The state of the American nuclear enterprise in 2017

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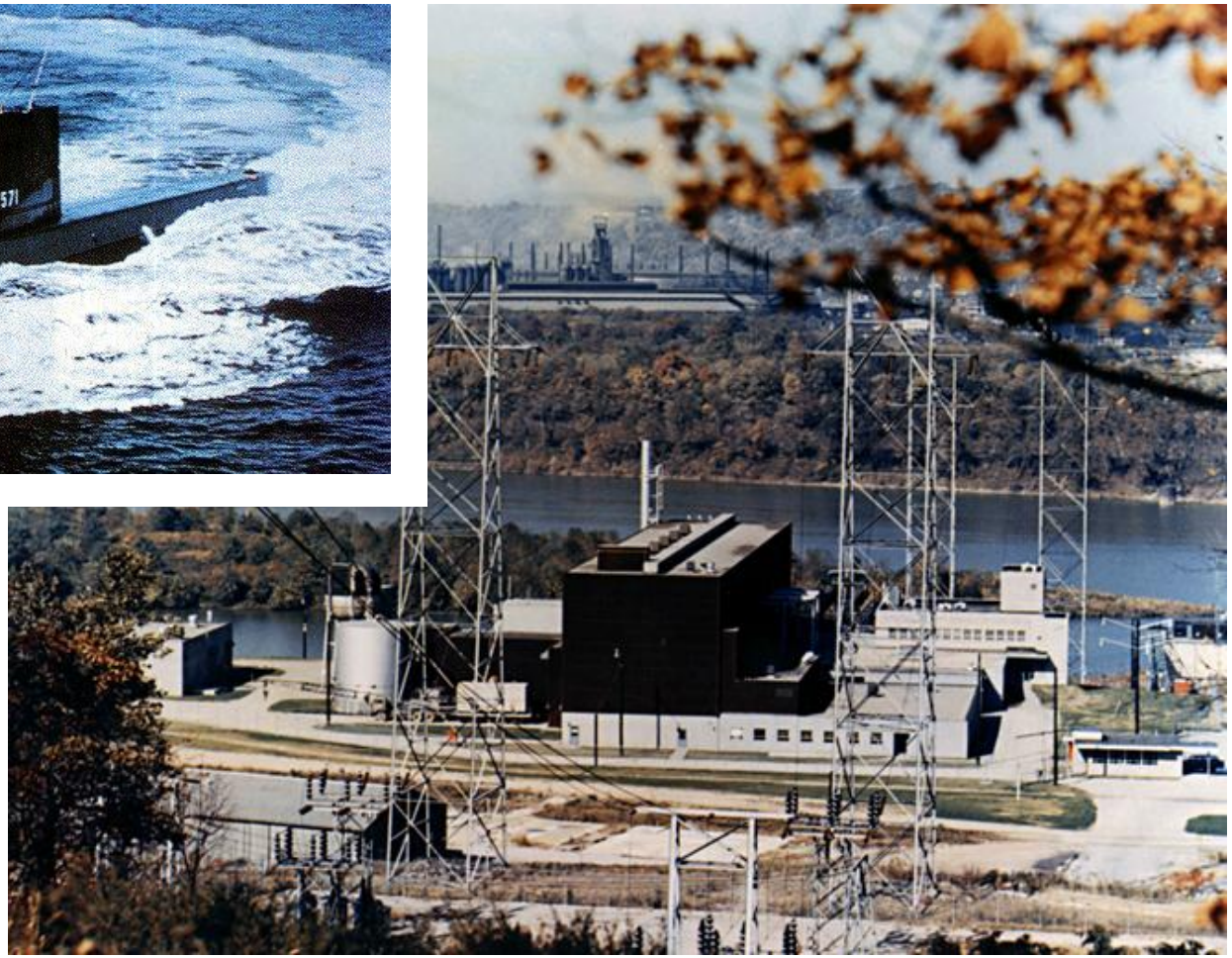
The U.S. created the nuclear enterprise

https://en.wikipedia.org/wiki/USS_Nautilus_(SSN-571)



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

But nuclear power is dead in the U.S.

My (controversial?) argument rests on the following premises:

1) Prospects for large light water reactors (LWRs) being deployed in the U.S. look extremely grim.
2) Probability of U.S.-designed advanced, non-light water reactors being developed and deployed in the time-critical window of 2030-2050 are exceedingly low.
    - *What is the likelihood of U.S. utilities purchasing advanced Chinese or Russian or Korean reactors?*
3) Light water small modular reactors (SMRs) are the only available option. Our research suggests that mass deployment is unlikely (I can discuss this in depth during the open forum).

What challenges is U.S. nuclear facing?

