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HOUSE OF REPRESENTATIVES
COMMONWEALTH of PENNSYLVANIA

House Democratic Policy Committee Hearing

Powering Pennsylvania: Fusion Energy
Tuesday, Aug. 9, 2022 | 10 a.m.
Representative Emily Kinkead

10 a.m. Opening remarks: Chairman Ryan Bizzarro and Rep. Emily Kinkead

PANEL ONE

10:10 a.m. Overview: Matthew Moynihan, PhD, nuclear fusion consultant, business owner
Member of the US Fusion Industry Association

Kristen Cullen, head of public affairs
Commonwealth Fusion Systems

Caroline Anderson, manager for outreach
Fusion Industry Association

Q & A with Legislators

PANEL TWO

11 a.m. Kieran Furlong, CEO
Realta Fusion

Mac Hatch, Vice President of Strategy
MetOx Technologies, Inc.

Ed LaHoda, consulting engineer
Westinghouse Electric Co. LLC

Q & A with Legislators

Comments for Powering PA Policy Hearing

Good morning. I would like to thank Committee Chairman Representative Bizzarro and Representative Kinkead for the opportunity to testify on this important issue.

My name is Dr. Matt Moynihan and I have been an advocate for fusion for the last 15 years. I hold a PhD focused on Inertial Confinement Fusion from the University of Rochester. I was formerly a Senior Nuclear Engineer for the US Navy at the Bettis Atomic Power Laboratory, here in Pittsburgh. My job was to ensure the safety of sailors on nuclear Submarines and Aircraft Carriers. I just completed a popular science book on fusion for Nature-Springer and I run a small business here in Pittsburgh helping investors understand the emerging fusion energy industry.

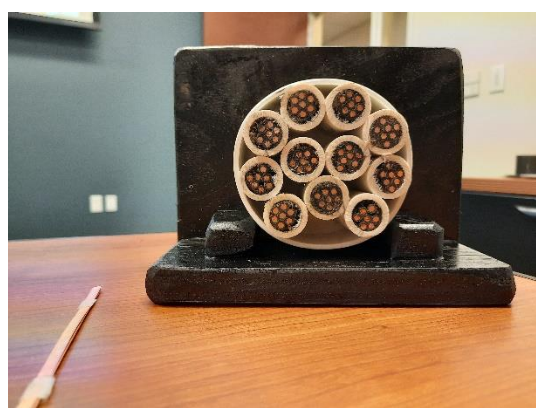
The reason that we are gathered together today is that we do not want the Commonwealth of Pennsylvania to miss an opportunity. Right now, the fusion industry is valued at 4.7 billion dollars [4]. But, if a private fusion energy company succeeds in doing something new – essentially recreating the power source of the sun in a fusion device – then this industry could be worth tens of billions, if not hundreds of billions, of dollars worldwide. There will be many potential jobs on the table.

Fusion is a low-carbon clean energy source that is many times more powerful than conventional nuclear fission energy. It is also inherently safer than fission. Fusion reactions do not “want” to happen and do not require unstable elements such as uranium or plutonium to happen. Consequently, fusion energy sources mean no meltdowns, no long-lived nuclear waste and no weapons risks. Importantly, Fusion power has major implications for fighting climate change as a clean baseload energy source.

Nuclear fission energy as we know it today takes a big atom (gesture with hands) and breaks it apart to release energy. Fusion takes two small atoms and fuses them together. In doing so, we duplicate the power source of the sun in a building. Realizing this power source has been the dream of scientists and engineers for the past 70 years [5].

However, In the past 20 years fusion has transitioned from an academic-, university-, and national laboratory-based endeavor to a private, privately funded, commercial activity. In fact, the first commercial product that used fusion was released in 2000 [1]. Today, you can buy a machine about the size of your car – for about a million dollars – that will perform fusion for about 132 hours continuously [2]. That machine will not generate electricity, but it can be used for other commercial applications.

There is no product that harnesses this process for electricity yet. Right now, the industry is composed of roughly 30 startups [4] that are racing to be the first organization to achieve this. Yes, some of these startups will fail. Investors should consider hiring experience advisors to help them navigate the industry, but with so many horses in this race, the odds of one of these companies getting there within the next 5 to 10 years have increased dramatically. The Commonwealth of Pennsylvania needs to find a way to position itself to capitalize on these developments, especially given this state's deep roots with the nuclear industry.



Private investors see now as the time for development because of the addition of superconducting wire to these fusion machines. I have a sample of this wire here (see insert). This thin bit of wire is roughly equivalent to all the copper wire you might buy at Home Depot (see notes). When you add this wire to fusion energy devices, the performance of these reactors becomes far more exciting for a power plant. Adding superconductors will allow companies to build smaller and cheaper fusion machines that can also run for far longer. In truth, what emerges is an entirely new class of fusion device. This new generation of power plants is fundamentally different than what has come before, and it is very exciting moment for everyone who has been working in this field for decades. This is why I would argue that the fields of fusion and of superconductivity will be inexorably linked together over the next decade.

Manufacturing this material in Pennsylvania could be a great new industry. This wire could also have applications in motors, generators, energy storage systems, weapons systems, and the computer industry; each spinoff market could be worth billions in their own right. This material is not new, but fusion energy is creating a new market demand signal that is helping to drive its commercialization and industrialization.

Achieving net power from a fusion machine is analogous to the Wright Brothers' glider taking off at Kitty Hawk. It signals the launch of a new industry. Much like flight, fusion is initially poorly understood by the public and poorly reported in the media. Much like flight, most citizens would have told you that fusion energy could never happen. Much like flight, fusion will create many commercial products that had their own large markets and spinoffs. Much like flight, fusion can strengthen the political, economic, and military of any country that got there first.

In conclusion, commercial fusion power is getting much closer to becoming a reality and this state needs to figure out how to position itself to capitalize on it.

Citations:

1. Sved, John, and T. Firestone. "Applications for gas-plasma target neutron generators." International Topical Meeting on Nuclear Research Applications and Utilization of Accelerators. 2009.

2. Private email with Dr. Ross Radel, CTO of Shine Medical Technologies. Monday August 1, 2022.
3. Molodyk, A., et al. "Development and large volume production of extremely high current density YBa2Cu3O7 superconducting wires for fusion." *Scientific reports* 11.1 (2021): 1-11.
4. "The Global Fusion Industry in 2022" Survey conducted by the Fusion Industry Association. July 14th 2022.
5. Phillips, J. A., & Tuck, P. S. J. (1983). Magnetic fusion. Los Alamos Science, 7, 64-67.

