Comparing Energy Sources (Nuclear vs Fossil)

Rizwan-uddin

Department of Nuclear, Plasma and Radiological Engg

Institute of Sustainability, Energy, and Environment

Director, Master of Engineering in Energy Systems

UNIVERSITY OF ILLINOIS

URBANA-CHAMPAIGN

Energy-2030

Paths to a Sustainable Future

iSEE Congress

University of Illinois

September 12-14, 2016

A more appropriate title would be

<u>NEED FOR QUANTITATIVE</u>
<u>Comparison OF Energy Sources</u>
<u>FOR THEIR LIFE CYCLE IMPACT</u>

Energy-2030

Paths to a Sustainable Future

2016

Why?

- Competition for base load is still between fossil and nuclear
- It is not the end of fossils
- It is not the end of nuclear
- Impact on climate is serious (fossil effects)
- Nuclear spent fuel issue is only partially addressed
- Probability of nuclear accidents is not zero

Is it the end-of-the-road for fossils?

- Not quite!
- Large scale energy storage still seems far away

Secretary Moniz's charge to the coal council to explore markets for CO2

Washington, DC 20585

February 23, 2016

Dr. Michael Durham
Chairman, The National Coal Council, Inc.
1101 Pennsylvania Avenue, NW, 6th Floor
Washington, DC 20004

Dear Chairman Durham:

I am writing to request the National Coal Council (NCC) develop an expanded white paper assessing opportunities to advance commercial markets for carbon dioxide (CO_2) from coal-base power generation.

The white paper should focus on profit-generating opportunities for CO_2 utilization, both for Enhanced Oil Recovery (EOR) and for non-EOR applications. The questions to be addressed are:

(1) What is the extent to which commercial EOR and non-EOR CO_2 markets could incentivize deployment of Carbon Capture and Storage (CCS) / Carbon Capture, Utilization, and Storage (CCUS) technologies?

(2) What economic opportunity does deployment of commercial-scale CCS/CCUS technology represent for the U.S.?

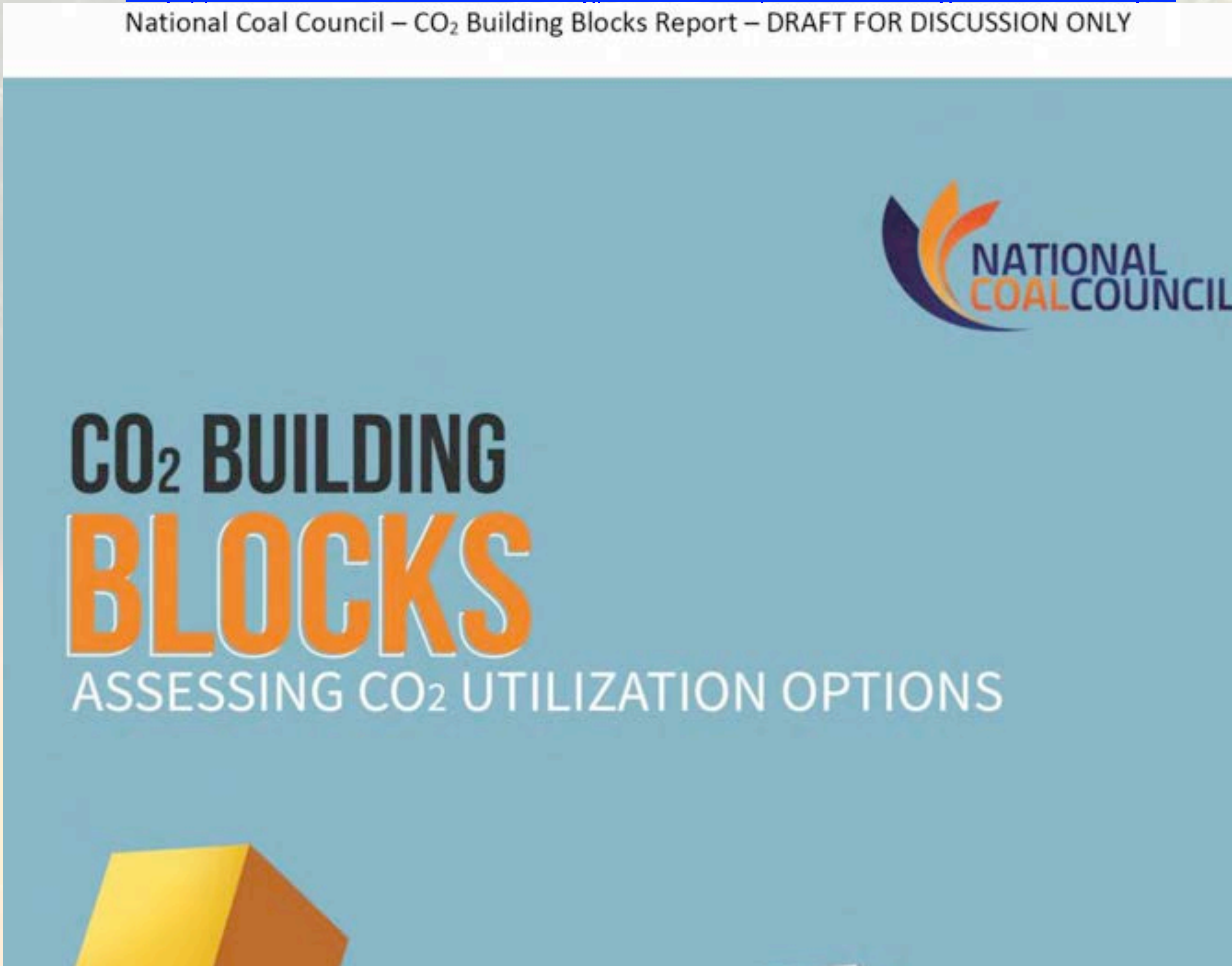
The white paper would be managed under the auspices of the Executive Advisory Board within the NCC. I ask that the white paper be completed no later than August 31.