High capital cost

Safety of reactor operations

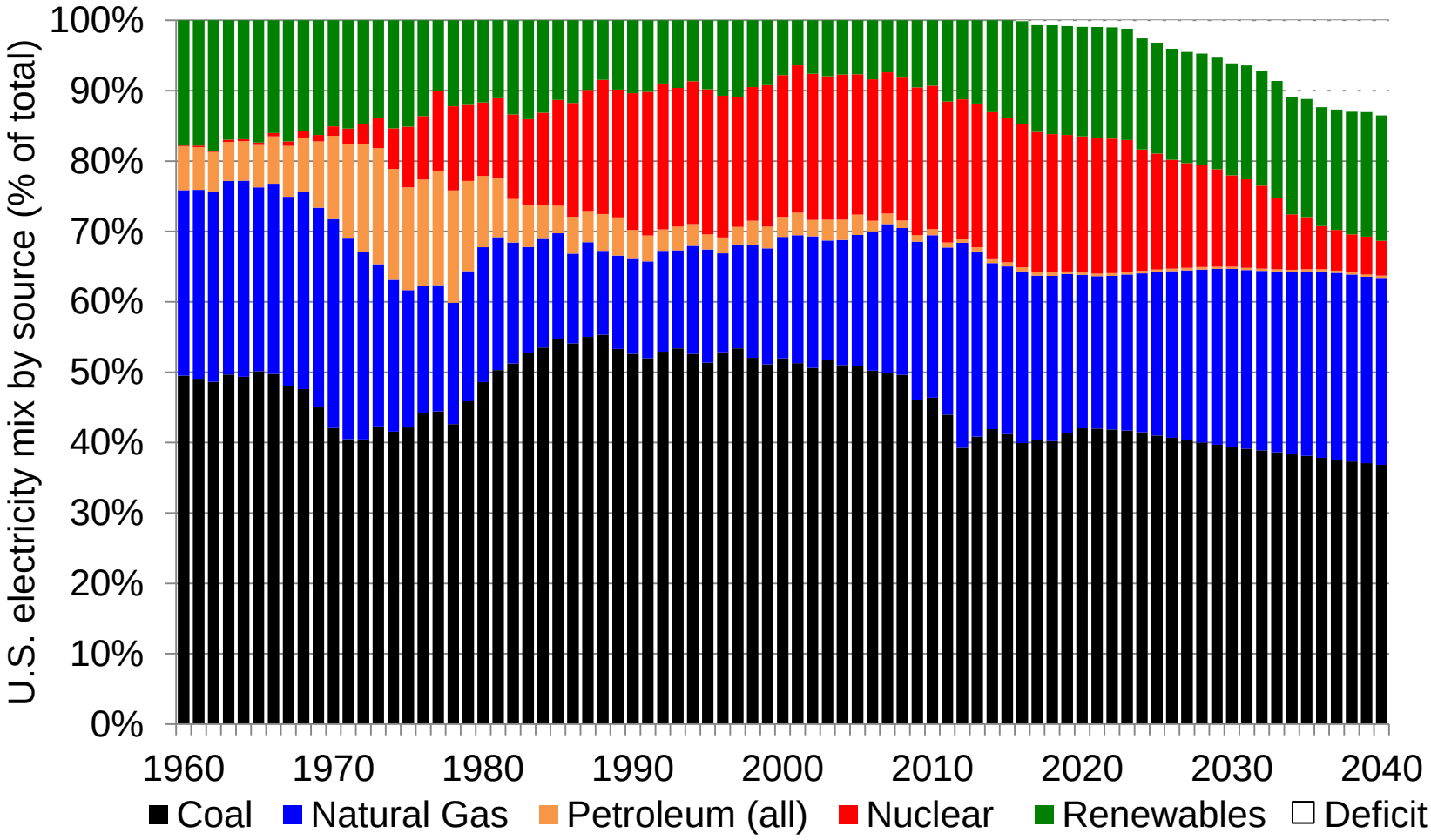
Waste management

Proliferation of nuclear materials

Most of the problems are institutional, not technical

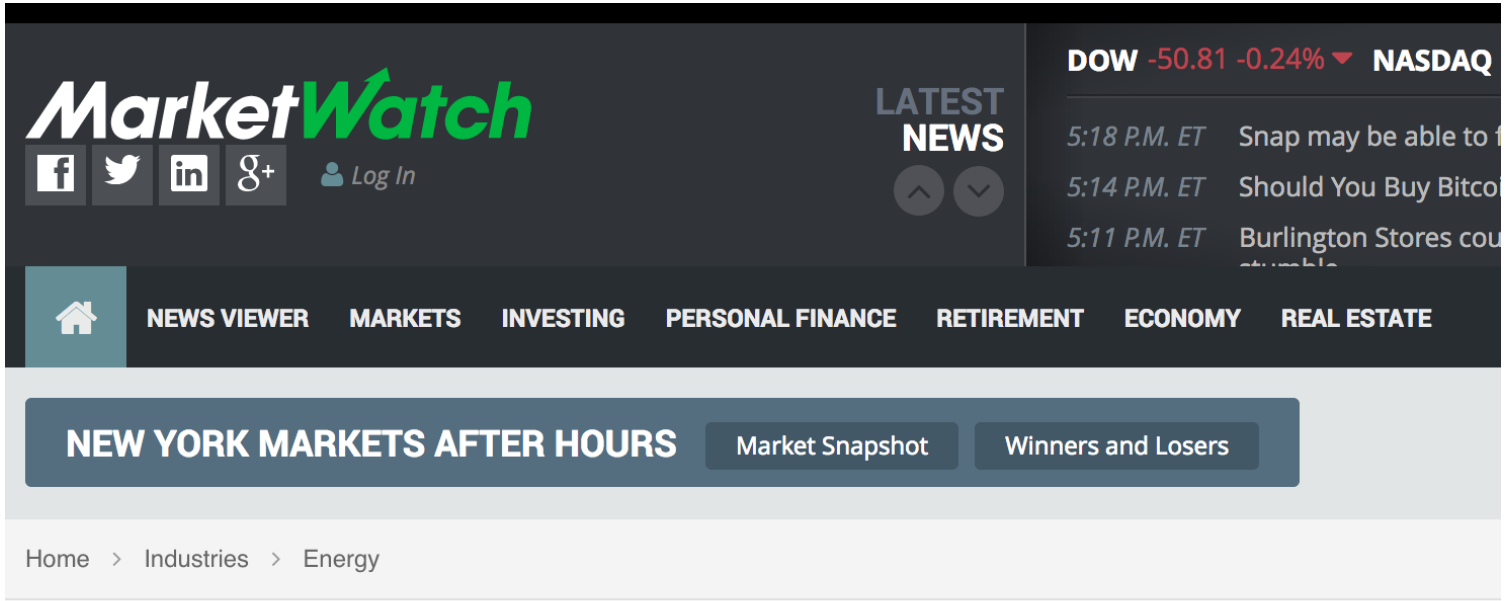
China AP1000® Project Photos (May 2011)

Nuclear power is vulnerable in the U.S.



Excluding biomass and waste, which account for 2% of electricity generation

Not accounting for threatened plants!



Exelon to retire Three Mile Island nuclear plant in 2019, earlier than expected

By Ciara Linnane

Published: May 30, 2017 8:58 a.m. ET

Efforts made to prevent early closures

Nuclear Plants, Despite Safety Concerns, Gain Support as Clean Energy Sources

By DIANE CARDWELL MAY 31, 2016

Without help, nuclear officials say, there will be far less nuclear power. Two Exelon plants… were **unable to submit winning bids in a recent auction** to meet future energy needs in the PJM territory,…

After the auction, Christopher M. Crane, chief executive at Exelon, said that **by itself the market "can't preserve zero-carbon emitting nuclear plants** that are facing the lowest wholesale energy prices in 15 years."

In New York, officials are taking a different approach. Public hearings were held last month on a **proposed clean energy mandate** that would include a credit paid to nuclear operators…

1) The political challenge of waste

o3.jpg

https://www.reviewjournal.com/wp-content/uploads/2017/01/web1_web1_yucca_040915sm_002_4_7889

http://www.iub.edu/~sierra/papers/2006/Hamburger_files/image001.jpg

Perpetual institutions are necessary

Social Institutions and Nuclear Energy

Science, 1972

Alvin M. Weinberg

“Is mankind prepared to exert the eternal vigilance needed to ensure proper and safe operation of its nuclear energy system?”

- “We nuclear people have made a Faustian bargain with society. On the one hand, we… offer energy that is cheaper than energy from fossil fuel. Moreover, this source of energy, when properly handled, is almost nonpolluting.”

Perpetual institutions are necessary

- “But the price that we demand of society… is both a vigilance and a longevity of our social institutions that we are quite unaccustomed to… We make two demands.
  - The first… is that we exercise in nuclear technology the very best techniques and that we use people of high expertise and purpose…
  - The second demand is less clear, and I hope it may prove to be unnecessary. This is the demand for longevity in human institutions. We have relatively little problem dealing with wastes if we can assume always that there will be intelligent people around to cope with eventualities we have not thought of.”

2) State, future of adv. fission innovation

Bill Gates: 'We need energy miracles' yet US invests paltry 2% of R&D budget in energy

The demand for clean energy innovation is rising, but R&D hasn't grown to meet the challenge. Bill Gates recently called for a massive increase in energy research. Here's why.

http://www.techrepublic.com/article/bill-gates-we-need-energy-miracles/

Enormous investments and radical tech needed
Little scholarship on the effectiveness of R&D spending
Information on where R&D flows often unavailable