Notes:

* The YBCO wire manufactured and tested by SuperOx for Commonwealth Fusion Systems reached a maximum conductance of 2,000 amperes per square millimeter at 4.2 kelvin temperatures [3]. The mockup presented consists of 77, No. 10 American Wire Gauge (AWG) copper wires, which are each rated for 30 amperes.

Commonwealth Fusion Systems

Kristen Cullen, Head of Public Affairs

Democratic Policy Committee Hearing

“Powering PA: Fusion Energy”

Commonwealth Fusion Systems

148 Sidney Street, Cambridge, MA 02139, USA

August 9th, 2022

Honorable Members of the Democratic Policy Committee, good morning.

I would like to thank Committee Chairman Rep. Ryan Bizzarro and Rep. Emily Kinkead for organizing this hearing on commercial fusion energy and for the opportunity to testify today.

My name is Kristen Cullen, and I am the Head of Public Affairs at Commonwealth Fusion Systems (CFS). CFS was founded in 2018 after spinning out of MIT with the goal of leveraging decades of fusion research, combined with the innovation and speed of the private sector to deliver commercial fusion energy on the fastest path possible.

CFS has now raised more than $2 billion in private funding from the world's leading investors in clean energy and we have grown to more than 300 employees from around the world. We have built a team of experts dedicated to our mission of delivering clean fusion energy to combat climate change.

Fusion will be a fundamentally new source of clean energy. Commercial fusion systems will harness the fusion process and create a heat source that we can convert into electricity. This electricity conversion is very similar to what happens in coal or gas power plants today without the production of greenhouse gases. Fusion power plants could leverage existing infrastructure, potentially even repowering old fossil generating facilities. In fact, we believe the workforce for future fusion power plants is very similar. Fusion energy will be baseload, dispatchable power that is inherently safe, with no long-lived nuclear waste, and no meltdown or proliferation risks.

Scientists have been working on fusion for more than half a century and they have made significant progress. However, no one has yet been able to achieve net energy from fusion, meaning we have not been able to generate more power out than it takes to start the process. This is the critical next step for commercialization.

CFS is working collaboratively with MIT, a combined team of more than 500 people, to build the world's first fusion energy device that will demonstrate net energy from fusion at a level that would be relevant for commercialization.

Our team is building a device called a tokamak which has been the highest performing fusion device in the world. In fact, there have been more than 150 tokamaks built and operated around the world. Tokamaks are essentially magnetic bottles that use very strong magnetic fields to confine the fusion process. The breakthrough at CFS has been in new high temperature superconducting magnets that we developed and successfully demonstrated in collaboration with MIT last September. These magnets will enable tokamaks with much stronger magnetic fields and as a result enable higher performing machines at a much smaller size. Ultimately, this means we can build compact, economical fusion devices that will enable commercial fusion energy.

We are now constructing our fusion power plant prototype, called SPARC, in Massachusetts, and we are on track to commence operations in 2025.

On a parallel track we are preparing for commercialization and have built a robust manufacturing and supply chain team to support these efforts. We are opening a large-scale manufacturing facility this fall in which we will build and assemble our magnet technology. This is an important step to support our plans to have our first commercial fusion power plants operating in the early 2030s.

We believe states like Pennsylvania have an important role to play in the future of fusion. The Commonwealth is already home to suppliers that are supporting CFS and this growing industry. We look forward to working together to develop the policies that will support the fusion energy industry.

Thank you for having us here today.

Kristen Cullen, Commonwealth Fusion Systems – Short Bio

Kristen Cullen is the Head of Public Affairs at Commonwealth Fusion Systems (CFS) where she leads efforts related to policy, government relations, and public outreach. She previously led the siting process for CFS' new campus that will be home to the world's first commercially relevant fusion energy prototype device in Devens, MA. Prior to CFS, she was a senior vice president for the public affairs practice at Rasky Partners. Kristen has also worked in the Massachusetts statehouse and as a campaign manager and communications director on federal, state and local political campaigns. She started her career as a television reporter working for local ABC and NBC affiliates. Kristen earned a bachelor's degree in Political Science from Wheaton College and a master's degree in Journalism from Emerson College.	

Democratic Policy Committee Hearing
“Powering PA: Fusion Energy”

Caroline Anderson, Manager for Outreach
Fusion Industry Association

FUSION INDUSTRY ASSOCIATION

Democratic Policy Committee Hearing
"Powering PA: Fusion Energy"
August 9, 2022

Caroline Anderson, Manager for Outreach
Fusion Industry Association

Good morning and thank you to Committee Chairman Representative Bizzarro and Representative Kinkead for today's hearing on fusion energy, and for allowing me the opportunity to testify. Thank you to my fellow panelists, and to all of you for being here today. My name is Caroline Anderson; I'm the Manager for Outreach at the Fusion Industry Association (FIA).

Based in Washington, DC, the FIA is an association of 30 member companies from around the world, all working to achieve fusion commercialization and broadscale deployment. Furthermore, the FIA is composed of an additional 50 affiliate member companies– mainly supply chain firms and other relevant stakeholders.

To give a snapshot of the fusion industry as it stands today– a few weeks ago on July 14, we published *The global fusion industry in 2022* report in partnership with the European Commission. This is the second version of our annual report in which we capture updates on the private fusion industry. We do this by surveying and analyzing data from fusion firms all over the world. Since this was our second version, we were also able to measure critical changes since last year's report. Highlighted this year was the massive increase in the industry's scale.

Over $4.7 billion has been privately invested in fusion. This represents a 139% increase in the past 12 months. 8 new fusion companies have entered the market in the past year. Seven firms have now raised $200 million or more each.

The report also demonstrated a growing confidence among the fusion firms in their projected timescales for achieving commercialization. 93% of companies expect fusion power on the grid in the 2030s or before. This is significant as it is an increase up from the 83% that thought this just last year. Furthermore, 84% expect commercial competitiveness on that same timeframe.

Companies also reiterated the focus of their goal in achieving fusion commercialization– with all respondents listing electricity generation as either their primary or secondary market. Other markets include: space propulsion, marine propulsion, medical, off-grid energy, hydrogen and clean fuels, and industrial heat– to name a few.

