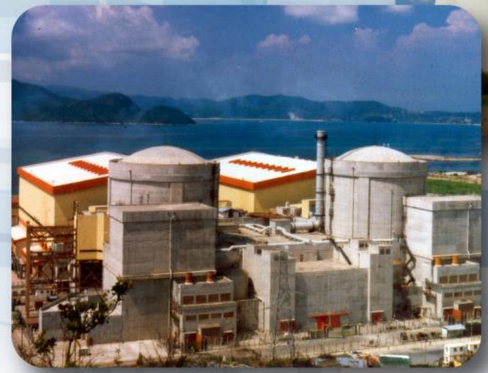
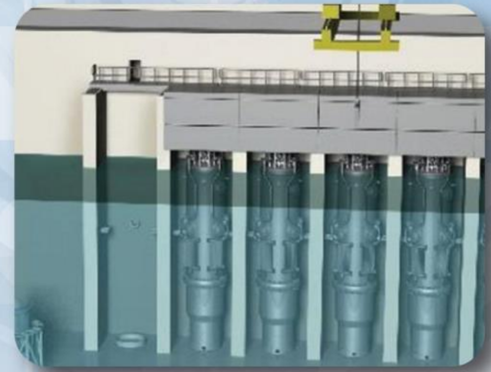
Microreactors: "not your grandparents' nuclear plants"*





John C. Wagner, Ph.D.

Associate Laboratory Director

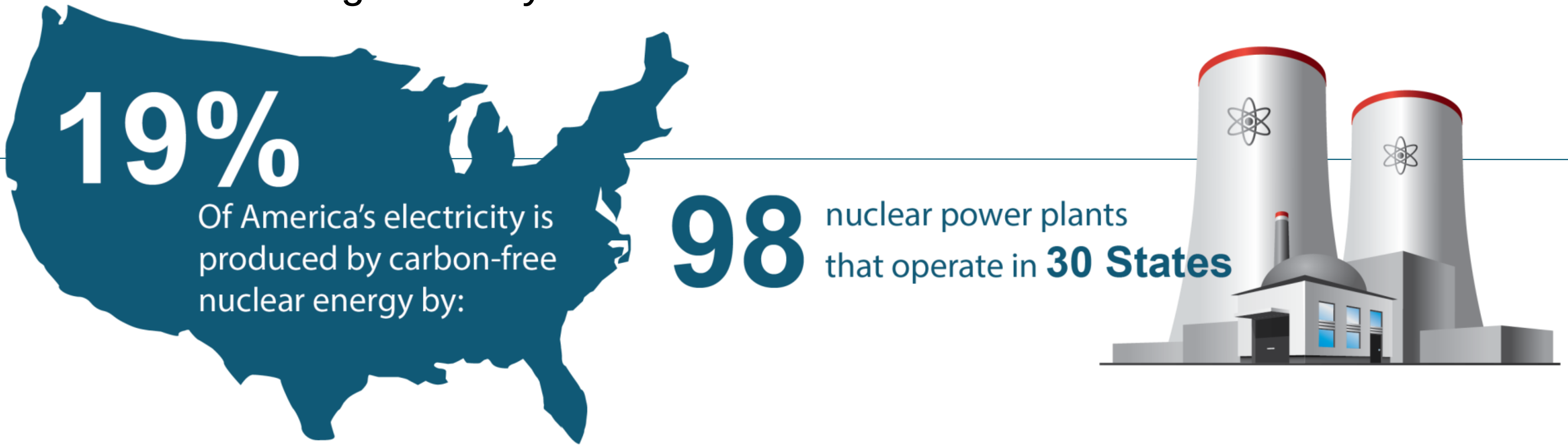
Nuclear Science & Technology Directorate

April 25, 2019

* Sen. Murkowski: An opportunity for nuclear energy in Alaska, Juneau Empire, April 19, 2019

Why nuclear energy?