Nuclear R&D has been spotty

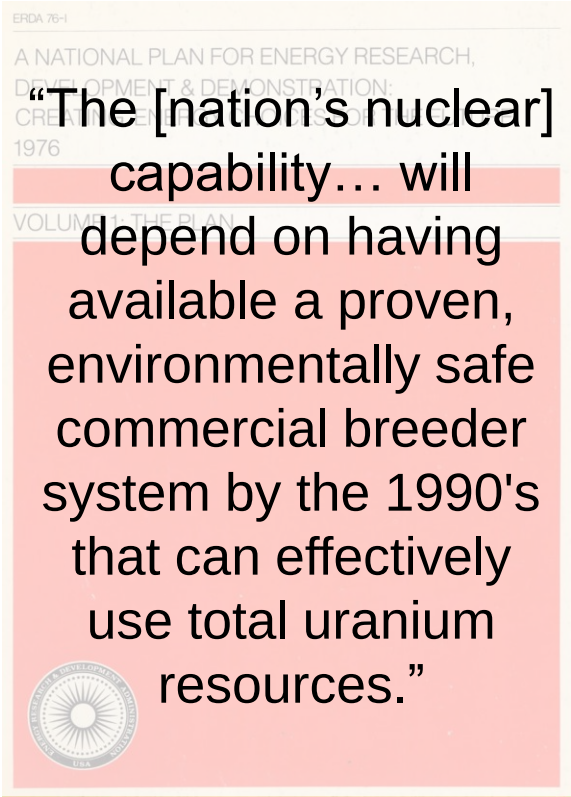
Light water reactors face too many challenges
Advanced reactors were meant to be deployed now

- Multiple technologies investigated
- Large technical capability gaps

- Inadequate regulatory framework
- Inequitable incentive structure

- Dwindling industrial base
- Dwindling **human capital**

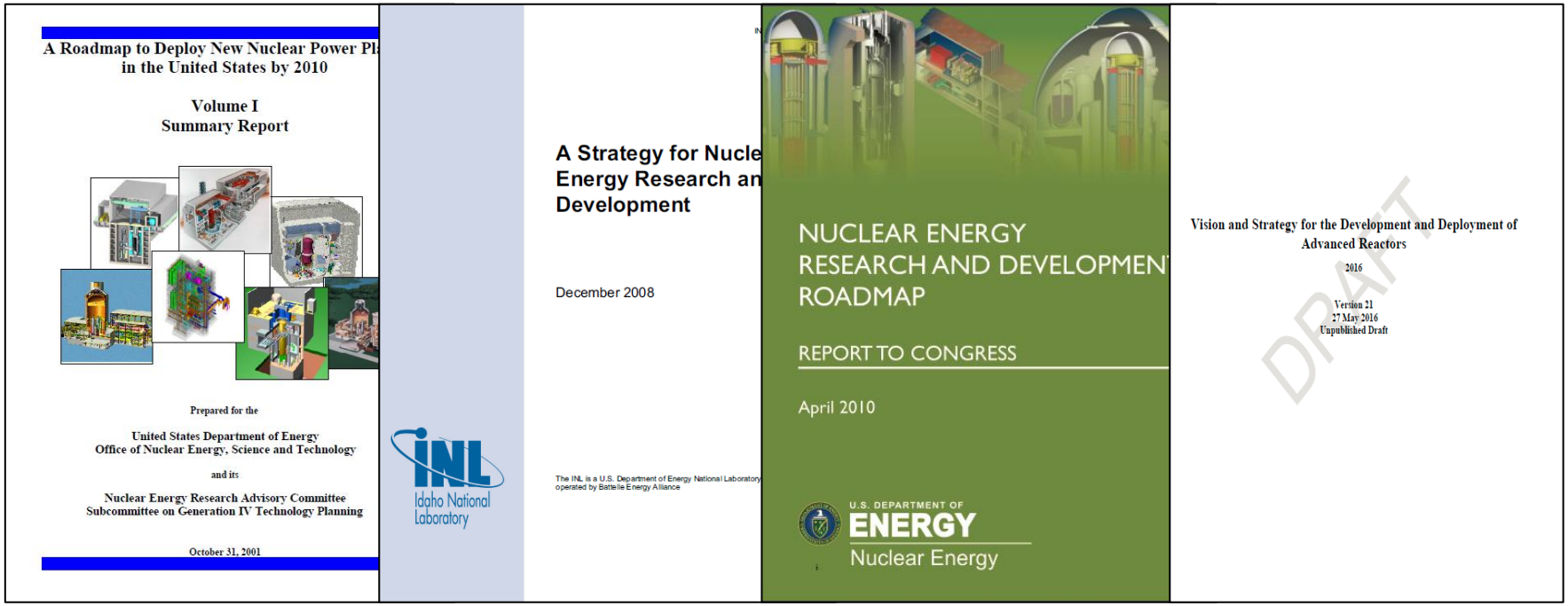
- Poor public perception
- Reticence in executive and Congress



"The [nation's nuclear] capability… will depend on having available a proven, environmentally safe commercial breeder system by the 1990's that can effectively use total uranium resources."

DOE has an advanced fission agenda

- DOE is charged with promoting advanced fission reactors through the Office of Nuclear Energy (NE)
  - NE has been allocated more than **$12B** since **1998**
- Has an advanced fission research agenda



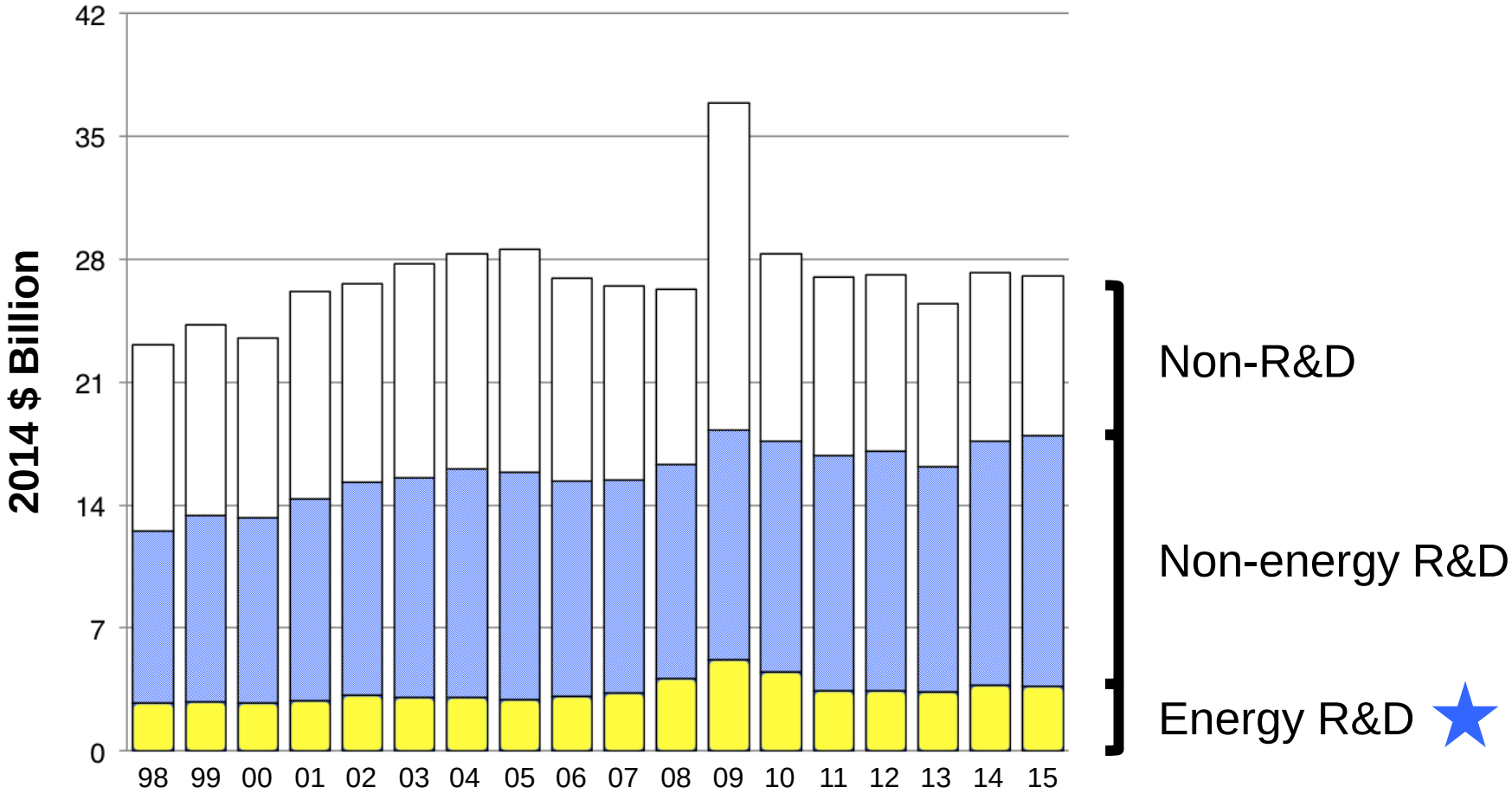
How effective has NE spending been?

