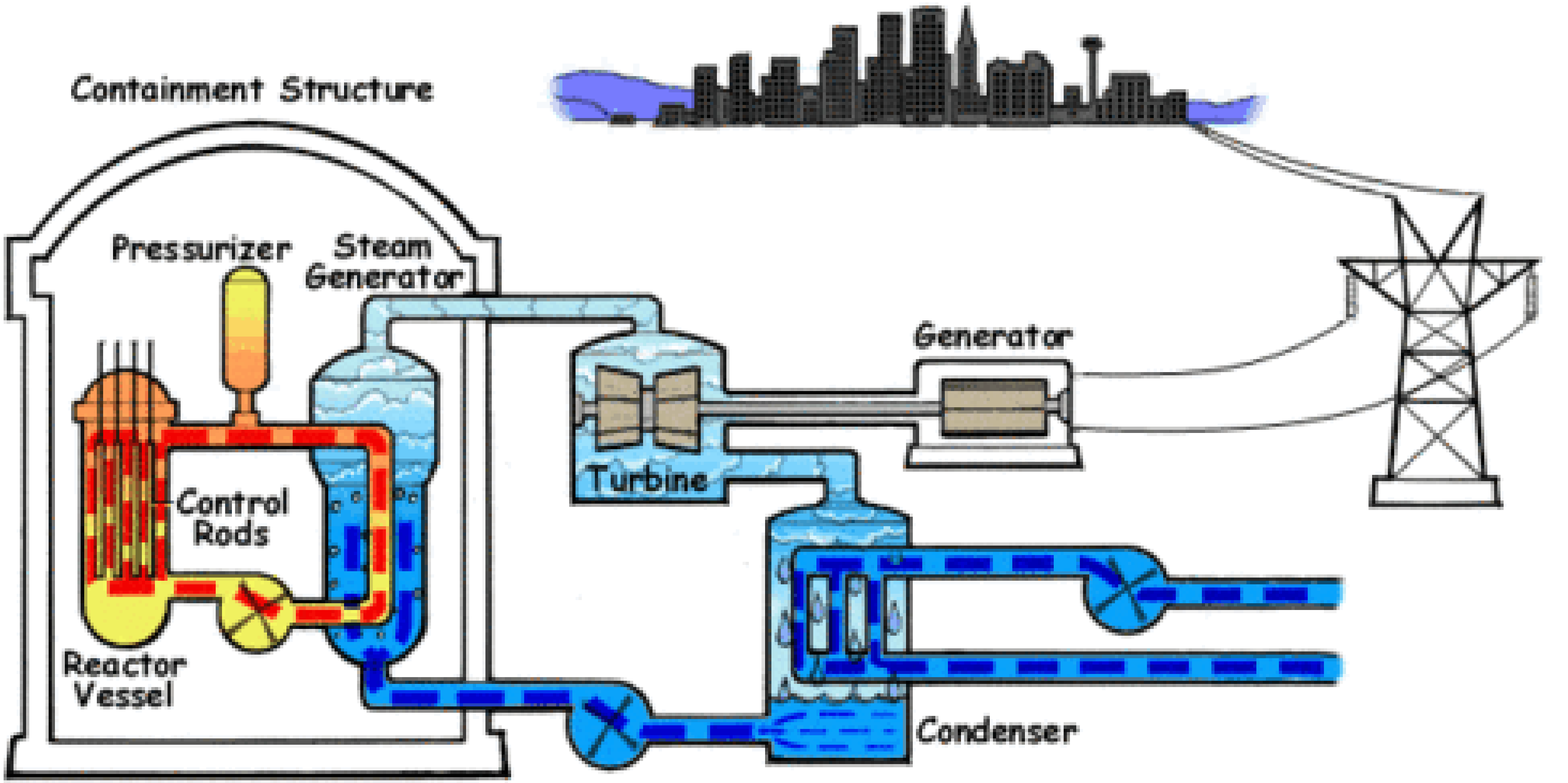
Nuclear Energy

By: Nathan Reck, Seth Cochran & Kristina Goldstein

Overview

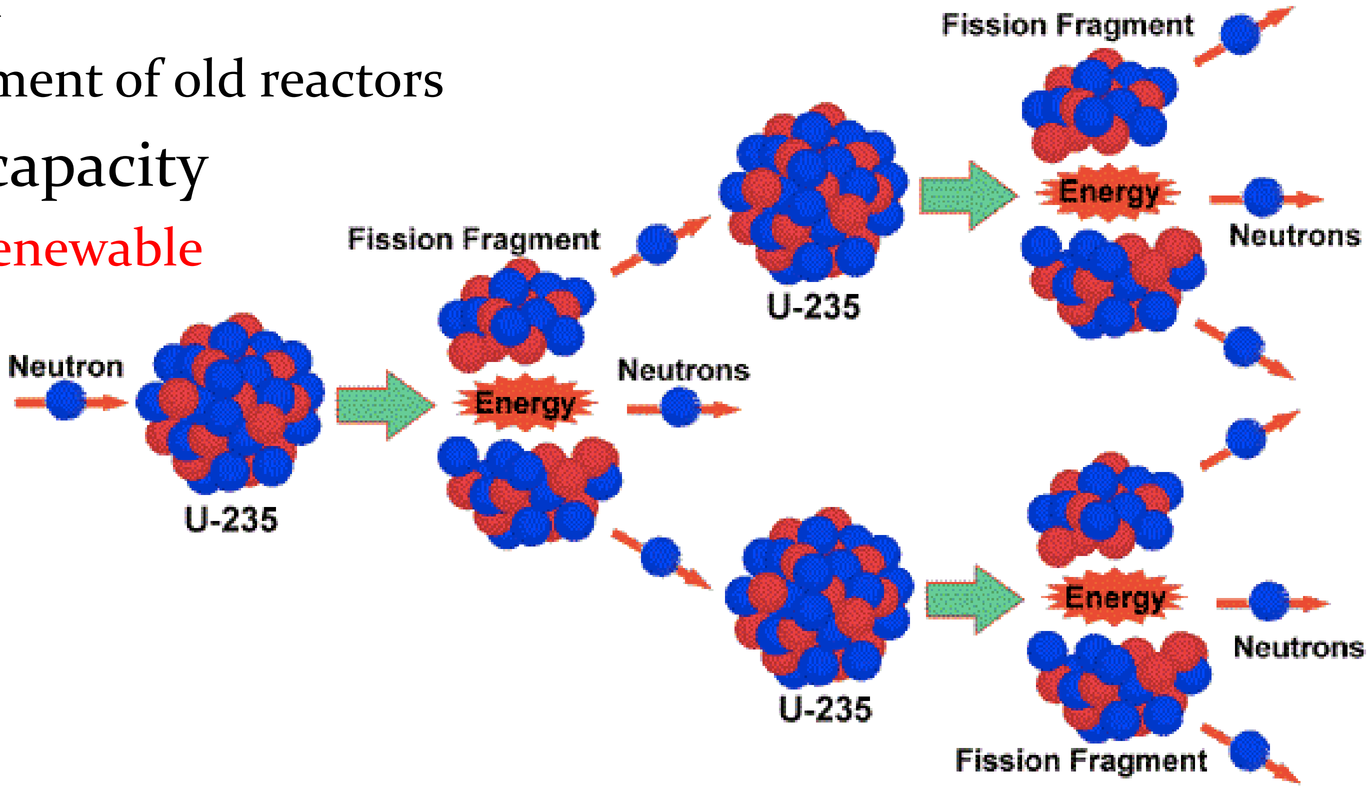
- Basics of Nuclear Energy
  - Reactor Design
  - Sustainability
- Waste
  - Generation: Comparison of Reactor Designs
  - Issues with Disposal
- Costs
  - Economic
  - Land
  - Environmental
  - Time
- Conclusions

Basic Reactor Design



Sustainability

- ^{235}U less than 1% of uranium isotopes
- 441 reactors in 30 countries
  - 14% of world's electricity
- ~ 25 year lifespan
  - Minimal replacement of old reactors
- Operated at full capacity
  - Uranium is nonrenewable



Uranium Resources

- Sources of Uranium
  - 51,000 tons mined in 2009 … but use about 68,000 ton/year
  - The rest comes from reserves
    - 200,000 and 300,000 tons estimated in the US and Russia
    - Collected from 1950- 1990, primarily during the Cold War
    - Level or quantity of enrichment is unknown
  - Several New Mines
    - Estimated total peak in 2035 with 98,000 – 141,000 tons/year
- Possibility of Recycling some fuel