Not only has the private sector recently seen immense growth towards commercialization, but the public sector has also made recent, significant strides to accelerate fusion development. In March, the White House hosted the first ever fusion summit on "Developing a Bold Decadal Vision for Fusion", bringing together leaders from government, industry, science, academia, public engagement, and social justice to speak about fusion and steps to accelerate its development, while ensuring the emerging industry benefits all members of society. In June, the Department of Energy hosted a three day fusion public-private partnership workshop, inviting representatives from all areas to collaborate on concrete steps to best capitalize on these current and future partnerships. This year, the federal budget included the most it ever has for fusion energy advancement, and the proposed budget for next year only increases that number.

It’s critical to invest in fusion, not only at the national level, but at the regional level as well.

Regions that invest in fusion development– and support through policy– will reap the benefit. Specific to economic impact, the industry envisions the future of commercial fusion energy as a new manufacturing industry. Fusion energy will be inexhaustible, built on a production line, not pulled from the ground. The scaling up of the fusion industry has the potential to involve building multiple power plants per day, support millions of jobs, create new regional “hubs”, and generate wealth from a vast export industry.

The crises of today– energy, climate, economic, and geopolitical instability– all demonstrate the need for a clean, efficient, affordable, widespread source of energy. Fusion energy has the capability to be all of these things. It has been called “the holy grail of clean energy”, for good reason. To give a more concrete idea of fusion compared to other energy sources: Fusion fuel is ten million times more power dense than fossil fuels. A single gram of fusion fuel can yield 90,000 kilowatt hours of energy. Ten pounds of coal is equivalent to energy as one pound of fusion fuel.

Fusion will finish the job that renewables have started. It is truly the efficient, clean, dispatchable, and accessible form of energy that the world so desperately needs.

Thank you very much for having us here today. I look forward to any questions.

INDUSTRIAL HEAT & POWER FROM FUSION

KIERAN FURLONG, CEO,

REALTA FUSION

DEMOCRATIC POLICY COMMITTEE HEARING

POWERING PA: FUSION ENERGY

AUGUST 9TH 2022, PITTSBURGH PA

Good morning, Chairman Bizzarro, Representative Kinkead and Members of the Policy Committee,

Thank you for the opportunity to speak before you today and I greatly appreciate and acknowledge your interest in fusion energy and the potential impact it could have in the Commonwealth of Pennsylvania.

My name is Kieran Furlong and I'm the CEO of Realta Fusion, an early-stage spin-out from the University of Wisconsin-Madison developing fusion technology to deliver industrial process heat and power.

While many proponents of fusion energy are focused on the generation of electrical power, we see a huge need for alternative sources of heat in our heavy industries. Addressing this energy need will be critical to tackling climate change but also to ensuring the competitiveness of U.S. manufacturing in the 21st century.

With the huge growth in renewables over the past two decades it may come as a surprise to some of you that globally, we still rely on fossil fuels for over 80% of our primary energy supply. Even best-case scenarios for a net-zero carbon future still have this share at over 70% in the 2030s. While transportation tends to get most visibility, if we want to arrest climate change, we really need to focus on industrial energy consumption. How we make things emits more greenhouse gases than how we move things. Industry accounts for almost half of our global energy consumption with the majority of that consisting of fossil fuels being burned to generate process heat.

When you think about the heavy industries that supply the steel, cement, fertilizers, glass, plastics, fuels and other absolutely essential building blocks for our modern civilization, they all involve high temperature processes. Since the Industrial Revolution, these industries have been powered by fossil fuels – coal, oil and natural gas. Pennsylvania is of course no stranger to these industries. Steel, glass and petroleum products have been pillars of the state economy for over a century providing employment and economic growth in the Keystone State, especially here in Pittsburgh.

Renewable electricity cannot and will not be able to generate the process heat needed for all these industries. However, if we wish to maintain US manufacturing in the 21st century it is increasingly clear that our citizens – particularly our younger ones – will demand, as consumers *and* voters, that industry is powered by less polluting, lower carbon energy. In order to maintain a "social license" to operate, these industries need an alternative low or zero-carbon source of process heat. We aim to provide that with fusion energy. This will be a firm, "always-on" source of energy (unlike intermittent renewables), capable of generating high-quality, high-temperature heat and can be directly co-located at industrial sites. This energy will enable US manufacturing to remain competitive in the world market, as well as sustainable into the future.

With abundant natural gas beneath our feet in the Marcellus Shale, Pennsylvania is poised for a manufacturing boom that it hasn't seen in decades. That gas can be the feedstock for polymers, fertilizers and hydrogen which people around the world need. Those consumers are also going to demand that the manufacturers of these products lower their carbon footprint. New petrochemical crackers are being planned and constructed here in Western PA. We at Realta Fusion aim to supply those plants with zero-carbon process heat, helping to decarbonize products that all of us use every day – from milk jugs to fleece jackets.

Industry can play a leading role in the energy transition. When further developed and commercialized, fusion can meet the high demands for the processes I've mentioned. Realta's fusion reactor design is very well suited for industry. It's shape (a cylinder, like distillation columns and rotary kilns) allows for direct integration into industrial processes and heat exchangers. The ease of access to our reactor will allow for periodic maintenance within typical plant shut-down windows leading to greater reliability. Most of all, the modular nature of our reactor, will allow for expansion of heat output to match capacity demands. So, we aim to build the first commercial fusion plant as an industrial heat generator. When industry has demonstrated commercially viable fusion energy, this will pave the way for public utilities across Pennsylvania and the rest of the country to adopt the technology and generate clean, safe, zero-carbon electrical power.

I greatly appreciate the interest this panel is taking in fusion energy and appreciate even more the opportunity to speak before you and alongside so many experts in the field. Pennsylvania has a long and storied industrial history. I believe there can be a bright and even longer future for manufacturing in the Commonwealth – especially if it is powered with fusion energy. Thank you and I look forward to answering your questions.

POWER OF POSSIBILITIES

Democratic Policy Committee Hearing
Powering PA: Fusion Energy
August 9, 2022

Mac Hatch, Vice President of Strategy
MetOx Technologies

Thank you, Chairman Ryan Bizzarro and Representative Emily Kinkead for organizing this hearing on commercial fusion energy and for the opportunity to testify today.