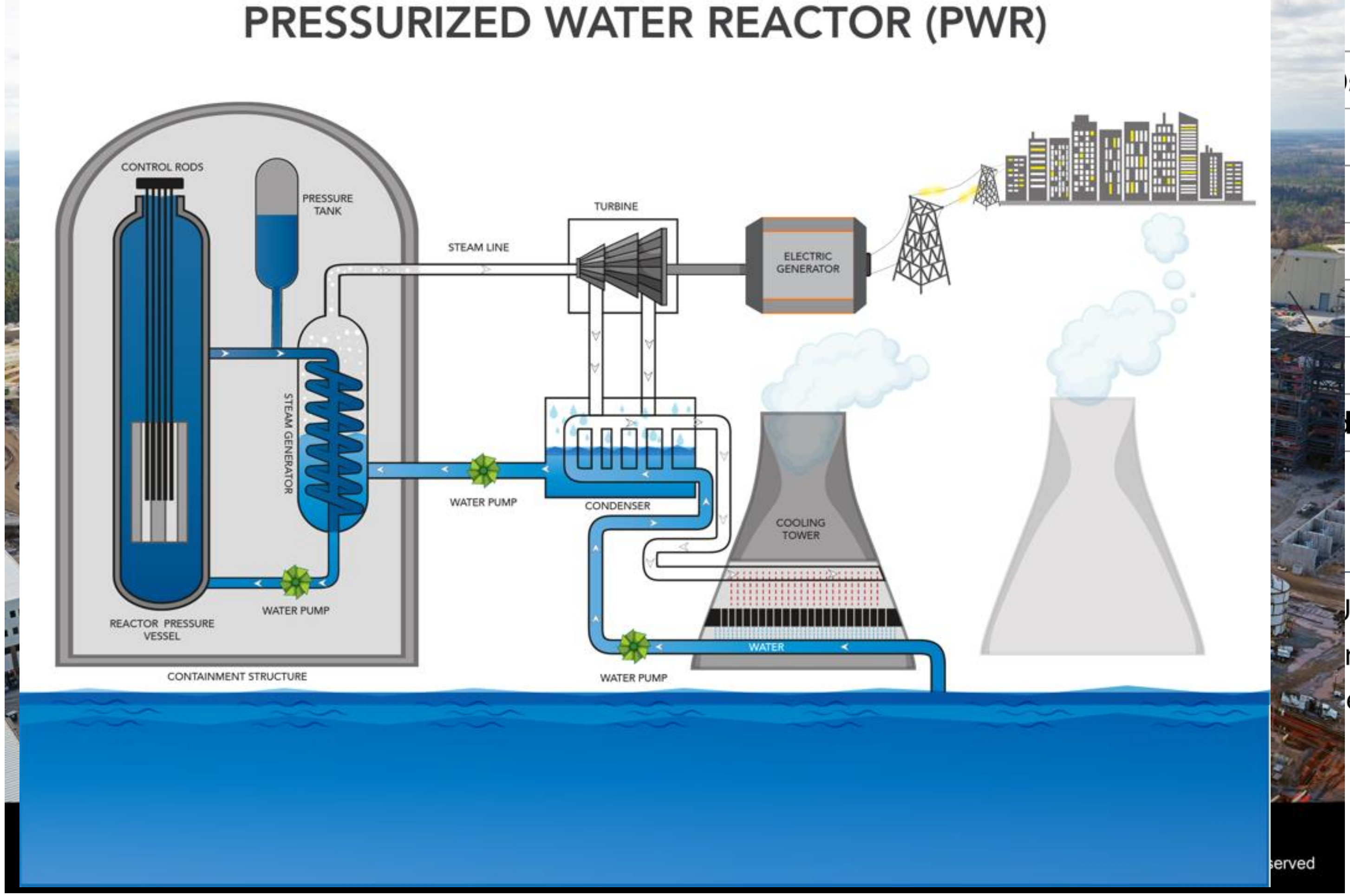
- Only carbon-free, scalable energy source that produces electricity 24-7-365
- Most reliable energy source in America – operating efficiency to 92%
- Produces, by far, America’s largest percentage of zero-carbon electricity, 56.1%
- New reactors can be:
    - “Right-sized” to location
    - Produce more than electricity
    - Designed to sync with renewable resources



One Size Does Not Fit All

Researchers at Idaho National Laboratory are collaborating with industry and academia to develop nuclear reactor concepts of various sizes for various use cases.