We investigated how well DOE's advanced fission R&D spending aligns with its research goals.

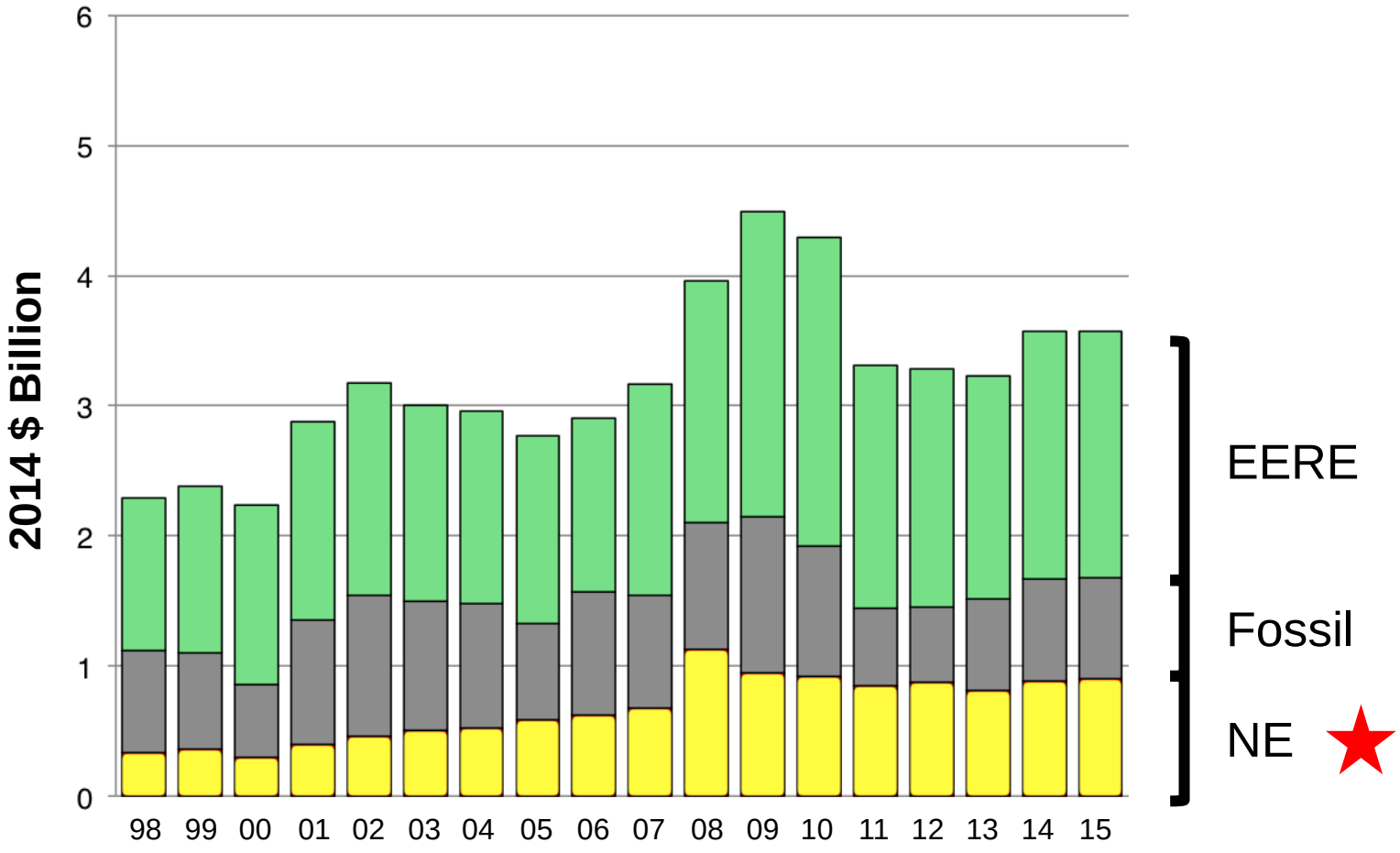
Phase I:
Retrospective analysis of U.S. advanced fission R&D
Data-driven analysis of DOE and Federal Budget documents – through FOIAs – down to individual programs

Phase II:
Expert assessments of current status and prospects
How can NE better enable nuclear innovation?
Answering this question requires expert judgment