Consequences

- Nonrenewable source
- Nuclear Energy is a sign of transition into modern society
  - Developing countries such as China and India are investing in nuclear energy
  - A potential financial disaster if not enough ^{235}U to fill reactor…
- Europe leads in % of electricity from nuclear power plant
  - Unfortunately, Europe is furthest away form uranium mines
  - USA and Western Pacific countries are closer to mines
- Militaries would take uranium first if there becomes a shortage
  - Submarines
  - Nuclear deterrence

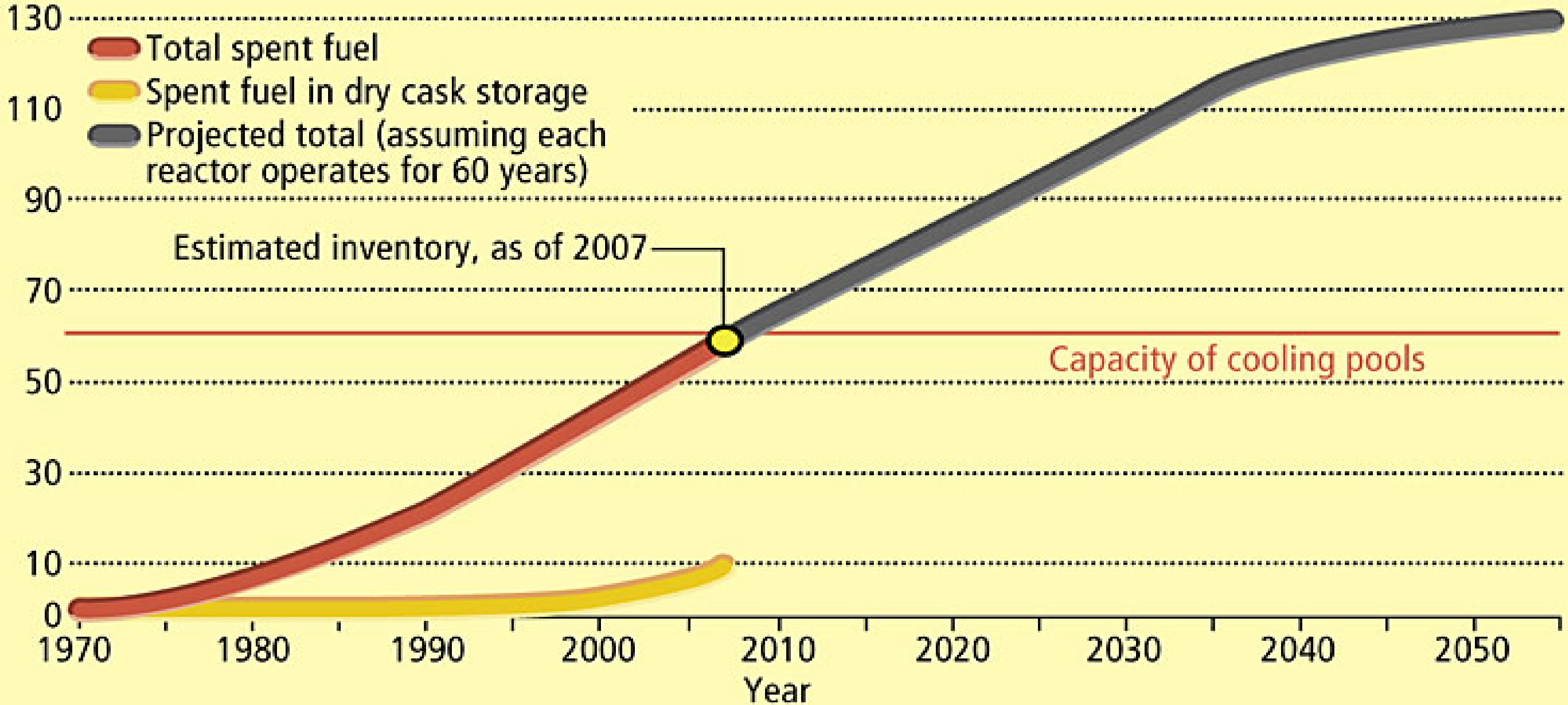
Waste Generation per Year

- USA generates ~2,000 metric tonnes of high-level waste per year.
- Over ~60 years ~70,000 metric tonnes of high-level waste has been created

Too Much Waste, Too Little Storage

ACCUMULATED SPENT FUEL FROM ALL U.S. NUCLEAR POWER REACTORS

(1,000 metric tons of uranium and associated reactor products)



The amount of spent fuel will rise substantially in coming decades even if no new reactors are built. Managers at nuclear power plants increasingly are forced to transfer the oldest spent fuel in their cooling pools to dry casks situated close by. Not surprisingly, the industry is pressuring the U.S. government to help find a solution to the problem.