Upon receiving this request and establishing your internal working groups, please advise me of your schedule for completing the white paper. The Department looks forward to working with you in this effort.

Sincerely,

Ernest J. Moniz

http://www.nationalcoalcouncil.org/Documents/CO2-Building-Blocks-2016.pdf



National Coal Council – CO_2 Building Blocks White Paper – DRAFT FOR DISCUSSION ONLY

Executive Summary

Fossil fuels – including coal, natural gas and oil – will remain the dominant global energy source well into the future by virtue of their abundance, supply security and affordability. There is a growing consensus among industry, the environmental community and governments that future carbon dioxide (CO_2) emission reduction goals cannot be met by renewable energy sources alone and that carbon capture, utilization and storage (CCUS) technologies for all fossil fuels will have to be deployed to achieve climate objectives in the U.S. and globally and to insure a reliable power grid. Advancing CCUS is not just about coal, nor is it just about fossil fuels generally. Rather, it is a sine qua non for achieving stabilization of greenhouse gas (GHG) concentrations in the atmosphere.

Fossil fuel will be around

A. Key Findings & Recommendations

Key Findings

Chapter B: Introduction – The Value of Coal

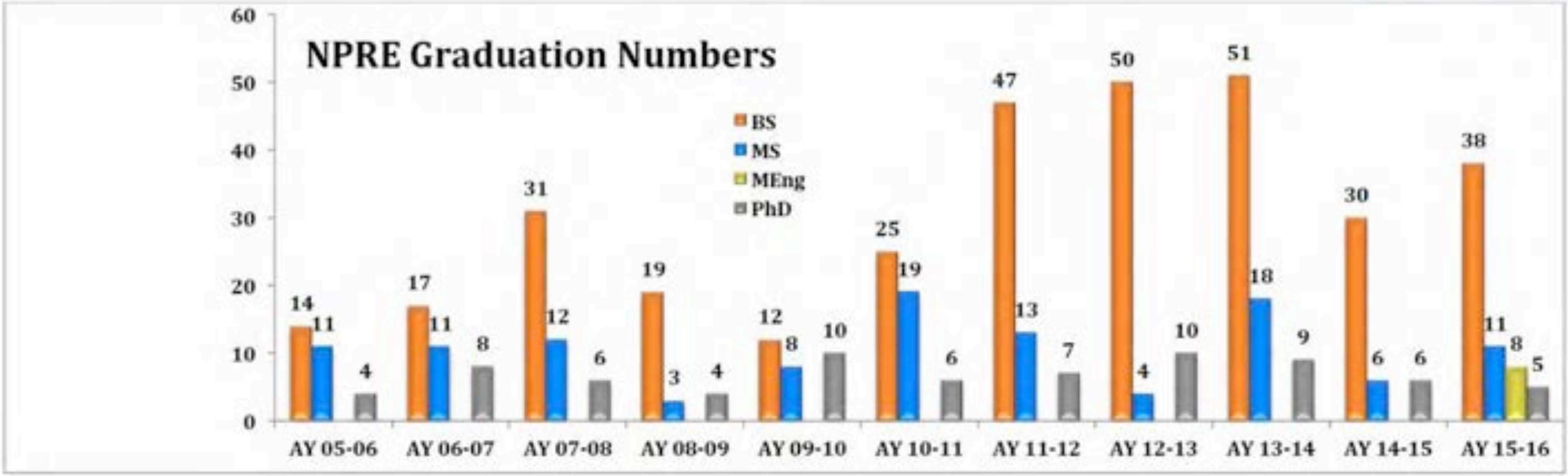
- Fossil fuels – including coal, natural gas and oil – will remain the dominant global energy source well into the future by virtue of their abundance, supply security and affordability.
- There is a growing consensus among industry, the environmental community and governments that future CO_2 emission reduction goals cannot be met by renewable energy sources alone and that CCUS technologies for all fossil fuels will have to be deployed to achieve climate objectives in the U.S. and globally and to ensure a reliable power grid.
- Each component of the CCUS value chain is critical - CO_2 capture, utilization and storage – and must be advanced in tandem to expeditiously advance CCUS deployment.
- CO_2 utilization can help to reduce CCUS costs and incentivize the technology's deployment.
- CCUS is not exclusively a "clean coal" strategy and will ultimately need to be adopted for all fossil fuels in the power and industrial sectors.