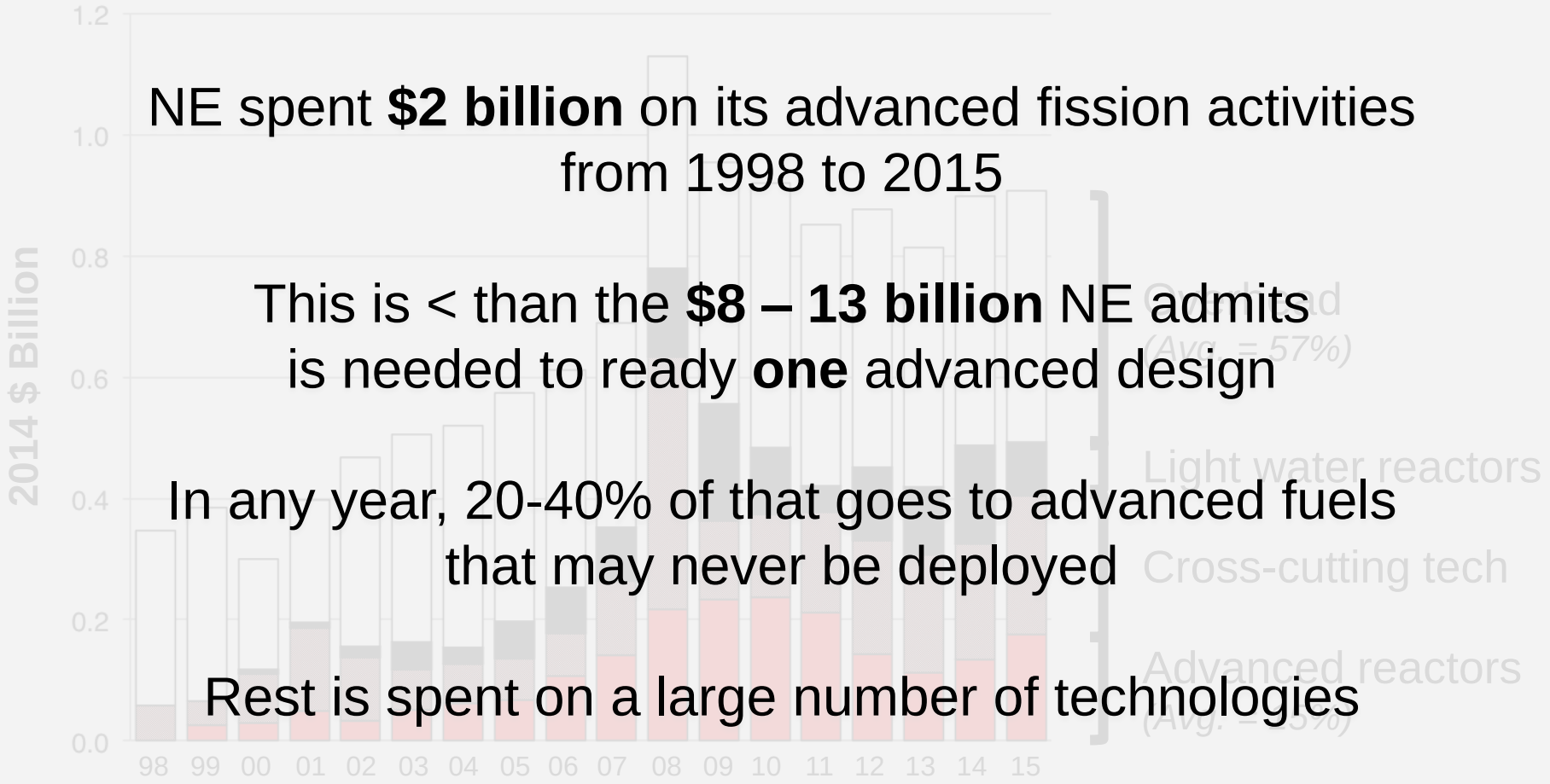
Phase I: Reconstructing DOE budget



NE averages 19% of Energy R&D



Weak funding for advanced reactors



NE spent **$2 billion** on its advanced fission activities from 1998 to 2015

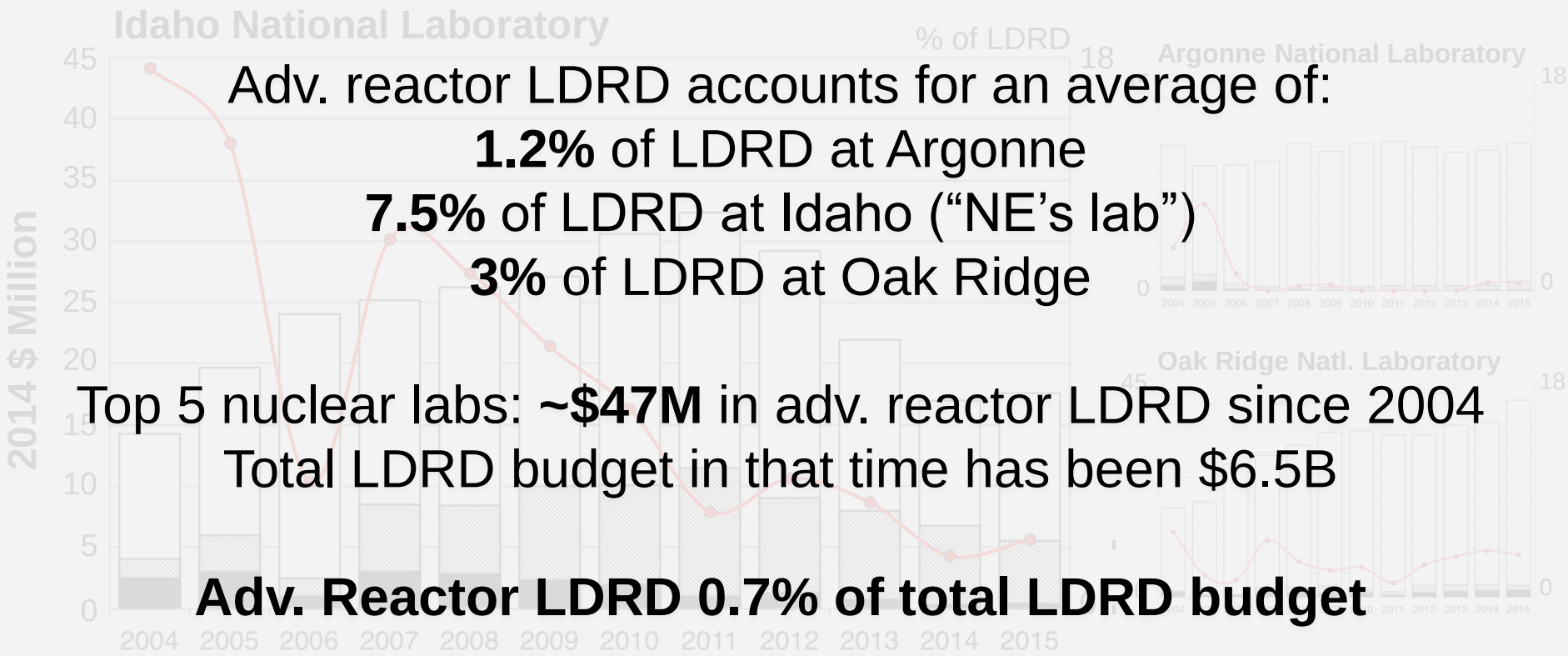
This is < than the **$8 – 13 billion** NE admits is needed to ready **one** advanced design

In any year, 20-40% of that goes to advanced fuels that may never be deployed

Rest is spent on a large number of technologies

This extends to fundamental R&D

Lab Directed R&D (LDRD) = competitively funded national lab projects exploring high-risk, cutting-edge concepts.



Adv. reactor LDRD accounts for an average of:

1.2% of LDRD at Argonne

7.5% of LDRD at Idaho (“NE’s lab”)

3% of LDRD at Oak Ridge

Top 5 nuclear labs: **~$47M** in adv. reactor LDRD since 2004

Total LDRD budget in that time has been $6.5B

Adv. Reactor LDRD 0.7% of total LDRD budget

Phase II: Expert assessments

- What is the state of advanced fission innovation in the U.S.?
- How have the organizations responsible performed?
- How can we chart a course for the future?

- **30** semi-structured interviews of **~2 hours** each
- Leaders of the nuclear enterprise from industry, government (executive + congressional) and academia
- **> 750 years** of cumulative experience
- Anonymity provided due to sensitivity of subject matter

Charting a course for innovation

Question: What capability gaps need to be filled as we move forward?

1) Diminished state of U.S. technical infrastructure
2) Light-water regulatory framework, which automatically disadvantages advanced designs
3) Evidence-based market signals that value nuclear power for its carbon-free generation

Conclusions and implications

- U.S. dead in the water with respect to adv. fission
- Most NE funding goes to overhead, light water reactor sustainability and ancillary tasks
- Utilities and public have no appetite for adv. fission
- Lack of focus, market pull undermining technological push
- Adv. fission research at the national labs lacks an agenda and has become a jobs program

Without significant changes, the advanced reactor R&D effort in the U.S. will not yield results that matter in the timeframe necessary to decarbonize the energy sector.

