Challenges for UNF Disposition: Putting Nuclear Waste Into Perspective

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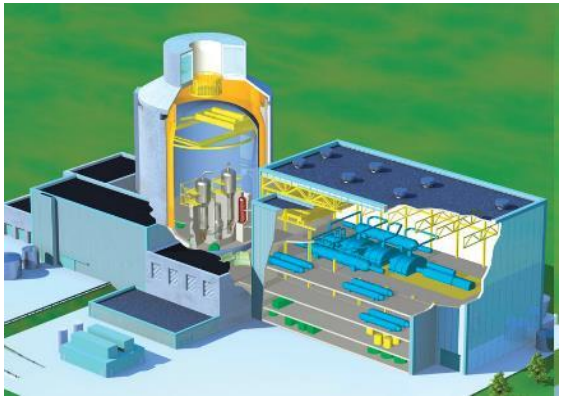
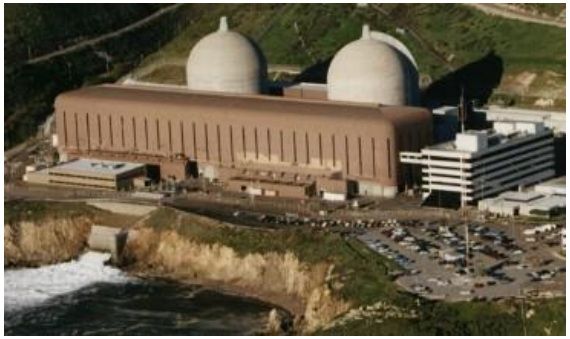
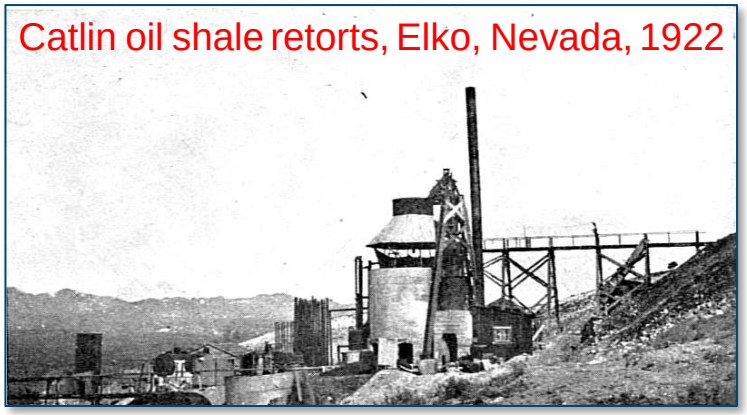




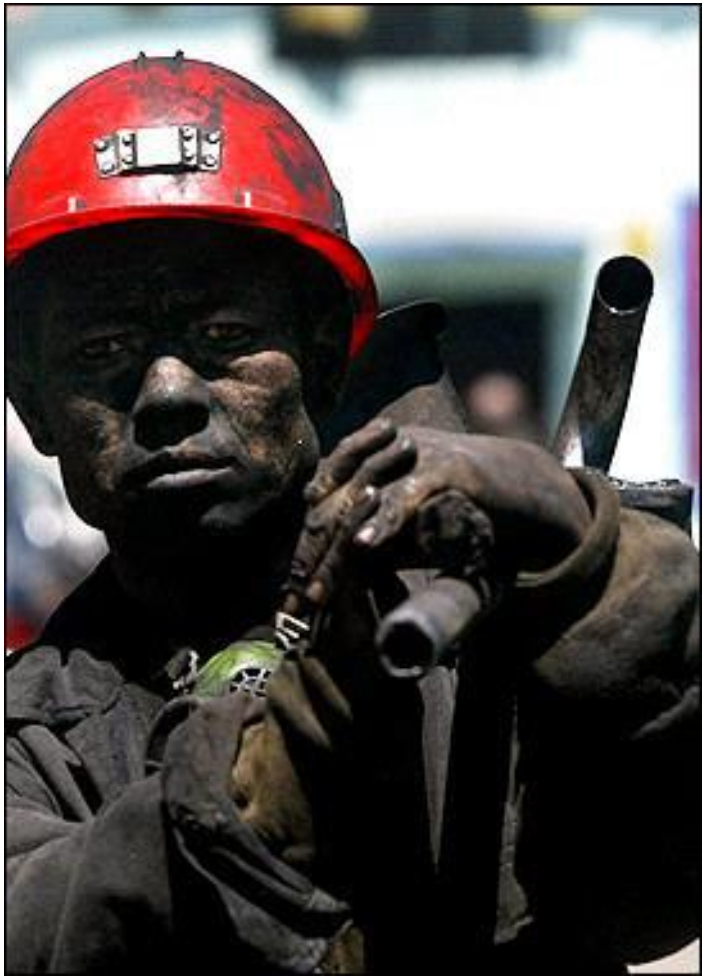
For nuclear energy, two different questions are commonly conflated