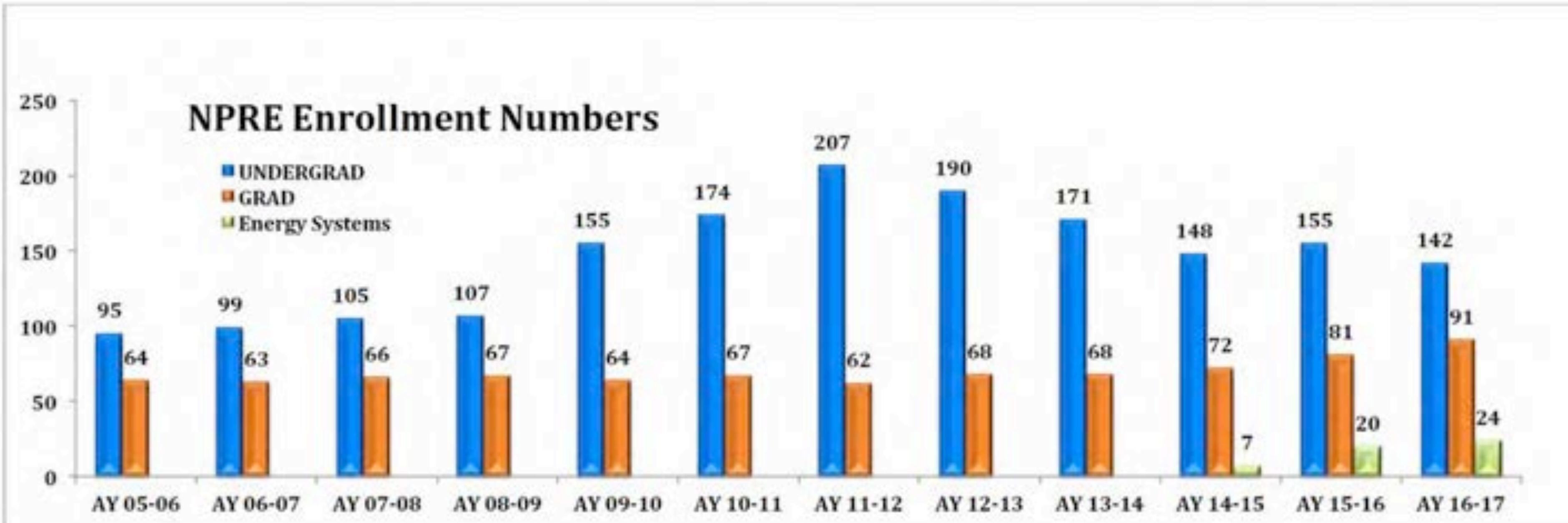
Nuclear has also shown its staying power, despite hiccups!

Nuclear's fortunes show some wild swings, but after every hiccup, public acceptance of nuclear power has returned to old levels (in many countries)

After laying low for at least two decades, had it not been for Fukushima and shale gas, nuclear had seemed poised for a major resurgence in the US

Student Enrollment





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The New Nuclear Renaissance

The future of nuclear energy in the U.S. is bright.

By Jim Inhofe , Sheldon Whitehouse, Mike Crapo and Cory Booker

f MORE

July 11, 2016, at 11:35 a.m.

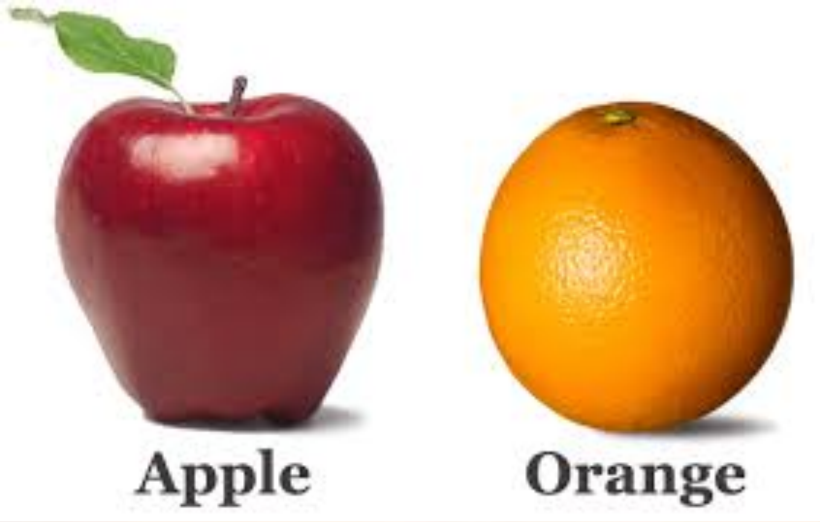
There has been a groundswell of activity and investment in recent years surrounding advanced nuclear reactors. A dynamic group of nuclear engineers and scientists are chasing the future – and racing against China and Russia – to develop innovative reactor designs. These technologies hold enormous promise to provide clean, safe, affordable, and reliable energy, not just for our country, but for the world. These innovators have a vision for the future, and they charge ahead backed by more than $1 billion in private capital. The future of nuclear energy is bright.

Some would argue that we have been here before. In 2005, Congress passed incentives to encourage a "nuclear renaissance" amid high natural gas prices. The industry stood ready

So, both are likely to be around for some time.

How do we make decisions?

We are often told that we cannot compare



- But, what if we are forced to!!