3) Parsing the public's fear of nuclear

- Decades-long history of studying the public's perception of nuclear power plants
- Among generally replicable results
  - Females oppose nuclear power more than males
  - Liberals oppose nuclear power more than conservatives
  - Trust in institutions declining (including in scientists, though they remain better than industry and gov.)
- Hypotheses for opposition to nuclear power:
  - Nuclear power's "disaster potential"
  - Connection between weapons and power
  - Lack of faith in the "risk communicators"

Tech faces unique perception challenge

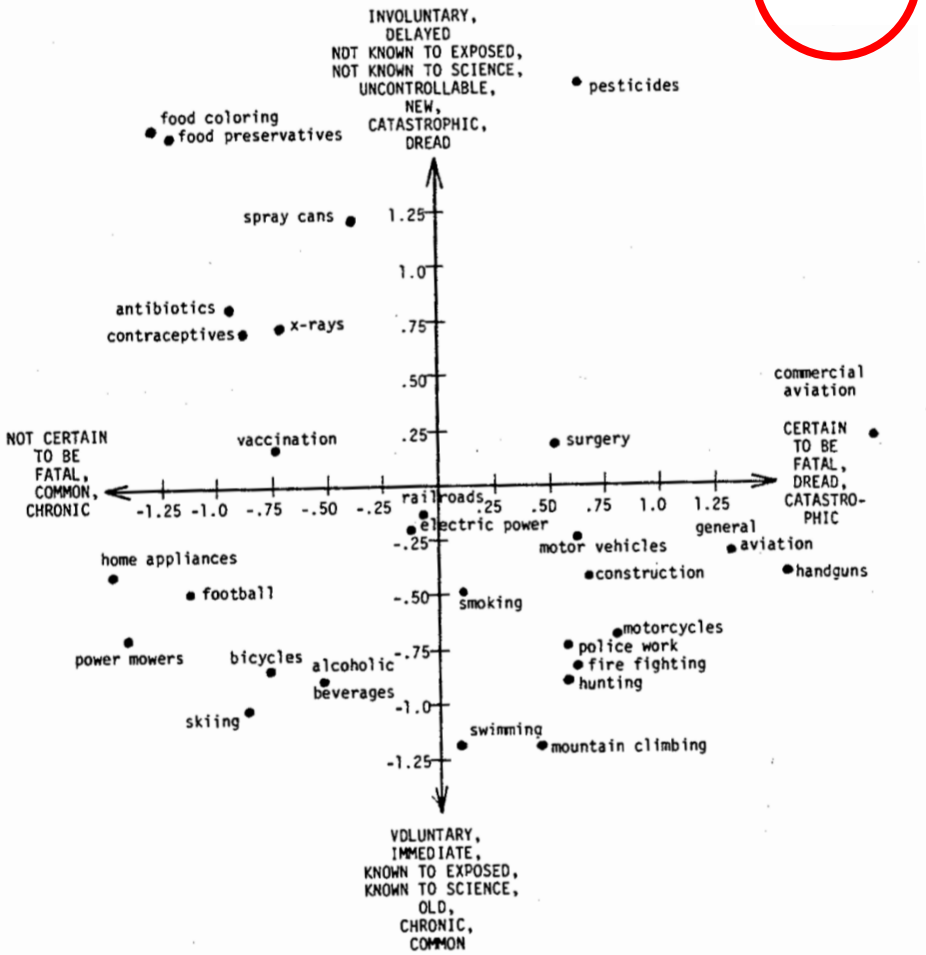


Fig. 7. Location of risk items within the two-factor space.

- Nuclear power elicits uniquely negative attitudes among technologies.
- Its risks are deemed involuntary, immediate, unknown, uncontrollable, catastrophic, and consequential. It engenders considerable “dread” in the public.

Energy planners deeply sensitive to this

- But the enterprise has failed to develop strategies to resolve the predicament:
  1) Deploy a new generation of advanced reactor designs that are safer than current reactors
  2) Develop accident and sabotage-proof designs (?)
  3) Emphasize automation in future technologies
  4) Appeal to stay the course, educating citizens about nuclear power's small risks and increasing their general scientific literacy and numeracy.

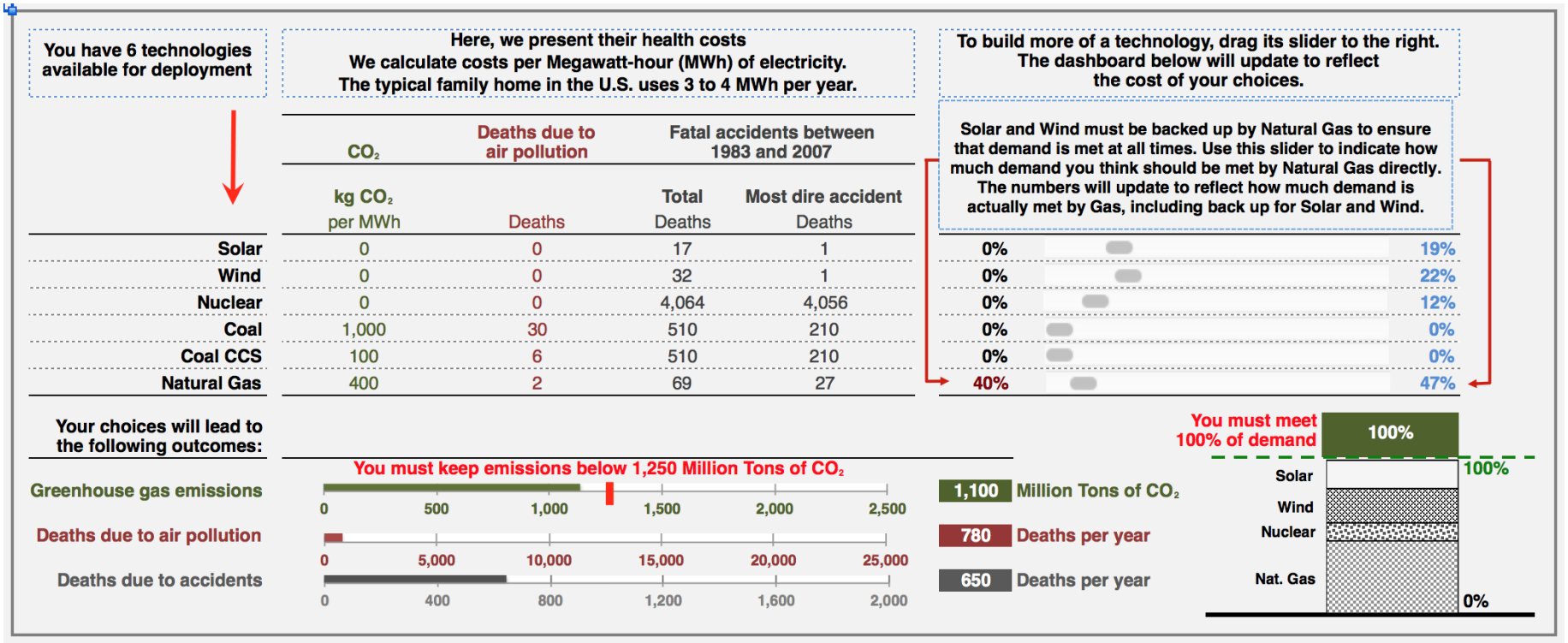
Would people really care if the core damage frequency is reduced to 10^{-8} from 10^{-7}?

What is in a name?