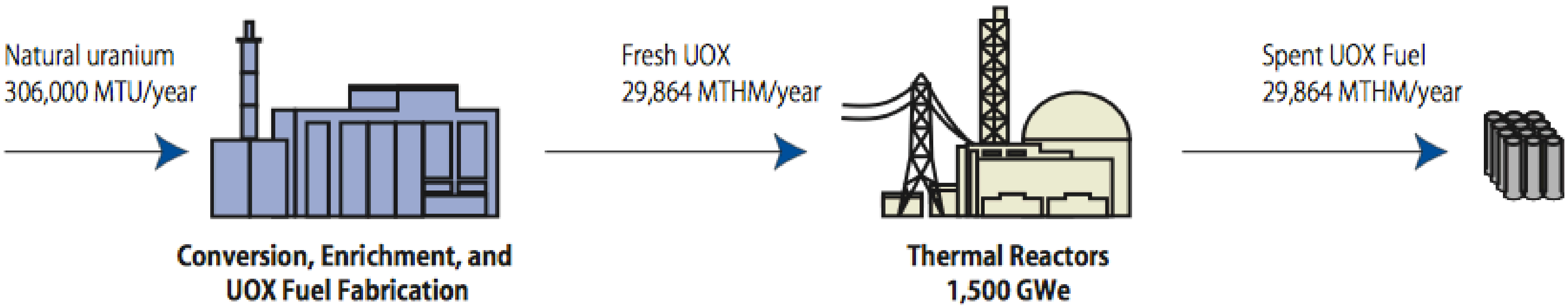
Recycling Used Nuclear Fuel

- Currently the United States does not recycle used nuclear fuel – "once-through" open fuel cycle

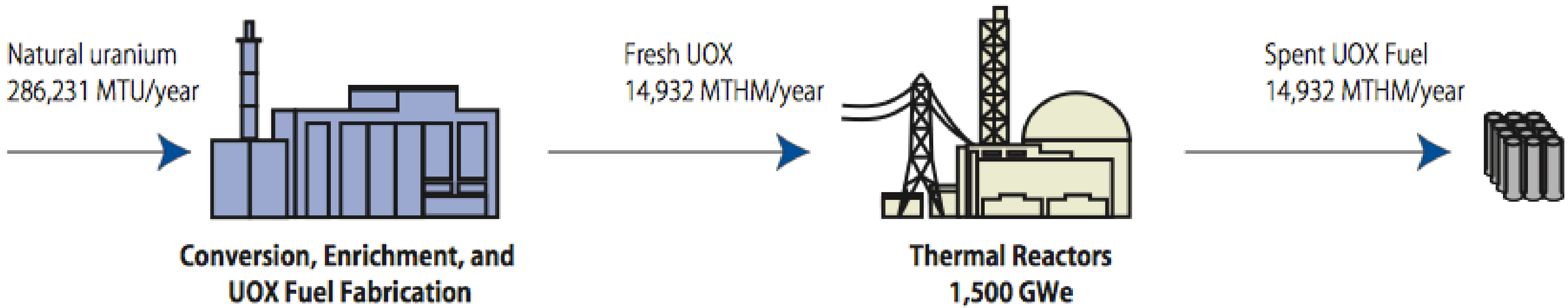
- The industry supports research, development and demonstration of improved or advanced fuel cycle technologies
  - Goal is to close the nuclear fuel cycle
  - Potentially reducing
    - Waste volume
    - Heat and toxicity of byproducts