My name is Mac Hatch, and I am the Vice President of Strategy at MetOx Technologies. MetOx has been developing high temperature superconducting (HTS) wire technology for 20 years and is in the process of building their first commercial HTS wire manufacturing plant which will be commissioned in 2023. HTS wires are essential for building the high-powered magnets used by companies such as Commonwealth Fusion Systems (CFS) to build compact, commercially viable fusion devices.

Fusion has the potential to change the world by providing a sustainable source of clean energy that will provide consistent energy outputs. These energy outputs can be used in a wide range of applications including replacing carbon intensive power plants, supplying heat sources for heavy industries, and fueling propulsion systems for space travel. Unlocking fusion is critical for the energy transition and reducing global carbon emissions.

Investments in the fusion industry are also fueling ancillary industries such as HTS manufacturing. Magnetic confinement-based fusion requires mass amounts of HTS wire to be produced with methods that are scalable, drive down cost barriers, and increase quality. This need has provided the near-term demand required to transform HTS wire manufacturing from a cottage industry into a commercial enterprise. This transformation has greatly increased the quality and consistency of available HTS wire.

While fusion was a driving force behind the HTS improvements, several other applications will also benefit. A train station in France is reconductoring their power supply with HTS cables that will bring in 5-10x more power required for growing rail traffic. South Korea is using HTS cables to downsize costly substations. In Denmark, a HTS EcoSwing wind generator was developed reducing weight by 25%. In Japan, a HTS MRI machine is being developed that will significantly increase image resolution advancing medical diagnostic capabilities. These developments have all been enabled by the advancements of HTS technology.

The growing fusion supply chain will have benefits outside of the fusion industry that can help enable the energy transition and other markets. States like Pennsylvania have an opportunity to take a leading role in this transformation and benefit from the associated jobs and investments that come with it.

Thank you for having us here today and I look forward to answering any questions.

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Mac Hatch
Vice President of Strategy
MetOx Technologies

Mac has a Bachelor's degree in Engineering Management, a Master's degree in Business Administration and 8 years of experience as a consultant. Mac has worked for clients across numerous industries on performance improvement, commercial due diligence, financial modeling, and transaction execution projects. Outside of consulting, Mac also has experience working on the Strategy and Business Development team at the Weather Channel where he helped obtain funding for new business verticals and assess new markets. At MetOx, Mac supports fund raising activities, market research, and other strategic initiatives.

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WAAP-12362 August 9, 2022

Westinghouse Commercialization of Fusion Energy

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Westinghouse Fusion Vision

Westinghouse has been evaluating fusion technologies for the past 10 years. During this time the number of potential fusion options have grown along with the monetary support of industry and government. Technical advances continue to move the fusion technology closer and closer to fruition. However, there is little or no work on the technologies that need to be implemented to run the support systems to make a complete fusion power plant (Figure 1). The hurdles that separate fusion from technical feasibility and economic viability are not inherent, unsolvable issues. While daunting, they are research and development, and engineering challenges which can be overcome.

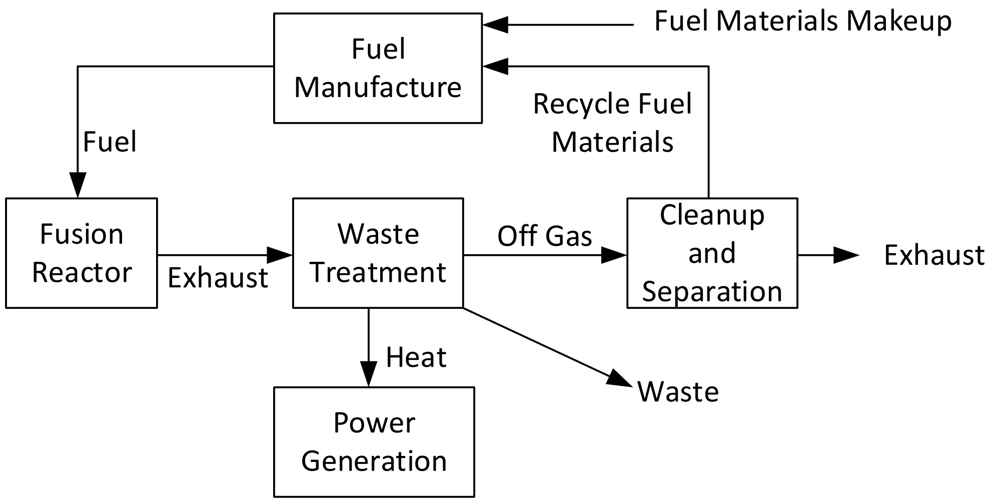


Figure 1 – Major Fusion Powerplant Systems

Fusion reactors could potentially eliminate some of the hurdles faced by fission reactors. All fusion concepts stop producing heat when fuel feeding is stopped, very much like a gas-fired burner. The only radioactive materials are tritium and the activated structural materials, thus achieving inherent safety and minimizing public impact through the elimination of residual heat generation or long-lived waste products. There are no significant proliferation issues, since there is no fissile material involved. All fusion reactor concepts would operate at temperatures that allow for co-generation opportunities.

Westinghouse Involvement in Fusion

As the premier worldwide supplier of green, fission-based power plants, fuel and services, Westinghouse is assessing fusion as a potential next-generation green energy source for electrical power generation. Westinghouse is agnostic on the type of fusion technology, so long as the fusion technology and the auxiliary systems that surround it can be operated economically, continuously and reliably to produce power.

Westinghouse does not view fusion as a competitor, but as the next step in evolving green energy production. Westinghouse has a long history of developing and implementing new technologies. Coupled with a robust background in neutronics, licensing, powerplant design, construction, servicing and operation of fission power plants, Westinghouse could utilize fusion to produce the next generation of green electrical generating plants.