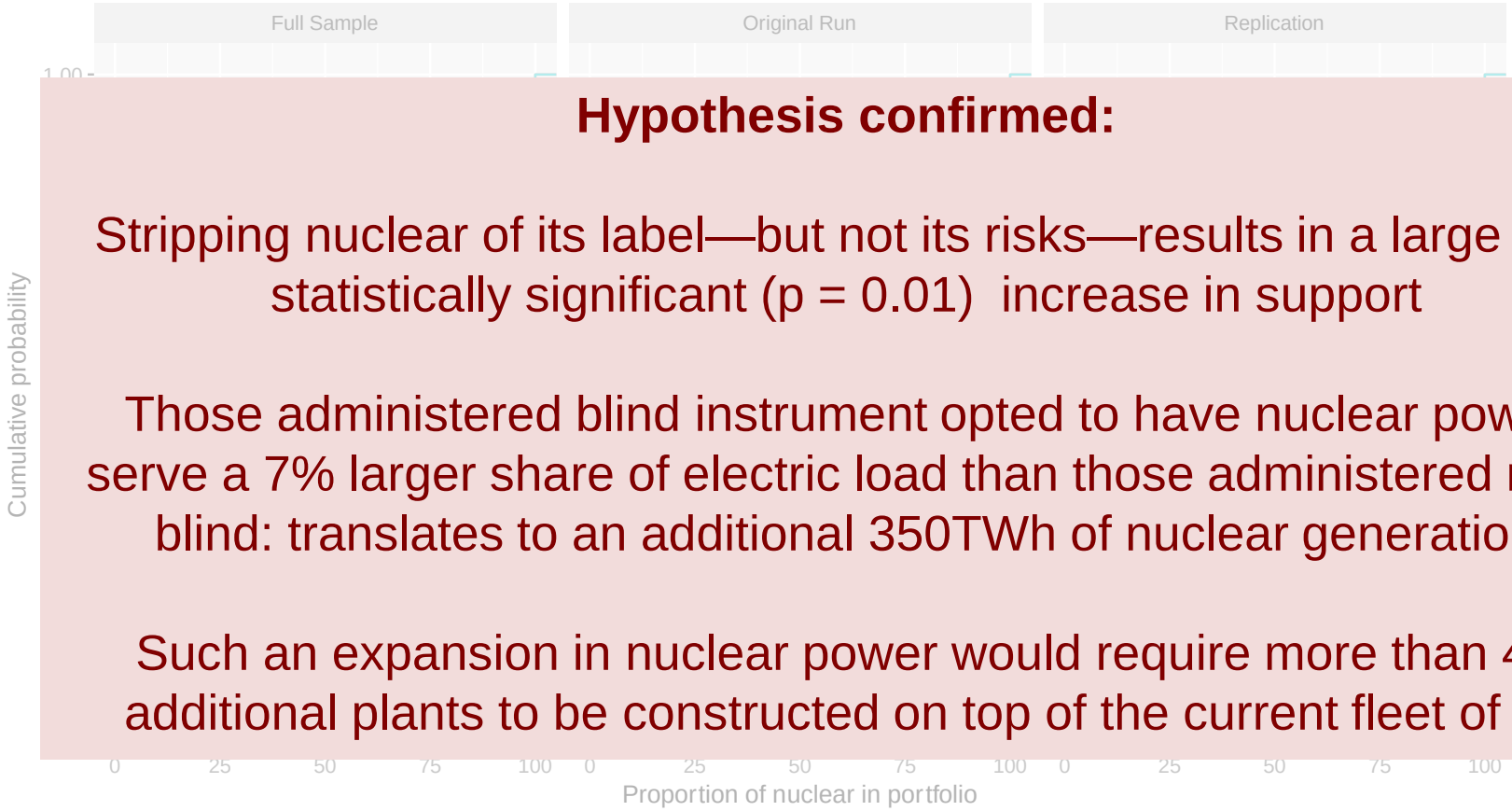
- We investigate an elementary problem facing the technology: its name.
  - What if you communicated the *exact same information* regarding emissions, mortality, and morbidity, but ascribed to nuclear power the name **Bananarama**
- Designed survey in Microsoft® Excel®
  - Allowed respondents to build electricity portfolio for the U.S. in the year 2050
  - Included 6 tech: wind, solar, nuclear, coal, coal CCS, gas
  - **Goal 1:** meet 100% of U.S. electricity demand
  - **Goal 2:** cut power sector emissions by 50%

Survey included extensive controls

- Random assignment of: **1)** “blinded” vs. “not blinded”; **2)** anchored to U.S. electricity mix vs. non-anchored; and **3)** position of nuclear among 6 technologies



We recruited 1226 respondents in total



Hypothesis confirmed:

Stripping nuclear of its label—but not its risks—results in a large and statistically significant (p = 0.01) increase in support

Those administered blind instrument opted to have nuclear power serve a 7% larger share of electric load than those administered non-blind: translates to an additional 350TWh of nuclear generation

Such an expansion in nuclear power would require more than 40 additional plants to be constructed on top of the current fleet of 99

Gender matters

No significant anchoring effects in either the initial position of our controls or the order in which technologies were listed

Environmental attitudes do not explain differences in preference for nuclear power. Reluctant acceptance vs. adamant opposition

Men are likely to choose a portfolio that has 10% more nuclear in it than women (p = 0); however both men and women choose more nuclear in their portfolios if they are blinded.

Main observation confirmed by a Kolmogorov–Smirnov (KS) test (p=0.001). The same is true for the male sample (p = 0.02) and the female sample (p=0.03).