An Aside;

- There are plenty of “qualitative” comparisons of energy sources; including fossils, nuclear, renewables.

http://cesa.org/assets/2011-Files/States-Advancing-Wind-2/CESA-Visual-Impacts-Methodology-May2011.pdf

State Clean Energy Program Guide

A VISUAL IMPACT ASSESSMENT PROCESS FOR WIND ENERGY PROJECTS

Principal Author
Jean Vissering, Jean Vissering Landscape Architecture

Contributing Authors
Mark Sinclair and Anne Margolis, Clean Energy States Alliance

MAY 2011

ENERGY > RENEWABLE ENERGY

Environmental Impacts of Renewable Energy Technologies

Contents

All energy sources have some impact on our environment. Fossil fuels — coal, oil, and natural gas — do substantially more harm than renewable energy sources by most measures, including air and water pollution, damage to public health, wildlife and habitat loss, water use, land use,

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ENERGY > RENEWABLE ENERGY

Environmental Impacts of Solar Power

Contents

The sun provides a tremendous resource for generating clean and sustainable electricity without toxic pollution or global warming emissions.

The potential environmental impacts associated with solar power — land use and habitat loss, water use, and the use of hazardous materials in manufacturing — can vary greatly depending on the technology, which includes two broad categories: photovoltaic (PV) solar cells or concentrating solar thermal plants (CSP).

energy4me®
Essential Energy Education

Energy > Sustainability > Environmental Impact by Source

Environmental Impact by Source

- Biofuels: Biomass, Ethanol and Biodiesel
- Coal
- Geothermal
- Hydropower
- Petroleum (Oil and Gas)
- Solar
- Uranium (Nuclear Energy)
- Wind

All energy sources affect the environment. There is no such thing as a completely "clean" energy source.

Getting the energy we need affects our environment in many different ways. Some energy sources have a greater impact than others. Energy is lost to the environment during any energy transformation, usually as heat. Notice the heat from your computer or car after it has been in use for a while. Nothing is completely energy efficient. Fortunately, the energy industry has become increasingly aware of the importance of environmental protection and is working to reduce its long-term impact.

Biofuels: Biomass, Ethanol and Biodiesel

On the surface, biofuels look like an ideal energy solution. Since plants absorb carbon dioxide as they grow, crops could counteract the carbon dioxide released by cars. They are also renewable, and can be planted to replenish supplies.

Unfortunately, it's not that easy. It takes a tremendous amount of energy to grow crops, make fertilizers

Energy Source Comparison

Energy Source	Pros	Cons
Solar Energy 	• Non-polluting • Most abundant energy source available • Systems last 15-30 years	• High initial investment • Dependent on sunny weather • Supplemental energy may be needed in low sunlight areas • Requires large physical space for PV cell panels • Limited availability of polysilicon for panels
Wind Energy 	• No emissions • Affordable • Little disruption of ecosystems	• Output is proportional to wind speed • Not feasible for all geographic locations • High initial investment/ongoing

- 1 d
- 2 d
- Sea

Biofuels 	• Abundant supply • Fewer emissions than fossil fuel sources • Can be used in diesel engines • Auto engines easily convert to run on biomass fuel	• Source must be near usage to cut transportation costs • Emits some pollution as gas/liquid waste • Increases emissions of nitrogen oxides, an air pollutant • Uses some fossil fuels in conversion
Coal 	• Abundant supply • Currently inexpensive to extract • Reliable and capable of generating large amounts of power	• Emits major greenhouse gases/acid rain • High environmental impact from mining and burning, although cleaner coal-burning technology is being developed • Mining can be dangerous for miners
Uranium 	• No greenhouse gases or CO2 emissions • Efficient at transforming energy into electricity • Uranium reserves are abundant • Refueled yearly (unlike coal plants that need trainloads of coal every day)	• Higher capital costs due to safety, emergency, containment, radioactive waste, and storage systems • Problem of long-term storage of radioactive waste • Heated waste water from nuclear plants harms aquatic life • Potential nuclear proliferation issue

But, what we need is a methodology for “quantitative” comparison?

CHALLENGES?