Existing (Large) Nuclear Reactors



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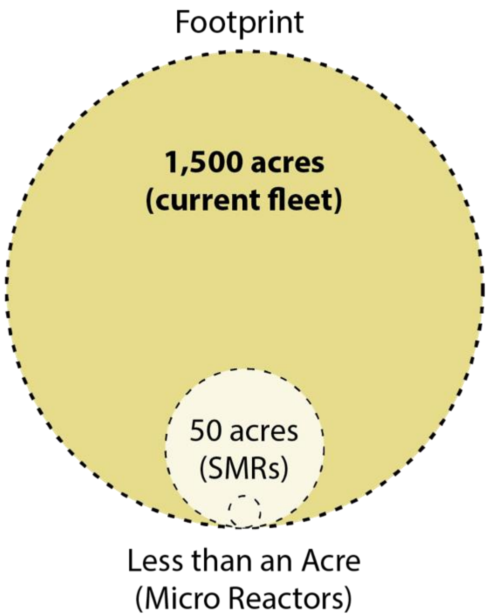
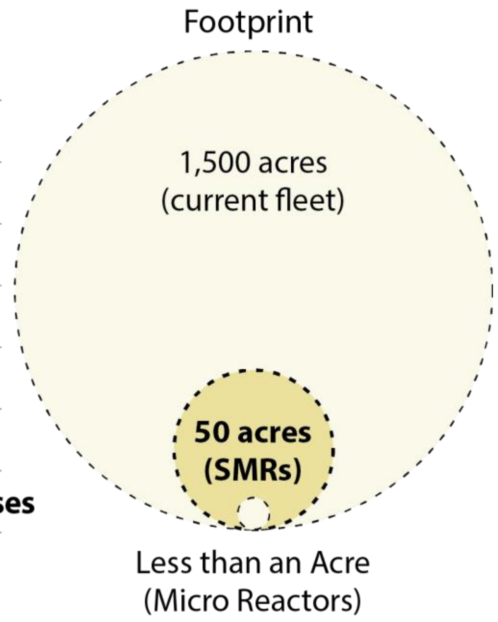


Jnion of Concerned Scientists recommended
ments adopt policies to preserve the
e current fleet of nuclear reactors provides.

Small Modular Reactors

Number in operation:	**None***
Timeframe:	**first reactors expected by 2026**
Products:	**Electricity, heat, and steam**
Megawatts:	**60-300 megawatts per module**
Customers:	**Large utilities; municipalities; industry**
Emergency zone:	**.19 miles**
Construction:	**Factory built; assembled on site**
Scalability:	**Reactor modules added as demand increases**



Applications:

Baseload electricity, industrial heat, industrial processes such as hydrogen production

**First SMR in U.S. is currently going through regulatory approval and siting process; UAMPS proposing 12-module SMR in Idaho using NuScale technology.*

Microreactors

Number in operation:	None in the
Timeframe:	first reacto
Products:	Electricity,
Megawatts:	20 megawa
Customers:	Military; mu
Emergency zone:	less than 1 a
Construction:	Factory buil
Scalability:	Reactors ad

Applications:
Power for remote locations, maritime shipping, military installations, mining, space missions, desalination, disaster relief

Sen. Lisa Murkowski, R-Alaska, April 14, 2019 Op-Ed in the Anchorage Daily News.

Improveme "microreact suggests, th communitie of providing

Holosgen^{TM} Deployment at Remote Site

Characteristics of Microreactors

Microreactors are:

- Small, easily transported sources of electricity and heat
- Fully factory built
- Easily and quickly installed and removed from site
- Self regulating, high degree of passive safety
- Reliable sources of demand-driven power
- Easier to operate and require minimal operations
- Capable of operating for several years without refueling
- Designed to serve a range of energy applications
- Distributed and integrated with other energy sources
- Non-emitting sources of power
- On track for demonstration within 3-5 years.

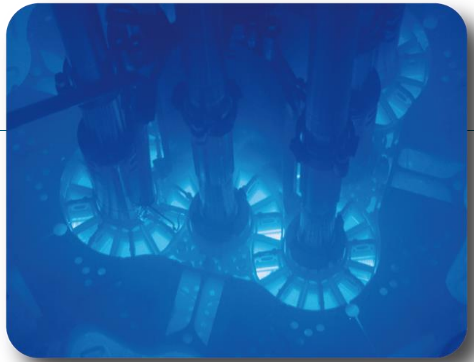
Renewed Interest in Advanced – and Small – Reactors

- Third Way identified >50 companies and developing advanced nuclear reactor designs
- Significant private sector investment, combined with private-public partnerships
- DOE, ARPA-E and GAIN providing resources through funding opportunities and voucher program
- DOE Office of Nuclear Energy programs performing R&D at National Labs to support reactor development (Microreactor, Advanced Reactor Technology, and Cross Cutting programs)
- DOD interest in microreactors

EVINCI™ Micro Reactor

Technology advances enabling microreactor development

- Continued development of advanced reactor designs based on coolants other than water.
- Advancements in heat removal technologies (heat pipes) and advanced, higher-efficiency power conversion systems *(Brayton cycle, super-critical CO^2, Stirling engines)*
- Materials with improved thermal and structural performance
- Development of advanced modeling and simulation capabilities
- Advanced manufacturing methods simplify fabrication
- Space reactor development and technology demonstration *(e.g. KRUSTY reactor)*
- Investment in infrastructure to support reactor development *(fuel fabrication, irradiation testing)*