ASME® 2022 ICONE 29

29th International Conference on Nuclear Engineering

Westinghouse

VIRTUAL CONFERENCE

AUGUST 8–12, 2022

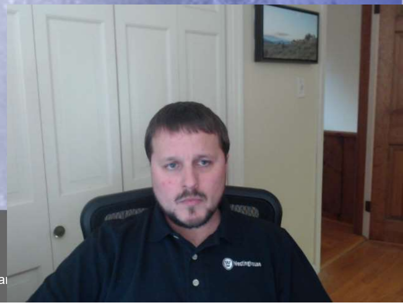
Nuclear Power in Integrated Energy Systems- a New Paradigm in How the World Produces and Uses Energy

Cory Stansbury

Principal Engineer- Global Technology Development

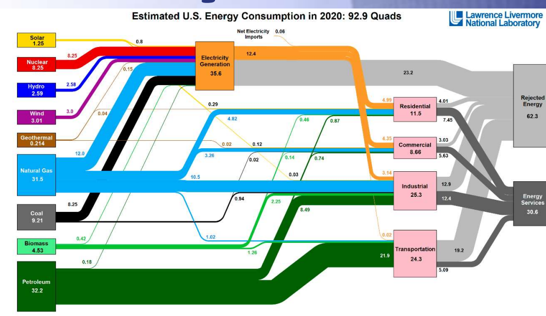
Chair of Integrated Energy Systems Expert Group with Idaho National Labs

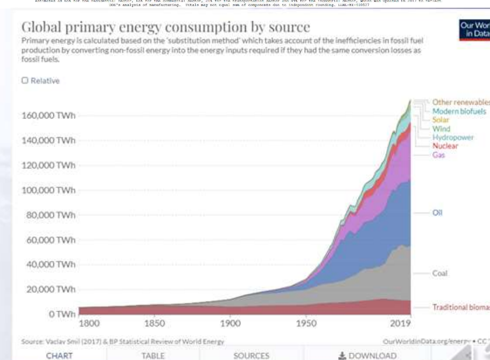
Westinghouse Electric Company LLC



Energy Use is a LOT More Than Electricity

- Electricity generation is the most significant use of input fuels
- However, it only represents ~40% of the total energy consumed
- A lot of energy is used in heating→ much of it is wasted
- The VAST majority of energy consumed is Gas, Oil, and Coal





1)https://flowcharts.llnl.gov/content/assets/images/energy/us/Energy_US_2020.png
2) https://ourworldindata.org/energy-production-consumption
3) http://insideenergy.org/2017/01/12/energy-explained/

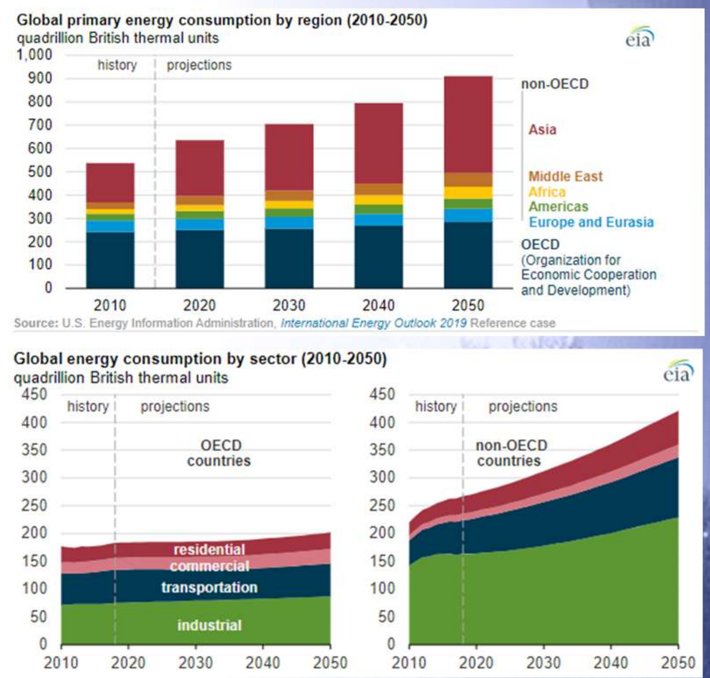
Putting Some Numbers to It → Interesting Takeaways

- Chart to the right represents ~96% of non-electrical generation in a table
  - Partially due to disparate info and likely incomplete definitions
  - Partially due to missing categories (lots of little things)
- Surprises?
  - Concrete is more energy than aircraft, refining and chemical (non-feedstock), maritime, and rail
  - Feedstock energy is nearly as significant as iron and steel production and not far off trucking
  - Freight rail is astoundingly efficient

Section	Use	Quads
Buildings	Building heating, Water Heating, Cooking	95.5
Transportation	Light Duty Vehicles	47.2
Industrial	Low and Medium Temp Process Heating	45.8
Transportation	Freight Heavy Truck	34.5
Industrial	Iron and steel	32.9
Industrial	Refining feedstock energy value	26.3
Industrial	Cement and Lime	20.4
Industrial	Refining and Chemical Industry	19.0
Transportation	Air (Commercial and Freight)	14.0
Transportation	International Maritime	12.7
Transportation	Busses, Three-wheel vehicles	11.3
Industrial	Paper	6.1
Industrial	Construction equipment / Mining	3.7
Transportation	Freight Rail	2.5
Transportation	Rail (Passenger)	0.6
Industrial	Glass	0.2
	Electric for Reference	**259**
	TOTAL	**373**

Trying to Predict the Future→ Why do we Care?

- Energy demand is going up and fossil fuels are anathema, can't we just sit back and wait for the thousands of plant orders?
- To some extent, perhaps→ a little bit of a big pie is still nice
- However, energy is changing in ways never seen
- Understanding these end use cases will prioritize the six questions; Who? What? Where? When? Why? How?



1) https://www.eia.gov/todayinenergy/detail.php?id=41433

Considerations on Future Markets

- The heart of decarbonization is electricity…but may be in the form of hydrogen
- Take your blinders off! Just because the world does things a certain way now doesn't mean they will in the future
- Electrification will win most things unless totally impractical
- Electricity and hydrogen can be produced with roughly similar efficiency, but transport and use are very different
- Don't neglect moving energy vs. producing it

Section	Use	Quads
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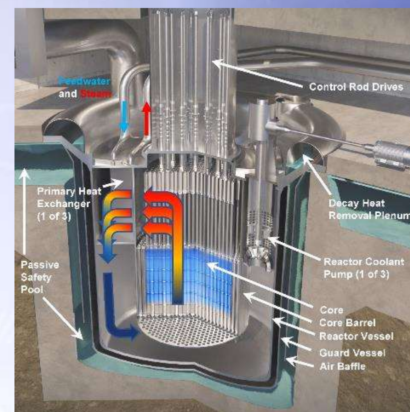
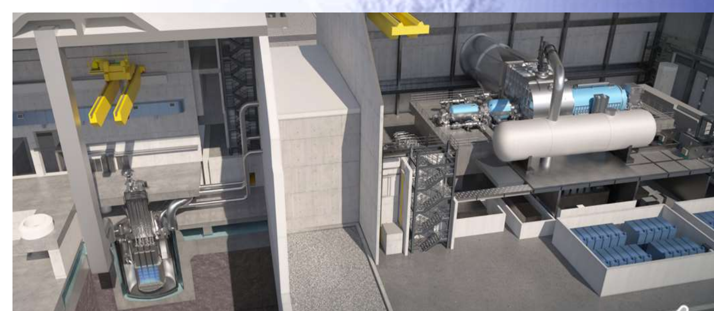
Industrial	Glass	0.2
	Electric for Reference	**259**
	TOTAL	**373**