Open Fuel Cycle – Once Through

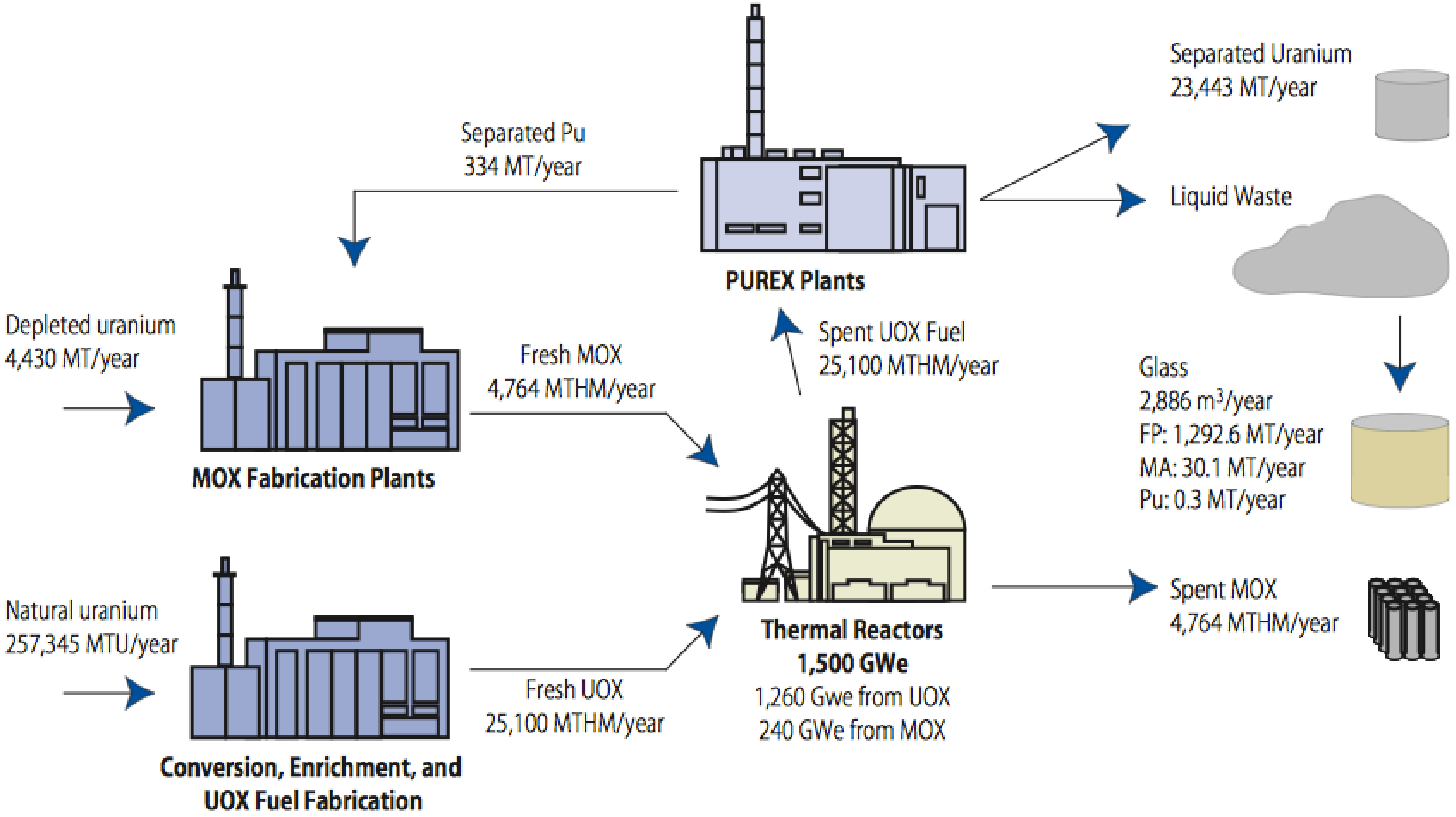
Current Burnup: 50 GWD/MTIHM:



High Burnup: 100 GWD/MTIHM:



Close Fuel Cycle – One Recycle



Close Fuel Cycle – Full Recycle

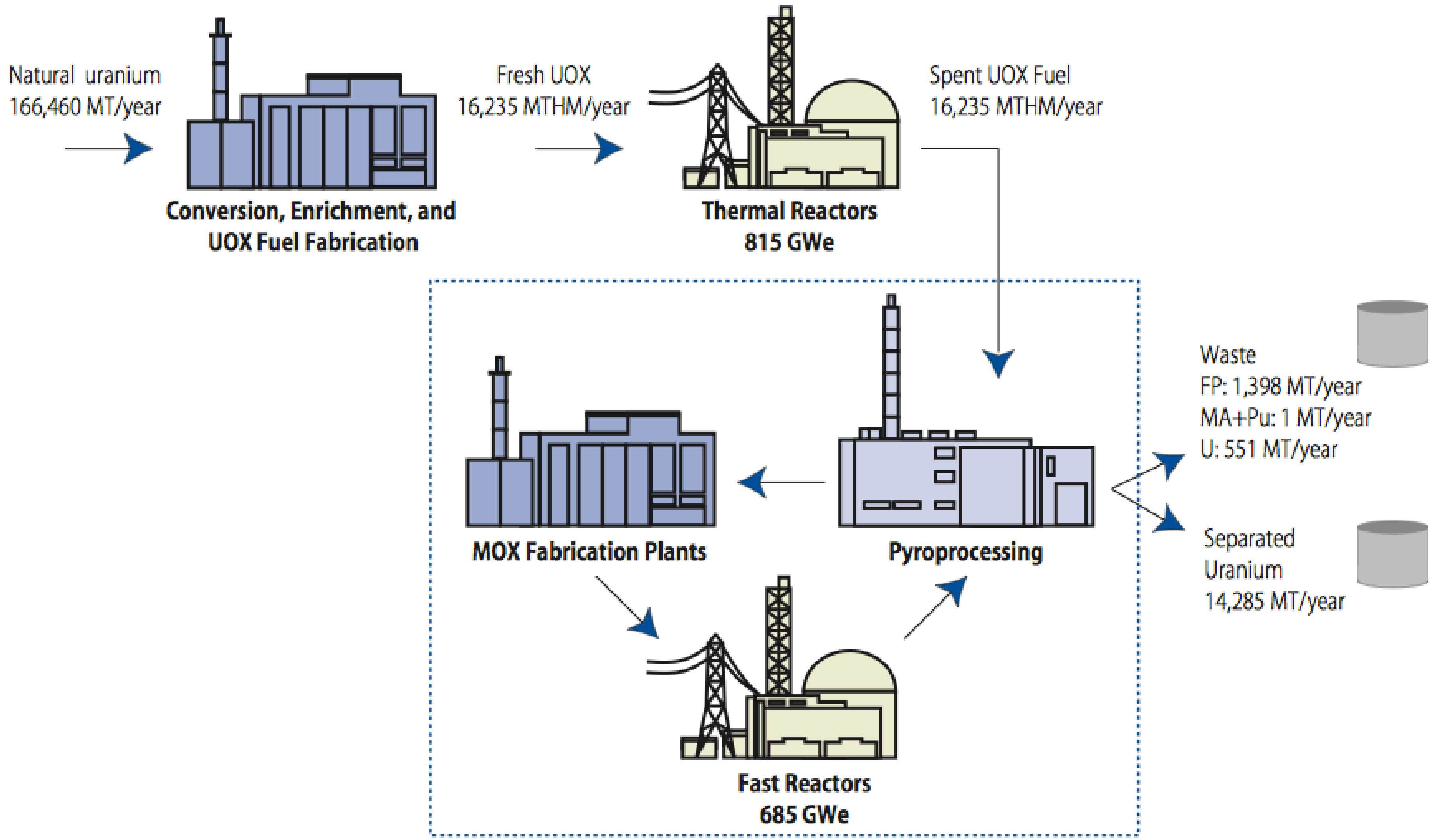


Table 4.3 Global Growth Scenario — Fuel Cycle Parameter comparison. Annual Amounts for 1500 GWe Deployment[a]
See Appendix 4 for fuel cycle calculations.

	OPTION 1A ONCE THROUGH LOW BURN UP	OPTION 1B ONCE THROUGH HIGH BURN UP	OPTION 3 LWR + FAST REACTOR[b]	
			LWR	Fast reactor
Capacity, GWe	1,500	1,500	815	685
Enrichment, %	4.5	8.2	4.5	25
Burn up, GWd/MTIHM	50	100	50	120
Uranium ore				
per year, 10^3 MT/yr	306	286	166	
cumulative, 10^6 MT	9.45	8.76	5.96	
Spent or repr. Fuel				
per year, 10^3 MTIHM/yr	29.9	14.9	Repr.: 20.9 (12.3 LHE[c])	
cumulative, 10^3 MTIHM	922 (13.7 YME)	516 (7.4 YME)	Spent : 4.1 YMEs	
HLW, MT/yr	Not applicable	Not applicable	FP: 1398; MA+Pu: 1.0	
Pu, MT/yr	397	294	0.7 (repr. losses)	
Waste decay heat[d]				
W/GWeY (100 yrs)	$1.1 \cdot 10^4$	$1.1 \cdot 10^4$	$2.8 \cdot 10^3$	
Waste ingestion hazard				
m^3/GWeY (1,000 yrs)	$6.9 \cdot 10^{11}$	$5.3 \cdot 10^{11}$	$2.2 \cdot 10^7$	

a. Thermal efficiency 33% for LWRs and 40% for FRs, capacity factor 90%, enrichment tails assay 0.3%. Capacity is assumed to increase linearly. Fast reactors start deployment in 15 years.