- Is used nuclear fuel an important economic resource?
  - Not today (economic value of recovered material does not pay for costs of recycle)
  - Nothing precludes used fuel becoming an economically attractive resource in the future
  - Enabling economic, beneficial recycle could be a future game changer
- Is nuclear waste produced by nuclear energy dangerous?
  - No



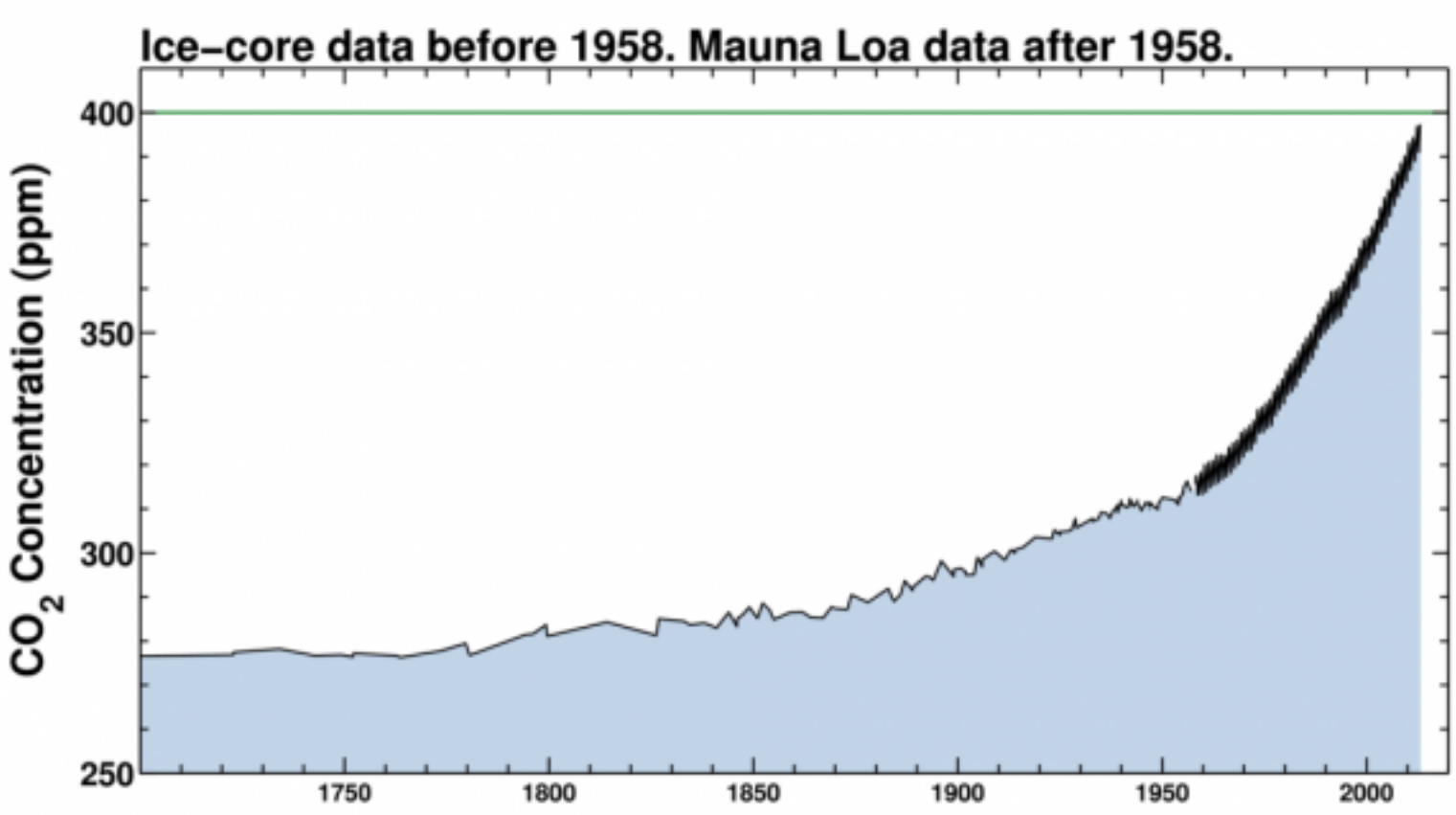
https://en.wikipedia.org/wiki/History_of_the_oil_shale_industry_in_the_United_States