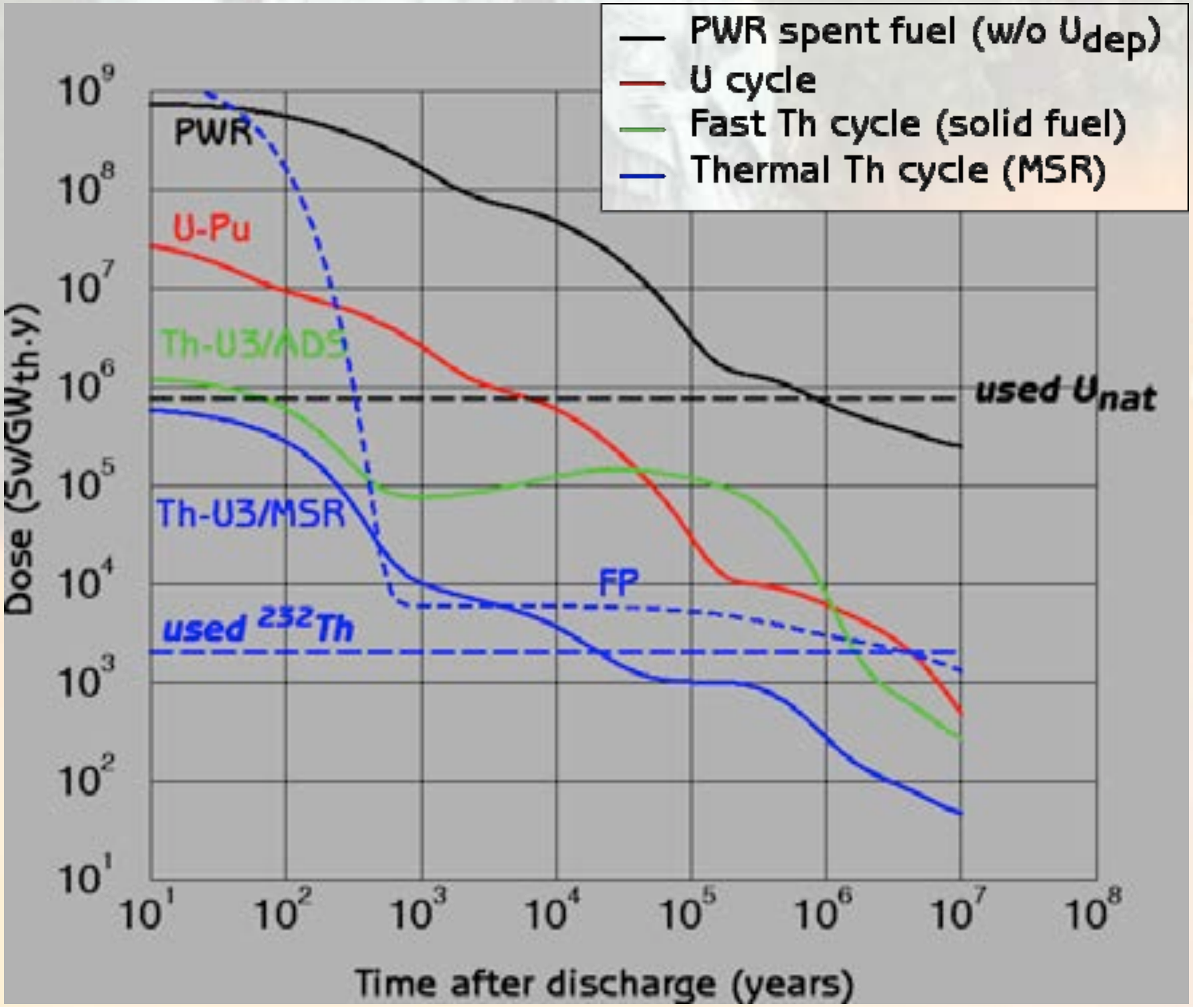
Cost & Risk

- Challenge:

    Evaluation of *cost* and *risks* associated with different energy sources and associated technologies over large spatial scales and over large spans of time—spanning centuries—coupled with the science of relatively rare events.

Should cost be in $s or life expectancy, or …

Time Scale: Nuclear side



IAEA

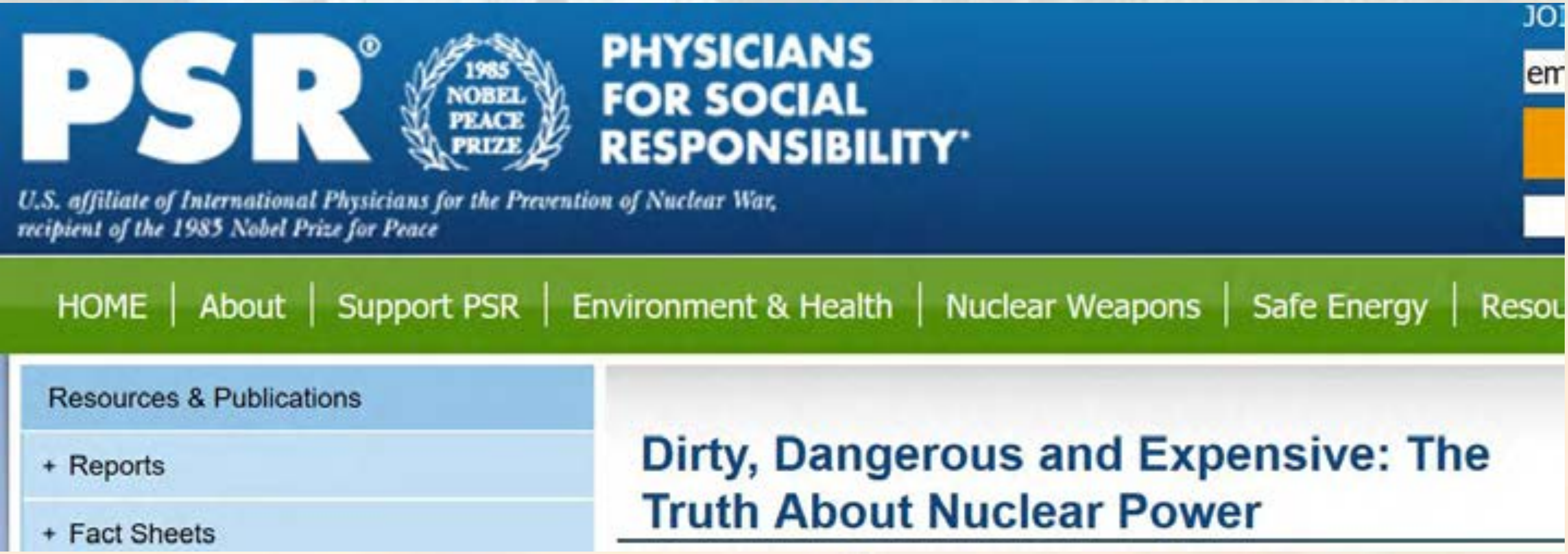
Most intense radioactivity in spent fuel.