b. Intended as generic fast reactor; data from ANL IFR.

c. LHE means La Hague equivalent (1,700 MTHM/year)

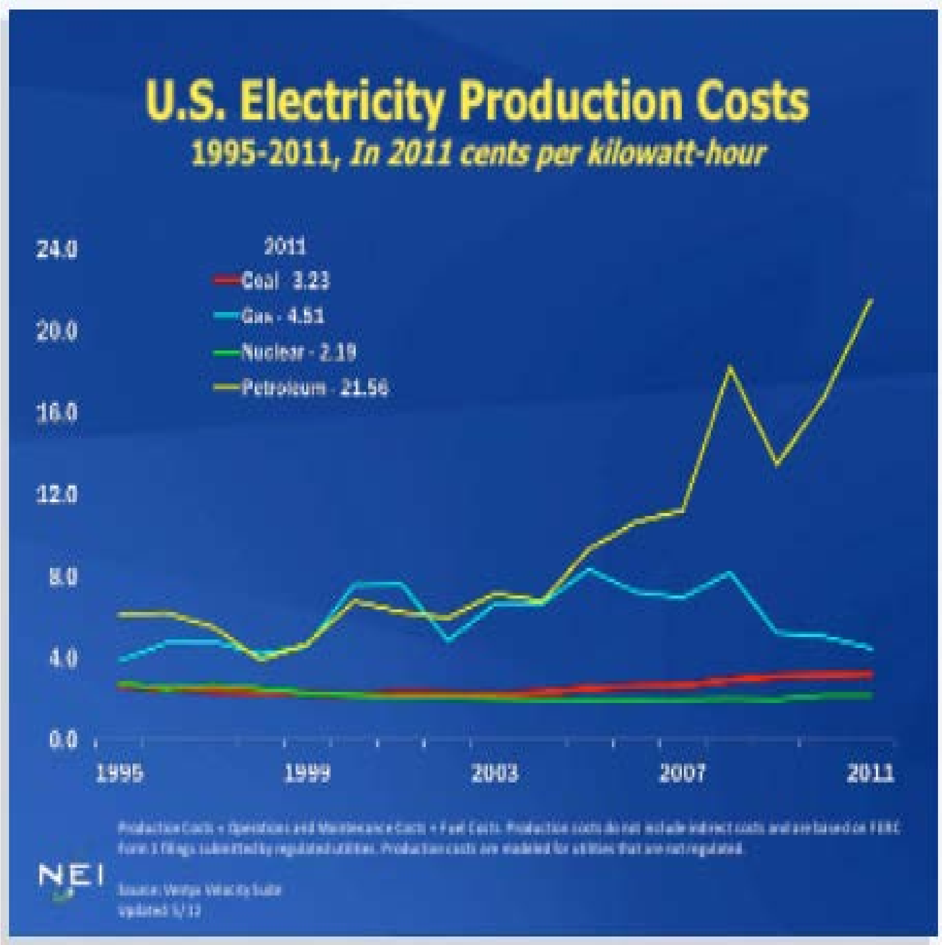
d. The decay heat and radiotoxicity are computed from and MCODE/ORIGEN run and expressed on a per GWe-y basis to establish a fair comparison between the various fuel cycles. The decay heat and radiotoxicity per unit mass can be obtained by dividing by the mass of spent fuel discharged per GWe-y. The spent fuel discharge for option 1A is 22.1 MTIHM/y, giving a decay heat at 100 years of 5.0·102 W/MTIHM and a radiotoxicity at 1000 years of 3.1·1010 m3/MTIHM, as shown in Figures 7.2 and 7.3.