Life-cycle impacts of energy production include effects on workers and on public health



Coal mine worker, China, 2004

Humans are embarked on an experiment that is radically changing the chemistry of the atmosphere and our oceans

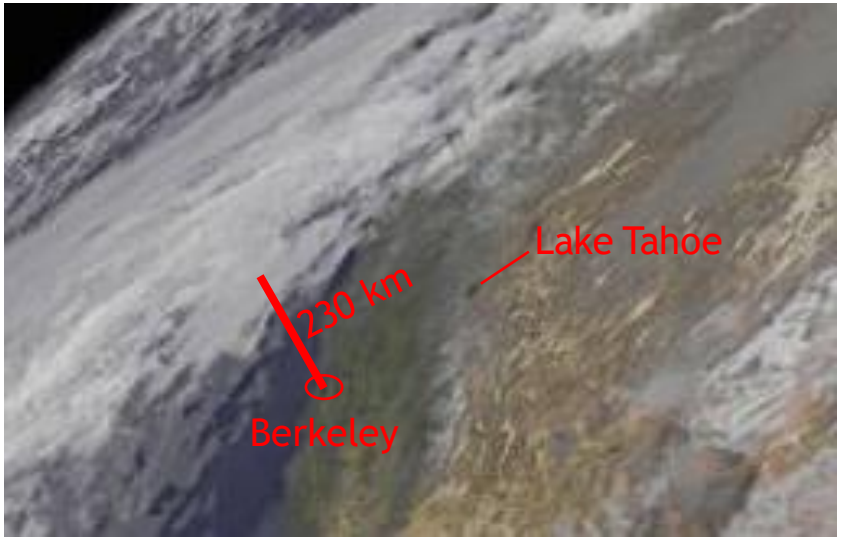


The atmosphere of Venus is 96% CO_2. That's not feasible for Earth, because only 20% of our atmosphere is oxygen that can react with fossil fuel.

Assumption is that half of CO_2 is absorbed by oceans, which is optimistic as atmospheric CO_2 increases. Earth's atmosphere is currently 21% oxygen (dry).

In 2014 nuclear energy produced 10.5% of electricity worldwide, equivalent to burning 1 billion tons of coal

Worldwide 2014 total spent nuclear fuel would fill Cal Memorial Stadium field to a depth of 1.3 meters