Most immediate hazards come from strontium-90 and cesium-137.

Time Scale: Fossil side

- We have some understanding of how long CO_2 stays in the atmosphere
- But much less for how long the impact of a climate change that has taken place, will last

Cost & Risk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Dirty, Dangerous and Expensive: The Truth About Nuclear Power

Cost & Risk

Dirty, Dangerous and Expensive: The Truth About Nuclear Power

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The nuclear industry seeks to revitalize itself by manipulating the public's concerns about global warming and energy insecurity to promote nuclear power as a clean and safe way to curb emissions of greenhouse gases and reduce dependence on foreign energy resources. Despite these claims by industry proponents, a thorough examination of the full life-cycle of nuclear power generation reveals nuclear power to be a dirty, dangerous and expensive form of energy that poses serious risks to human health, national security and U.S. taxpayers.

Nuclear Power is Dirty

Each year, enormous quantities of radioactive waste are created during the nuclear fuel process, including 2,000 metric tons of high-level radioactive waste(1) and 12 million cubic feet of low-level radioactive waste(2) in the U.S. alone. More than 58,000 metric tons of highly radioactive spent fuel already has accumulated at reactor sites around the U.S. for which there

Cost & Risk

Serious Safety Concerns

Despite proponents' claims that it is safe, the history of nuclear energy is marked by a number of disasters and near disasters. The 1986 Chernobyl disaster in Ukraine is one of the most frightening examples of the potentially catastrophic consequences of a nuclear accident. An estimated 220,000 people were displaced from their homes, and the radioactive fallout from the accident made 4,440 square kilometers of agricultural land and 6,820 square kilometers of forests in Belarus and Ukraine unusable. It is extremely difficult to get accurate information about the health effects from Chernobyl. Government agencies in Ukraine, Russia, and Belarus estimate that about 25,000 of the 600,000 involved in fire-fighting and clean up operations have died so far because of radiation exposure from the accident.(4) According to an April 2006 report commissioned by the European Greens for the European Parliament, there will be an additional 30,000 to 60,000 fatal cancer deaths worldwide from the accident.(5)

In 1979, the United States had its own disaster following an accident at the Three Mile Island Nuclear Reactor in

Proliferation, Loose Nukes and Terrorism

The inextricable link between nuclear energy and nuclear weapons is arguably the greatest danger of nuclear power. The same process used to manufacture low-enriched uranium for nuclear fuel also can be employed for the production of highly enriched uranium for nuclear weapons. As it has in the past, expansion of nuclear power could lead to an increase in the number of both nuclear weapons states and 'threshold' nuclear states that could quickly produce weapons by utilizing facilities and materials from their 'civil' nuclear programs a scenario many fear may be playing out in Iran. Expanded use of nuclear power would increase the risk that commercial nuclear technology will be used to construct clandestine weapons facilities, as was done by Pakistan.

Making the Safe, Sustainable Investment

It is clear that alternatives to fossil fuels must be developed on a large scale. However, nuclear power is neither renewable nor clean and therefore not a wise option. Even if one were to disregard the waste problems, safety risks and dismal economics, nuclear power is both too slow and too limited a solution to global warming and energy insecurity. Given the urgent need to begin reducing greenhouse gas emissions, the long lead times required for the design, permitting and construction of nuclear reactors render nuclear power an ineffective option for addressing global warming.

Cost & Risk

When the very serious risk of accidents, proliferation, terrorism and nuclear war are considered, it is clear that investment in nuclear power as a climate change solution is not only misguided, but also highly dangerous. As we look for solutions to the

Cost & Risk

MAR 10, 2016 @ 06:00 AM 8,455 VIEWS

The Little Bl

After Five Years, What Is The Cost Of Fukushima?

James Conca, CONTRIBUTOR

I write about nuclear, energy and the environment **FULL BIO**

The disaster at the Fukushima Daiichi Power Plant following the devastating tsunami in Japan on the 11th of March in 2011 has proven costly in many ways – politically, economically and emotionally. Strangely, the costs that never materialized were the most feared, those of radiation-induced cancer and death. No radiological health effects have yet to result from the Fukushima disaster – neither cancers, deaths nor radiation sickness – although the WHO models indicate a slight increase is statistically possible. No one received enough dose, even the 20,000 workers who have worked tirelessly to recover from this event.

Cost & Risk

The direct costs of the Fukushima disaster will be about $15 billion in clean-up over the next 20 years and over $60 billion in refugee compensation. Replacing Japan's 300 billion kWhs from nuclear each year with fossil fuels has cost Japan over $200 billion, mostly from fuel costs for natural gas, fuel oil and coal, as renewables have failed to expand in Japan. This cost will at least double, and that only if the nuclear fleet is mostly restarted by 2020.

The reconstruction and recovery costs associated with just the earthquake and the tsunami will top $250 billion. Since 2011, Japan's trade deficit has become the worst in its history, and Japan is now the second largest net importer of fossil fuel in the world, right behind China.