The Costs of Nuclear Energy

- Four main costs are:
  - Financial
  - Land
  - Time
  - Emissions

Costs: Economic

- High initial cost for construction
    - Consumers pay more at the beginning
- Low ongoing costs due to routine maintenance and intermittent refueling
- Costs more to build a new reactor versus updating a current reactor



Cost: Land

- Buffer zone needed for safety
  - U.S. divides plants into an owner-controlled buffer region (area restricted to some plant employees and monitored visitors) and a vital area with more restrictions
- Needed for uranium mining and waste disposal
- Grand total for one plant: 20.5 km^2 (7.88 mi^2)
- Nuclear Waste Fund
  - \$ 25,000,000,000 that is unspent
  - Collecting \$750,000,000 per year in fee revenues from utility plants until 2013

Cost: Environmental

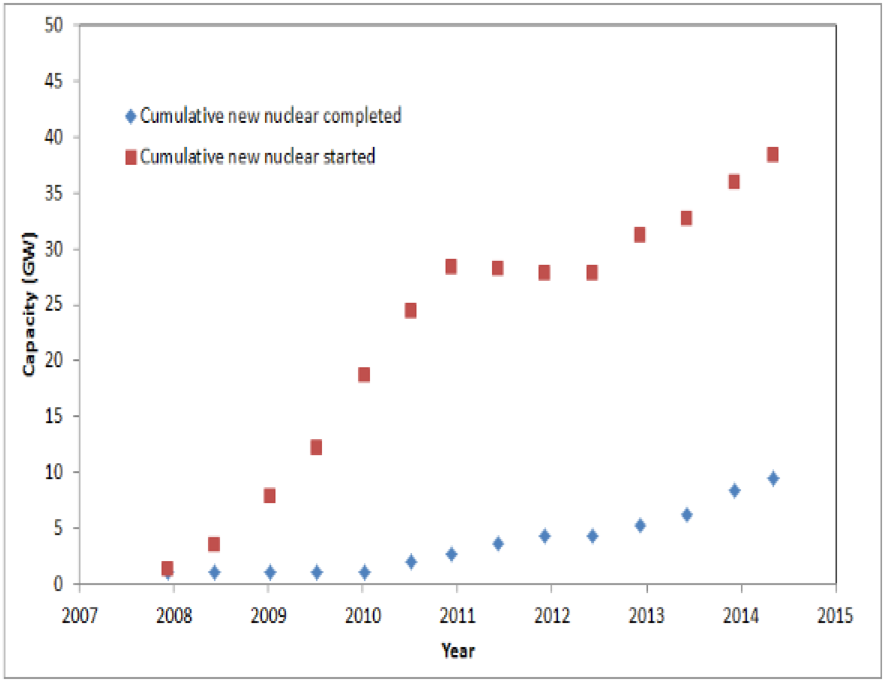
- Due to uranium mining, enrichment, transport, and waste disposal
- Also due to construction, operation, and decommissioning of the reactors
- Opportunity-cost from emissions: the more time that passes, more emissions will be released

Table 3 Equivalent carbon dioxide lifecycle, opportunity-cost emissions due to planning-to-operation delays relative to the technology with the least delay, and war/terrorism/leakage emissions for each electric power source considered (g CO_2e kWh^{-1}). All numbers are referenced or derived in ESI†

Technology	Lifecycle	Opportunity cost emissions due to delays	War/terrorism (nuclear) or 500 yr leakage (CCS)	Total
Solar PV	19–59	0	0	19–59
CSP	8.5–11.3	0	0	8.5–11.3
Wind	2.8–7.4	0	0	2.8–7.4
Geothermal	15.1–55	1–6	0	16.1–61
Hydroelectric	17–22	31–49	0	48–71
Wave	21.7	20–41	0	41.7–62.7
Tidal	14	20–41	0	34–55
Nuclear	9–70	59–106	0–4.1	68–180.1
Coal-CCS	255–442	51–87	1.8–42	307.8–571

Cost: Time

- Time in between planning and operation of a technology includes the time to site, finance, permit, insure, construct, license, and connect technology to utility grid
  - 6-10 years for approvals and financing
  - 4-9 to construct plant and connect to utility grid
- Issues such as inflation and more stringent safety regulations, especially after accidents, cause the increase in time to build and finance



Conclusions

- Nuclear energy provides a cleaner alternative to coal
  - Significant reduction of CO_2 emissions
- Still an nonrenewable resource
- Waste disposal and storage are still unresolved issues
- Closing the fuel cycle can dramatically improve yield and reduce waste
  - Once Through vs One Recycle vs Full Recycle
- Cost:
  - Higher upfront capital cost
  - Lower operating costs
  - Significantly lower environmental cost (emissions)

Resources

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