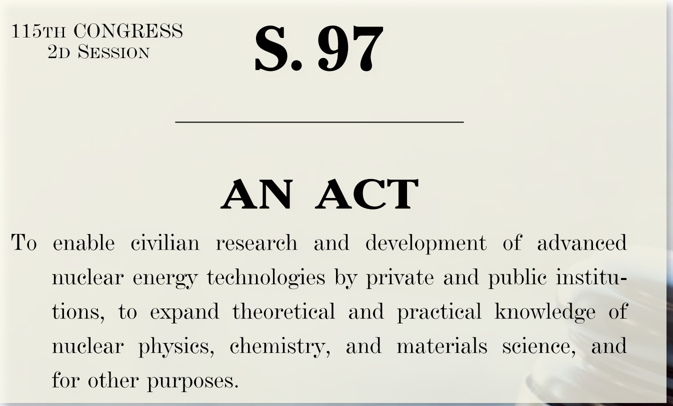
Advanced Test Reactor

The KRUSTY Experimental Assembly

Transient Reactor Test Facility

Recent Legislation Supports Microreactor Development

- Nuclear Energy Innovation Capabilities Act (NEICA)
  - Signed in to law September 2018
  - Calls for the creation of a National Reactor Innovation Center to support demonstration of cost-shared private reactors
- Nuclear Energy Leadership Act
  - Introduced in March by Senator Murkowski and others
  - Calls for demonstration of two advanced reactors by end of 2025, and 2-5 additional reactors by end of 2035
- 2019 National Defense Authorization Act
  - DOE to develop a report to Congress on requirements for a pilot program for microreactors



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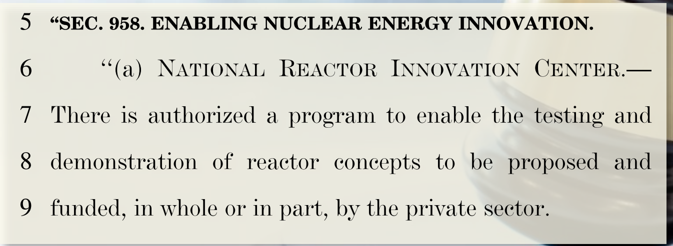
AN ACT

To enable civilian research and development of advanced nuclear energy technologies by private and public institutions, to expand theoretical and practical knowledge of nuclear physics, chemistry, and materials science, and for other purposes.

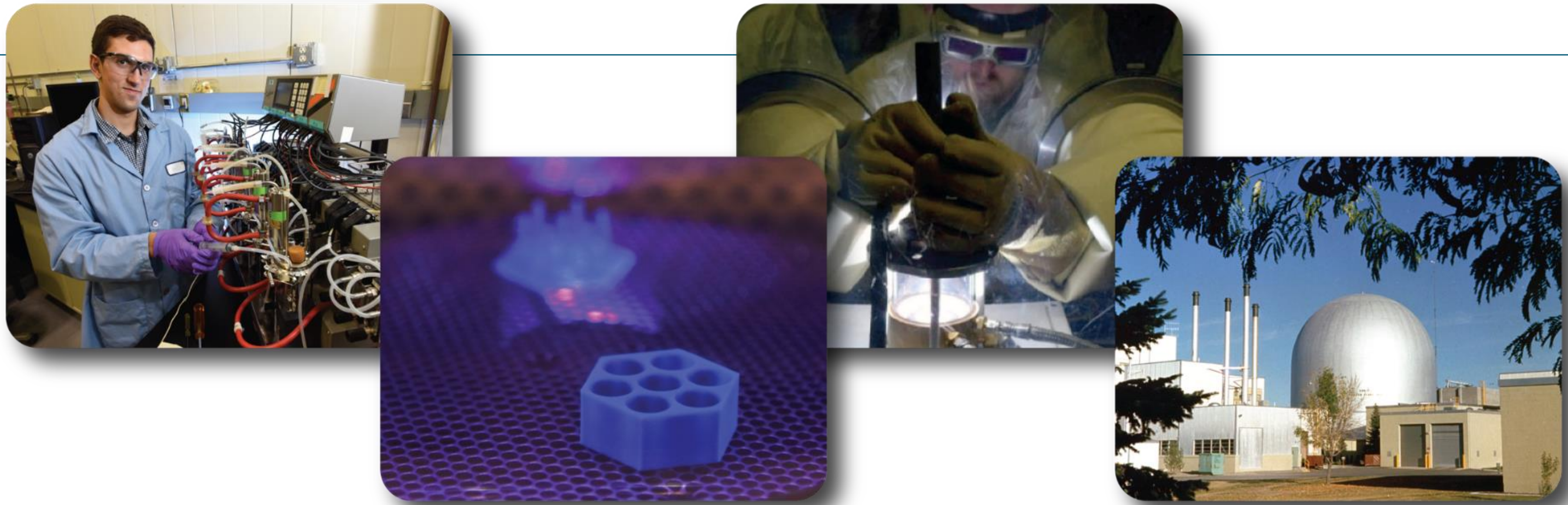


"SEC. 958. ENABLING NUCLEAR ENERGY INNOVATION.