Westinghouse Lead Fast Reactor (LFR)

Reactor power	Economic optimum: 450 MWe Net
Efficiency (Net)	~47%
Primary / secondary coolant	Liquid lead / Supercritical water
Plant design life, yrs.	60
Neutron spectrum	Fast
Ultimate heat sink	Atmosphere. No water bodies needed
Fuel type	Oxide (Phase 1); Uranium Nitride (Phase 2)
Cycle length and refueling scheme	8-15 years; direct-to-cask refueling
Operating pressure, MPa	0.1 (primary) / ~34 (secondary)
Lead coolant min/max temperature, ˚C	390 / 530 (Phase 1); 390 / 650 (Phase 2)

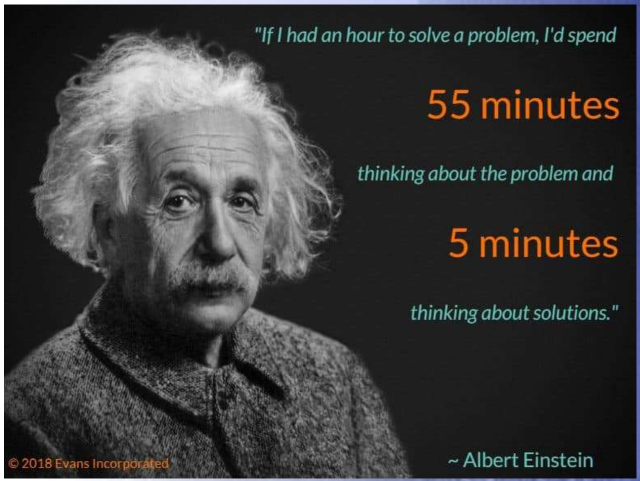


- Building unique BoP in concert w/ leading vendors and technology providers
- Air-cooled condenser by default
- Capable of integral energy storage, desalination, hydrogen production, process heat, and solar boosting with minimal hardware modification or control challenges
- Leading and participating in multiple efforts in grid modeling and optimization on next generation energy systems
- Westinghouse is a leading developer of hydrogen-integrated systems for nuclear power plants



Concluding Thoughts

- Nuclear power of all forms has nearly unlimited potential to solve the world's energy challenges in an economic, reliable, and low-impact way
- It's imperative that we be flexible and agile to the needs of markets, regulation, and unknown unknowns
- Be sensitive to assuming what was done in the past is what will be done in the future
- Try to avoid designs and market situations which add multiple high-CAPEX systems fighting over capacity factor



ASME® 2022 ICONE 29
29th International Conference on Nuclear Engineering
VIRTUAL CONFERENCE
AUGUST 8–12, 2022

Westinghouse

Lead Fast Reactor

Next Generation Utility Scale Energy Source

Overview Presentation

Cory Stansbury
Principal Engineer- Global Technology Development
Systems and Equipment Lead for Westinghouse Lead Fast Reactor

Industry Challenge

Obtaining an economical, sustainable, clean, and versatile energy source

THE CHALLENGES	THE CONTEXT
Simultaneous Economies of Scale & Affordability	Power plants, especially nuclear, have historically needed large scale & thus capital-intensive investments to reach competitive levelized generation costs.
Decarbonization beyond Electricity	Only **~40%** of energy consumed worldwide is electricity, the rest is mostly generated by fossil fuels. There will continue to be other applications that require non-electric inputs (e.g. heat).
Fuel Availability & Cost Volatility	Generation is built assuming a “fuel” source (including renewables) availability and price. When this changes dramatically, it can make a large generating asset uneconomic.
Non-dispatchable Generation	Power profile of generation sources such as wind & solar does not always match generation demand, resulting in generation curtailment and often load following by less clean & more expensive sources.
Environmental Impact	Power generation often requires large amounts of materials including rare earth and ecologically invasive production, often producing large amounts of carbon & requiring considerable uptake of water.

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Westinghouse LFR

Delivering Best-in-Class Economics in a Flexible, Robust & Easily Deployable Solution

Economical

More than

20X as power dense than most common legacy designs

- Simple, power dense and highly efficient
- Utilizes inherent lead characteristics & unique design solutions
- Produces more power from less plant volume & material
- Eliminates components with high fixed costs & simplifies non-generating components

Sustainable

Up to

60X reduction in the amount of natural uranium needed

- High temperature operation
- Efficient production of hydrogen, delivery of process heat & integrated desalination
- Fast neutron operation makes it capable of closing the fuel cycle & long fuel cycle
- Up to 60x reduction in nuclear waste. More than 8 years before refueling.

Versatile

Less than

25% the cost of Lithium ion, providing high efficiency energy storage

- Allows for non-reactor-based load follow between 300–600MW
- High round trip efficiency & a proprietary inexpensive heat storage technology
- Enables participation in a host of grid services
- Reduces the need for curtailment of renewables & meets clean peaking standards

Clean

0 requirement for large bodies of water, simple city water connection

- High Power density & low uranium requirements
- Opportunity to be among the highest EROI generation technologies
- LFR's default heat rejection is air-cooled enabling wider sitting opportunities
- Dramatically reduces the amount of water consumed