Cost & Risk

The fifth anniversary of the accident brings more optimism than could have been predicted five years ago. The government has removed almost 10 million cubic yards of contaminated soil and debris, and washed down buildings and roadways to get outdoor radiation exposures to below 1 mSv /year (100 mrem/year), a level lower than almost anywhere in the United States. Rural decontamination is complete in more than half of the evacuation zone. Fukushima-grown food has no detectable radiation from the accident. The fishing stocks off the Japanese coast are not contaminated. The ocean off the coast of Fukushima is not contaminated. Even though some radiation is still leaking from the site, the volume is too small to effect anyone or anything offsite, and containment is almost complete.

Air pollution cuts life expectancy by 5.5 years in China - study

by Charles Riley @CRrileyCNN

July 9, 2013: 5:17 AM ET

Thick clouds of smog have blanketed Chinese cities like Beijing this year.

Severe pollution has slashed an average of five and half years from life expectancy in northern China, as toxic air has led to higher rates of stroke, heart disease and cancer.

International Union for Conservation of Nature (IUCN)

Soaring ocean temperature is 'greatest hidden challenge of our generation'

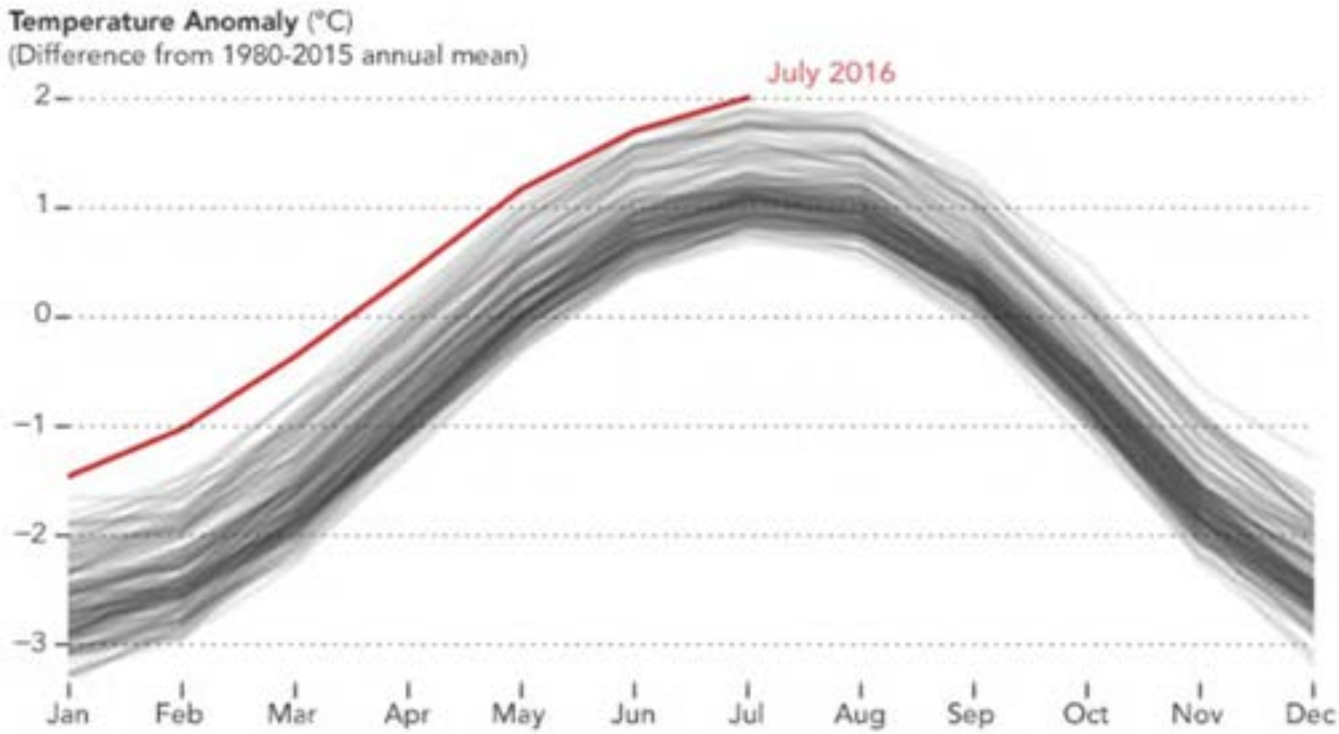
IUCN report warns that 'truly staggering' rate of warming is changing the behaviour of marine species, reducing fishing zones and spreading disease

The scale of warming in the ocean is 'truly staggering', the report warns. Photograph: Ralph Lee Hopkins/Alamy

- https://www.theguardian.com/environment/2016/sep/05/soaring-ocean-temperature-is-greatest-hidden-challenge-of-our-generation

Put a $ amount on:

Recent research found that just five more years of carbon dioxide emissions at current levels will virtually wipe out any chance of restraining temperatures to a 1.5C increase and avoid runaway climate change.



Temperature reconstructions by Nasa, using work from its sister agency the National Oceanic and Atmospheric Administration, found that the global temperature typically rose by between 4-7C over a period of 5,000 years as the world moved out of ice ages. The temperature rise clocked up over the past century is around 10 times faster than this previous rate of warming.