"(a) NATIONAL REACTOR INNOVATION CENTER.—There is authorized a program to enable the testing and demonstration of reactor concepts to be proposed and funded, in whole or in part, by the private sector.

INL will support microreactor demonstrations

- Proven record of nuclear facility operations
- Existing buildings and green field sites for reactor demonstrations
- Engineering-scale fuel fabrication and advanced manufacturing capabilities
- Utility connections, integrated energy systems testing
- Adjacent world-class nuclear R&D experimental facilities and capabilities to support development
- Common site characterization, controlled emergency planning zone
- NRC-licensing and DOE-authorization for facilities as appropriate



Summary

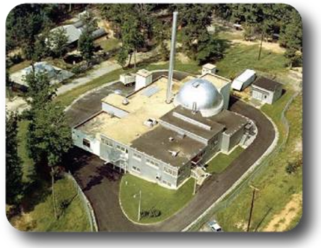
- Microreactors may offer significant advantages for some applications
- Microreactors have characteristics that enable rapid development and deployment
- Technology advancements and experience provide improved reactor designs
- A U.S. advanced reactor industry is developing several microreactor concepts
- Government is supporting development through funding and legislation
- INL is enabling developers by providing technical resources, capabilities and a demonstration site
- A demonstration is foreseen in the next 3-5 years, meaning its time to consider applications of this emerging power source

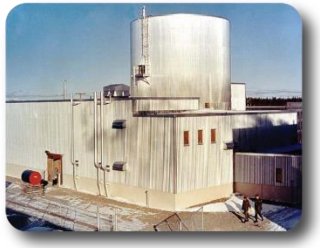
Nuclear Energy Reimagined Image courtesy of GAIN and ThirdWay

Historical Context: Army Nuclear Power Program (1954– 1977)

- **Goal:** Develop reactors for remote and isolated sites.
- Largely scaled-down version of technologies used for large reactors
- **Objectives**:
  - Reduction or elimination of dependence on fuel sources
  - Reduction or elimination of logistics necessary for conventional power plants
  - Reliable operation
  - Limited refueling and maintenance
  - Reduced crew size, with goal of unattended operation
  - Transportability, mobility, and reaction times compatible with mission or equipment supported
  - Improved cost-effectiveness
- Cost and reliability issues prevented these reactor designs from meeting Army's needs

Reactor			Operation	
Name	Type	T/E (MW)	Start	Shut
SL-1	BWR		1958	1961*
SM-1	PWR	10/1.85	1957	1973
ML-1	DGCR (N2)	3.4/0.33	1962	1966
SM-1A	PWR	20/1.6	1962	1972
PM-1	PWR	9.5/1	1962	1968
PM-2A	PWR	10/1.6	1961	1964
PM-3A	PWR	9.3/1.5	1962	1972
MH-1A	PWR	45/10	1965	1977





INL and Alaska

INL researchers are working with the village of Cordova to design a system of “self-healing” microgrids.

- Part of a $6.2M DOE-funded demonstration
- Restores power after a catastrophic event or cyberattack
- Automatically reroutes power to ensure hospitals, emergency shelters and other services if grid is damaged
- Includes switches that isolate or “island” undamaged parts of grid in emergencies
- Partners include Alaska Center for Energy and Power at the University of Alaska Fairbanks, the City of Cordova, the Alaska Village Electric Cooperative (AVEC) and the Cordova Electrical Cooperative

Idaho National Laboratory

Global Reality

28% by 2040

Projected increase in world energy use by U.S. Energy Information Administration.*

2.7 degrees by 2040

Projected increase in atmospheric temperatures if global greenhouse gas emission continue at current rate by Intergovernmental Panel on Climate Change

Nuclear Power Can Save the World
Expanding the technology is the fastest way to slash greenhouse gas emissions and decarbonize the economy.
By Joshua S. Goldstein, Staffan A. Qvist and Steven Pinker

Drs. Goldstein and Qvist are the authors of "A Bright Future: How Some Countries Have Solved Climate Change and the Rest Can Follow." Dr. Pinker is a psychology professor at Harvard.

https://www.nytimes.com/2019/04/06/opinion/sunday/climate-change-nuclear-power.html