Advanced Technology

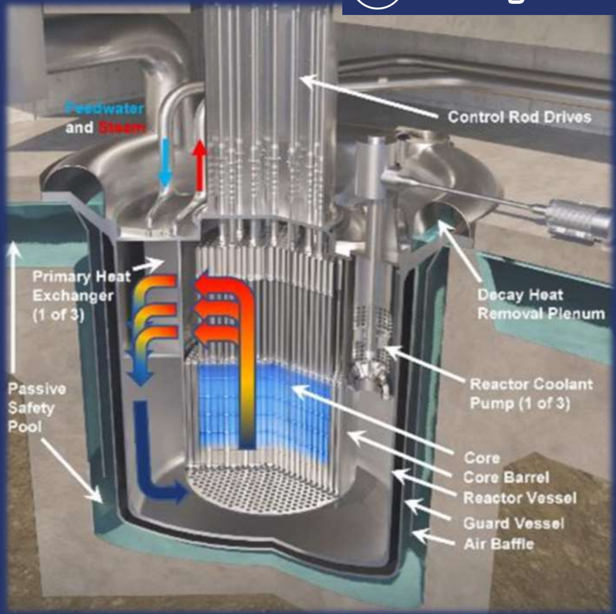
Intrinsic Lead Attributes combined with Design Innovation creates the Next Generation Energy Source

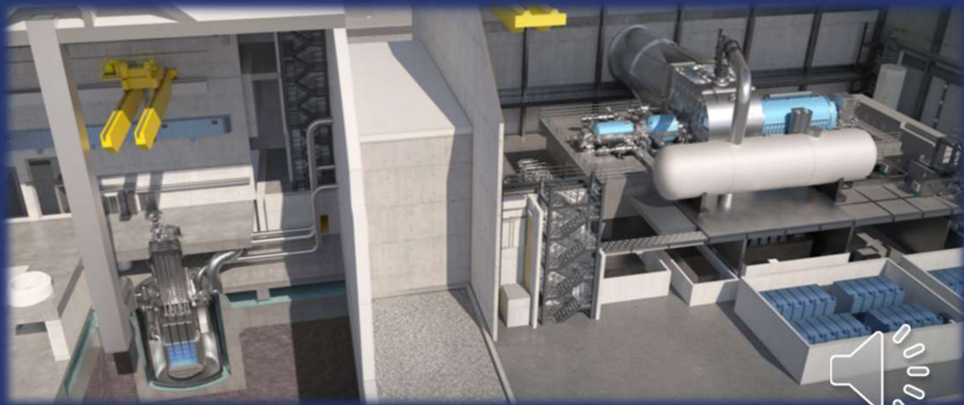
Westinghouse Lead Fast Reactor

Intrinsic Lead Characteristics	+	Westinghouse Design Innovations
Extremely high boiling point Lack of exothermic reactions Atmospheric pressure operation		Micro-channel primary heat exchanger Category B heat removal system
Barrier against radionuclides release Excellent shielding capabilities		Low power density core Direct to cask refueling
Fast reactor neutronics Excellent heat transfer properties		Energy storage system AUSC power conversion system Air-cooled condensers

Westinghouse LFR’s key characteristics

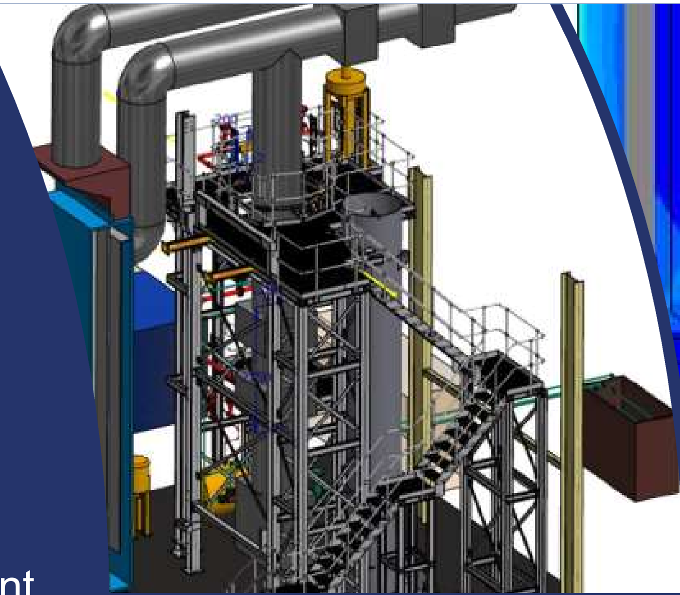
Reactor power	Economic optimum: 450 MWe Net
Efficiency (Net)	~47%
Primary / secondary coolant	Liquid lead / Supercritical water
Plant design life, yrs.	60
Neutron spectrum	Fast
Ultimate heat sink	Atmosphere. No water bodies needed
Fuel type	Oxide (Phase 1); Uranium Nitride (Phase 2)
Cycle length and refueling scheme	8-15 years; direct-to-cask refueling
Operating pressure, MPa	0.1 (primary) / ~34 (secondary)
Lead coolant min/max temperature, ˚C	390 / 530 (Phase 1); 390 / 650 (Phase 2)

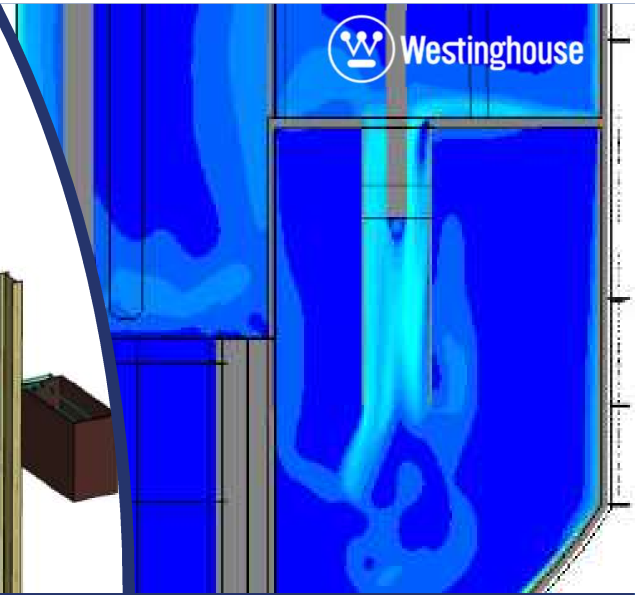




LFR development program

- The Westinghouse LFR is a global program, pursued by multiple Westinghouse offices
  - Near completion of conceptual design
  - Exp. demonstration of key enabling technologies ongoing
  - Plant's modular delivery strategy developed for representative sites
  - Synergies with Westinghouse's Accident Tolerant Fuel (i.e., uranium nitride, coated cladding) and Energy Storage programs
  - Pre-licensing meeting ongoing with UK Regulators
- **Westinghouse gives LFR technology an industry-driven economics-focused spin informed by 60+ years of expertise in NPP commercialization**