•**Lots of CO_2 (usually in the atmosphere) vs very highly concentrated (but small in volume) radioactive waste**

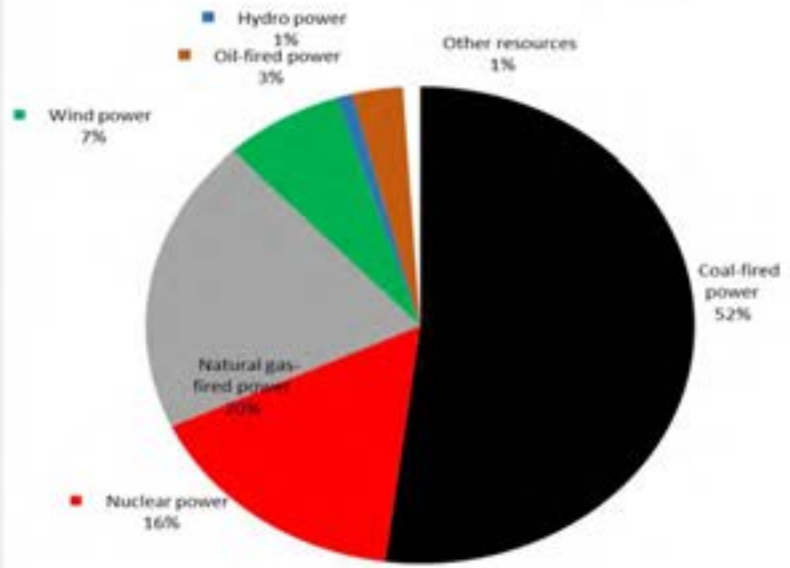
AEP Energy Environmental Disclosure Statement In Ameren's Service Territory

AEP ENERGY®

The following distribution of energy resources was used to produce electricity in the MISO Region from the System Mix.

Biomass power	0%
Coal-fired power	52%
Hydro power	1%
Natural gas-fired power	20%
Nuclear power	16%
Oil-fired power	3%
Solar power	0%
Wind power	7%
Other resources	1%
Unknown resources purchased from other cos.	0%
TOTAL	100%

Sources of Electricity Supplied for the 12 months ending December 31, 2015



The MISO System average emission levels are based on data from the system mix for 12 months ending December 31, 2015

AEP Energy reports fuel sources and emissions data from MISO to its customers quarterly, allowing customers

Sources of Electricity Supplied for the 12 months ending December 31, 2015

Average Amounts of Emissions and Amount of Nuclear Waste per 1000 kilowatt-hours (kWh) Produced from Known* Sources for the 12 months ending December 31, 2015

Air Emissions

Average Nitrogen Oxides (NO_x), Sulfur Dioxide (SO_2), and Carbon Dioxide (CO_2) emissions for the system mix used by AEP Energy in the MISO region as compared to the overall Supply Mix.

Carbon Dioxide	1,374lbs
Nitrogen Oxides	0.79lbs
Sulfur Dioxide	1.51 lbs
High-Level Nuclear Waste	0.0009 lbs
Low-Level Nuclear Waste	0.0002 ft

CO_2 is a "greenhouse gas" which may contribute to global climate change. SO_2 and NO_x released into the atmosphere react to form acid rain. Nitrogen Oxides also react to form ground level ozone, an unhealthful component of "smog".

Average Amounts of Emissions and Amount of Nuclear Waste per 1000 kilowatt-hours (kWh) Produced from Known* Sources for the 12 months ending December 31, 2015

Air Emissions

Dirty, Dangerous and Expensive: The Truth About Nuclear Power

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Low-Level Nuclear Waste	0.0002 ft

CO_2 is a "greenhouse gas" which may contribute to global climate change. SO_2 and NO_x released into the atmosphere react to form acid rain. Nitrogen Oxides also react to form ground level ozone, an unhealthful component of "smog".

Put a $ amount on:

- Chernobyl accident
- Fukushima nuclear accident
- Fukushima tsunami
- 1 degree rise in temperature
- 2 degree rise in temperature
- Sea level rise of n inches

- Number of *Severe* Nuclear Accidents over the next 100 years? 1000 years?
- Cost associated with an accident at Yucca mountain fuel repository
- Real, long term cost of fracking

What is needed?

- Risk analysis
- Uncertainty quantification (UQ)
- Economic analysis
- Social science to associate “cost of disruptions” in life, etc
- Incorporate flexibility to include different value systems in the model
- Impact on current, near future, and distant future; (different weights?)

Thank you

Q and Comments?

Nuclear Waste Disposal, Radioactivity, and Accidents

- Units for measuring radioactivity
  - 1 curie = amount of material that produces 3.7×10^{10} nuclear decays per second, equivalent to the activity of 1 gram of radium.
  - 1 becquerel = amount of material producing 1 nuclear decay per second
- Absorbed Dose of Radiation
  - 1 rad is defined as the absorbed radiation dose of 0.01 joules of energy per kilogram of tissue.
  - 1 gray is defined as 1 joule of deposited energy per kilogram of tissue
- Biologically Effective Dose is the absorbed dose multiplied by the relative biological effectiveness of radiation to get the biological dose equivalent in rems or sieverts.
  - 1 rem is the radiation dose in rads multiplied by the relative biological effectiveness
  - 1 sievert is equal to 100 rems (SI unit)
  - Light radiation sickness begins at about 50–100 rad

- http://www.nationalcoalcouncil.org/Documents/CO2-Building-Blocks-2016.pdf