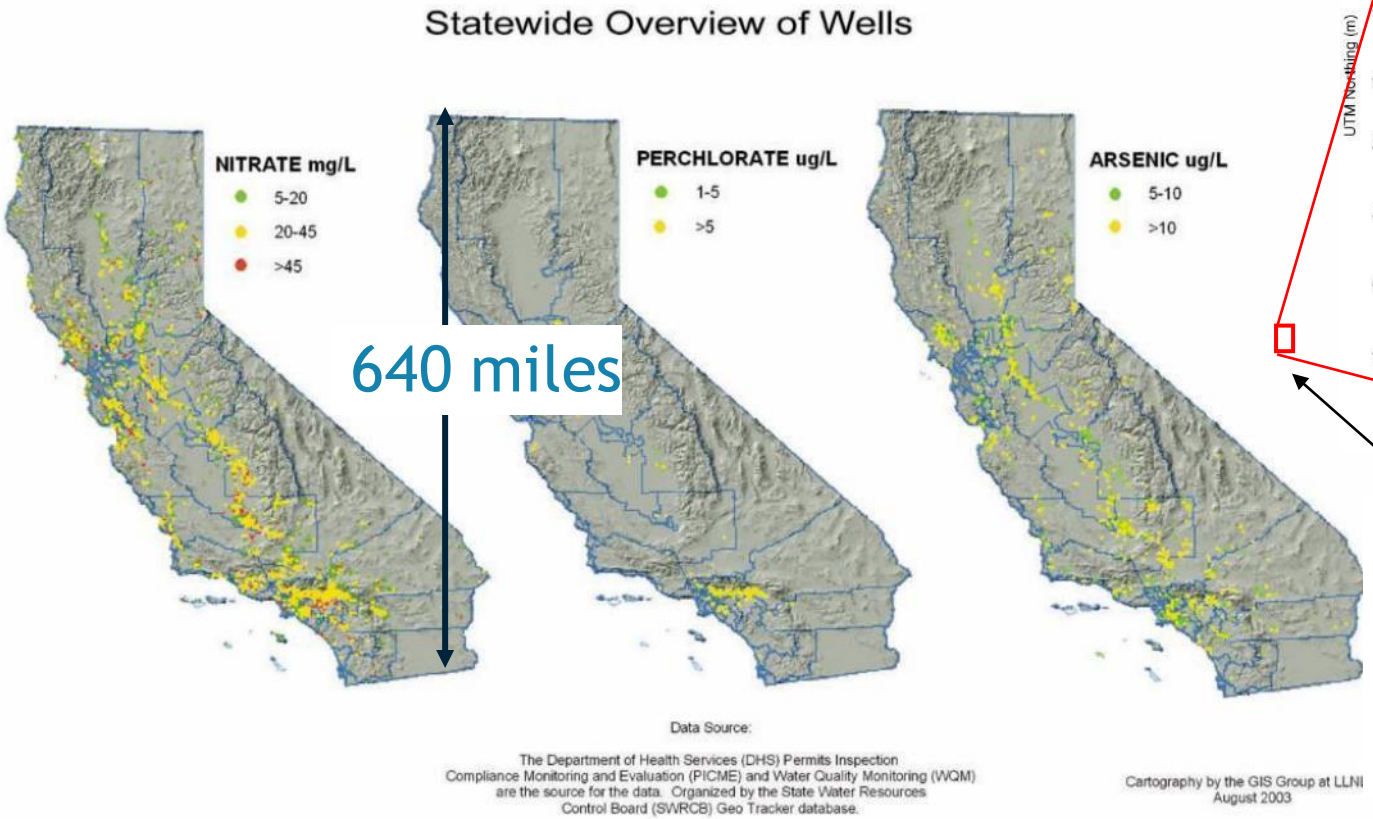
1 billion tons of coal would fill Cal Memorial Stadium field to a depth of 230 kilometers

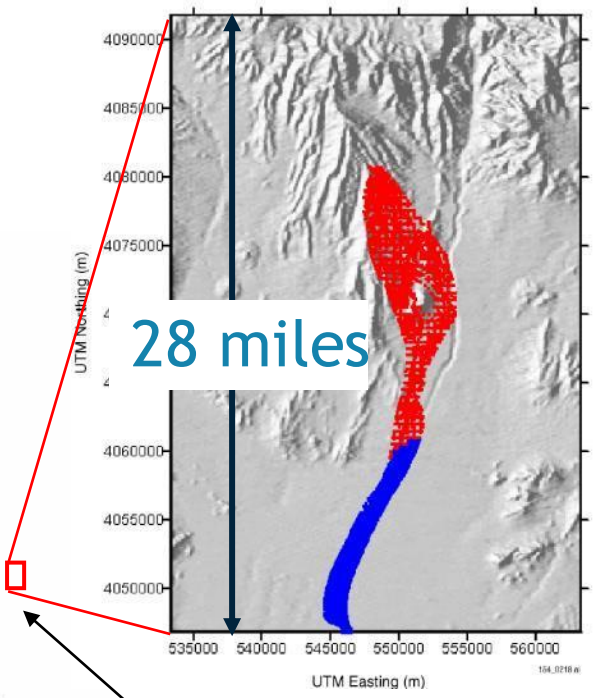
"Nuclear power's waste by-products aren't a mark against the technology, they are its key selling point."
- Michael Shellenberger, 2018

P.F. Peterson, "Spent Fuel is Not the Problem," Proceedings of the IEEE, Vol. 105, No. 3, March 2017.
https://www.forbes.com/sites/michaelshellenberger/2018/06/19/stop-letting-your-ridiculous-fears-of-nuclear-waste-kill-the-planet/

If placed in deep geologic disposal, long-term impacts from nuclear waste are very small

Groundwater contamination is a problem that current public health systems in the developed world already understand how to manage





The worst-case impact from a Yucca Mountain repository in the next 1 million years, compared to fossil and chemical wastes, is tiny

How much does nuclear fuel cost today?