Cumulative probability

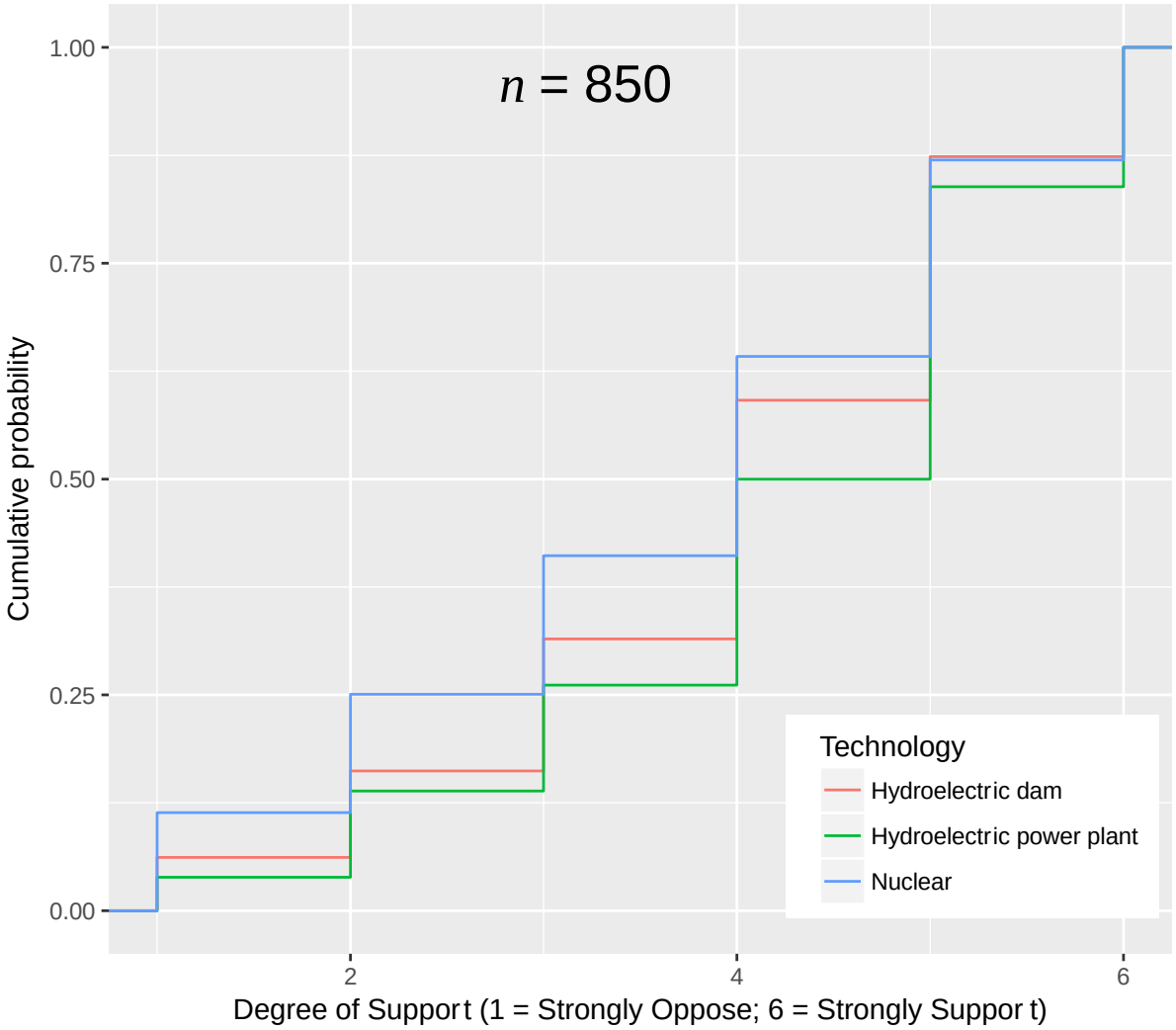
We devised a 2nd test of our hypothesis

- We created three vignettes, and administered them to 850 respondents in the U.S. One read:

"Your local electric utility plans to construct a new hydroelectric power plant that generates enough electricity to power 700,000 homes. Like all facilities that produce electricity, there is a risk associated with this project. While accidents at hydroelectric power plants are very rare, the worst possible accident can result in approximately 2,000 deaths. To what extent do you support the development of this power plant?"

Strongly Oppose	Oppose	Somewhat Oppose	Somewhat Support	Support	Strongly Support
○	○	○	○	○	○

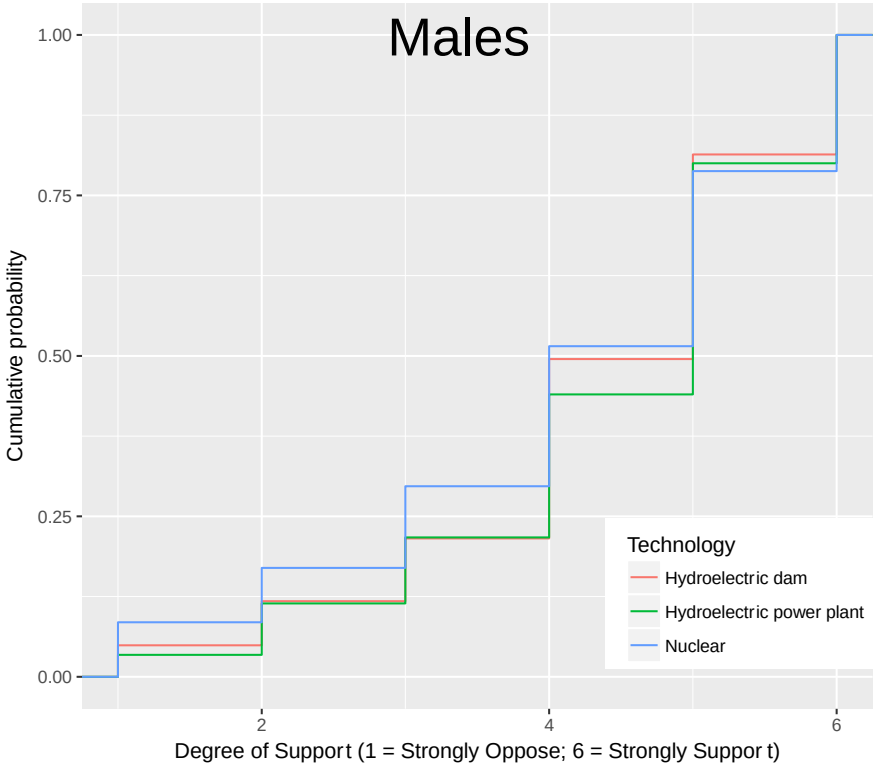
Respondents heavily disfavored nuclear

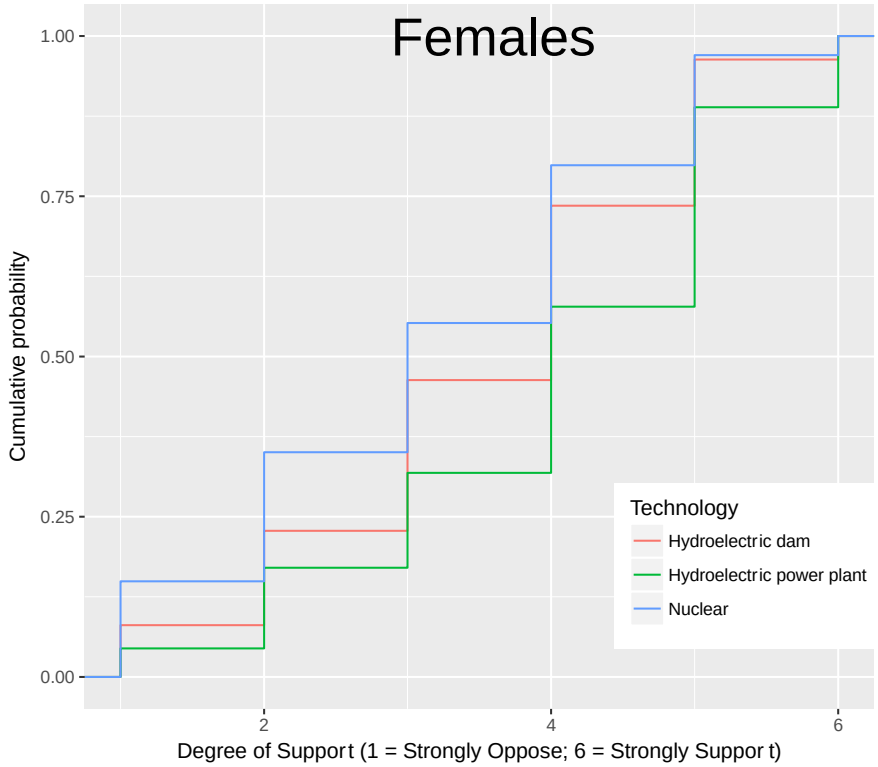


Hydro power plant
>
Hydro dam
>
Nuclear

Former two provide a *third* test of our hypothesis:
they are identical!

Again, gender discrepancies exist





Conclusions and implications

- Developing accident-proof reactors not good enough for nuclear power to gain wide global acceptability
  - Stakeholders must be disabused of the notion that better safety would improve nuclear power's prospects
  - Efforts to correct misconceptions hampered by low level of trust in risk communicators
- Work is of greater import to emergent energy technologies
  - e.g. CCS being tied in public consciousness to human-induced earthquakes.

In world where nuclear, CCS, gas, and batteries are deemed unacceptable, eliminating emissions becomes utterly impossible. Climate implications profound.

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