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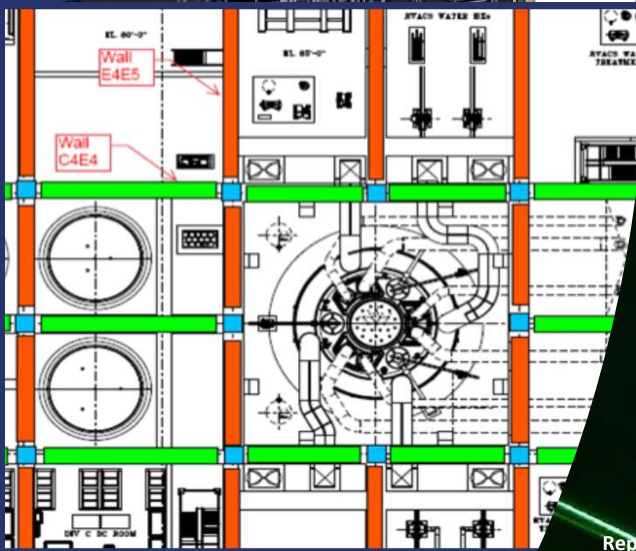
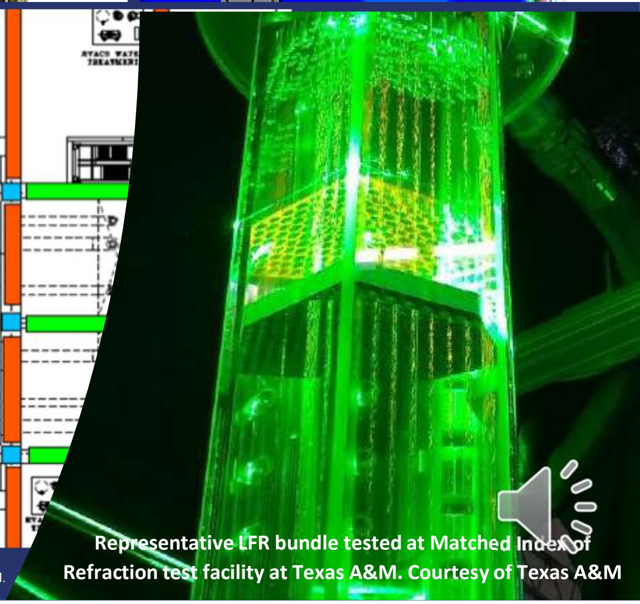




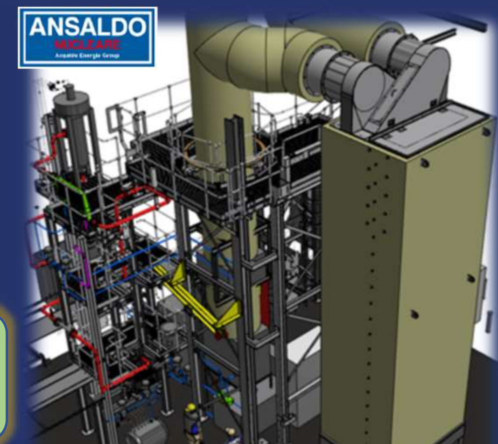
Representative LFR bundle tested at Matched Index of Refraction test facility at Texas A&M. Courtesy of Texas A&M

Westinghouse LFR Testing Program

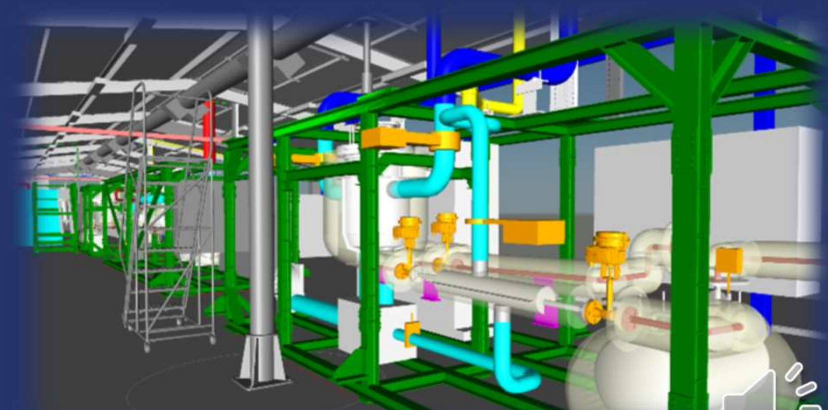
- In the UK, Westinghouse is leading a team of nine international organizations in the setup and operation of eight state-of-the-art LFR test facilities
- ~$15M program, supported by the UK Government

Lead Freezing and Under-Lead-Viewing Facility	**Westinghouse- Springfields**
Primary Heat Exchanger Failure Facility	
High-temperature Flowing Lead Corrosion Facility	
Versatile Loop Facility for component testing	**Ansaldo Nuclear - Wolverhampton**
Passive Heat Removal Facility	
High-temperature Stagnant Lead Corrosion Facility	**Jacobs - Warrington**
Materials Mechanical Property Characterization Facility	
High-Velocity flowing Lead Corrosion/Erosion Facility	**Univ. of Bangor**
Fuel development and testing	**National Nuclear Laboratory**

Start of testing: Fall 2022



Versatile Lead Loop Facility and Passive Heat Removal Facility at Ansaldo Nuclear



LFR testing building at Westinghouse-Springfields (UK)

- Ongoing/planned testing in the US:
  - **Westinghouse-Churchill**: Lead effect on materials' mechanical properties (ongoing)
  - **University of New Mexico**: corrosion testing (ongoing)
  - **University of Pittsburgh**: multi-purpose lead test rig (being installed)
  - **Virginia Tech**: measurement of radionuclides retention capability of lead (planned)
  - **MIT**: effect of irradiation on corrosion (planned)

Conclusions

- Westinghouse is continuing development of LFR as its Next Generation high-capacity nuclear power plant
- LFR's primary mission is economic competitiveness even in the most challenging global markets, combined with versatility in applications
- A significant testing program is starting in the UK, which will act as springboard toward reactor demonstration
- Collaborations are being pursued to accelerate development further

AP1000® plant operating in China

Westinghouse LFR rendering