- From the World Nuclear Association:

Process	Amount required x price*	Cost	Proportion of total
Uranium	8.9 kg U_3O_8 x $68	$605	43%
Conversion	7.5 kg U x $14	$105	8%
Enrichment	7.3 SWU x $52	$380	27%
Fuel fabrication	per kg	$300	22%
Total		$1390	

Front end fuel cycle costs of 1 kg of uranium as UO_2 fuel
* Prices are approximate and as of March 2017.
At 45,000 MWd/t burn-up this gives 360,000 kWh electrical per kg, hence fuel cost = 0.39 ¢/kWh.

- For a typical 45 MW-day/kg, the cost of nuclear heat is
  ($1390/kg)/(45 MW-day/kg)(81.9 MMBtu/MW-day)
  = $0.38 / MMBtu
- In the U.S., the NWF fee was $1.0 / MWe-hr
  = $0.32 / MWt-hr = $0.09 / MMBtu
- Compare to "cheap" natural gas at $3 / MMBtu
  - (Does not include external costs)

https://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx

Currently U.S. nuclear waste disposal is free

- Current balance in U.S. Nuclear Waste Fund is over $40B
  - Now collecting over $1.5B interest per year
  - Interest payments are now double the $0.75B per year collected when the NWF fee was 0.1 cent/kWh
- The DC District Court of Appeals ordered DOE to stop collection of the NWF fee in November, 2013
  - "Our ruling here does not provide petitioners with any form of compensation, nor does it relieve them of their obligation to ultimately pay for the cost of their waste disposal. When the Secretary is again able to conduct a sufficient assessment, either because the Yucca Mountain project is revived, or because Congress enacts an alternative plan, then payments will resume (assuming that some future determination concludes that further fees are necessary).

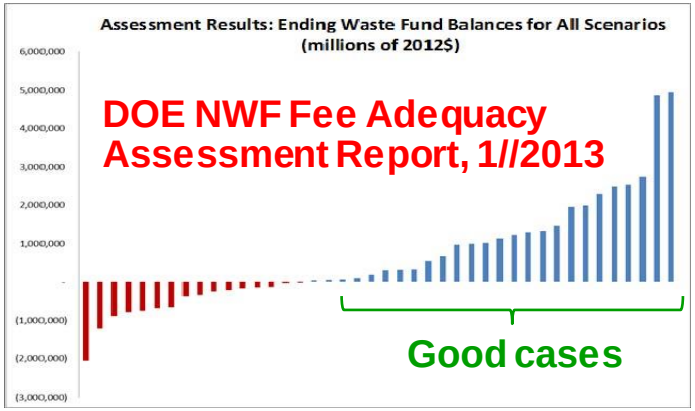


Figure 1: Assessment Results: Ending Waste Fund Balances for All Scenarios (millions of 2012$)

Will it ever be necessary to restart collecting the NWF fee?

Innovation in Nuclear Waste Disposal: Deep Isolation

- Co-founded in 2016 by Liz and Rich Muller (Berkeley Earth)
- Emplace waste canisters into horizontal drill holes using same technologies as modern oil and gas
- Isolation enhanced by sloping borehole upward from turning point
- Eliminates the need to construct mined, underground facilities used for conventional repositories
- Very low overhead costs reduce urgency to put spent fuel into permanent disposal before possible future economic value has been determined

http://deepisolation.com

Advanced Nuclear: Good Practices

- Kairos Power example
  - TRISO pebble fueled, molten salt cooled reactor
- Assure that used fuel can be stored on site and packaged for acceptance by DOE
  - Minimize differences for handling and transportation compared to LWR used fuel (same transport casks)
- Package used fuel to maximize flexibility for disposition
  - Pebble canister diameter supports borehole disposal without repackaging
  - Pebble canisters can be transported in full-size MPC canister for conventional geologic disposal
  - Pebbles can be recycled
- Optimize KP-FHR fuel for disposition
  - KP-FHR fuel volume 25% of Xe-100, 17% of HTR-PM and 175% of PWRs
  - KP-FHR fuel heavy metal 67% of Xe-100, 45% of HTR-PM, and 20% of PWRs

Discussion:

The elephants in the room: Is spent fuel a waste or a resource? How does the U.S. fundamentally reboot our nuclear waste program? How can new technology enable this reboot?