Advanced Manufacturing Techniques – Key to SMR Deployment Around the World

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May 22, 2019 ANS San Diego Local Section Meeting

Tonight's Discussion on SMR's

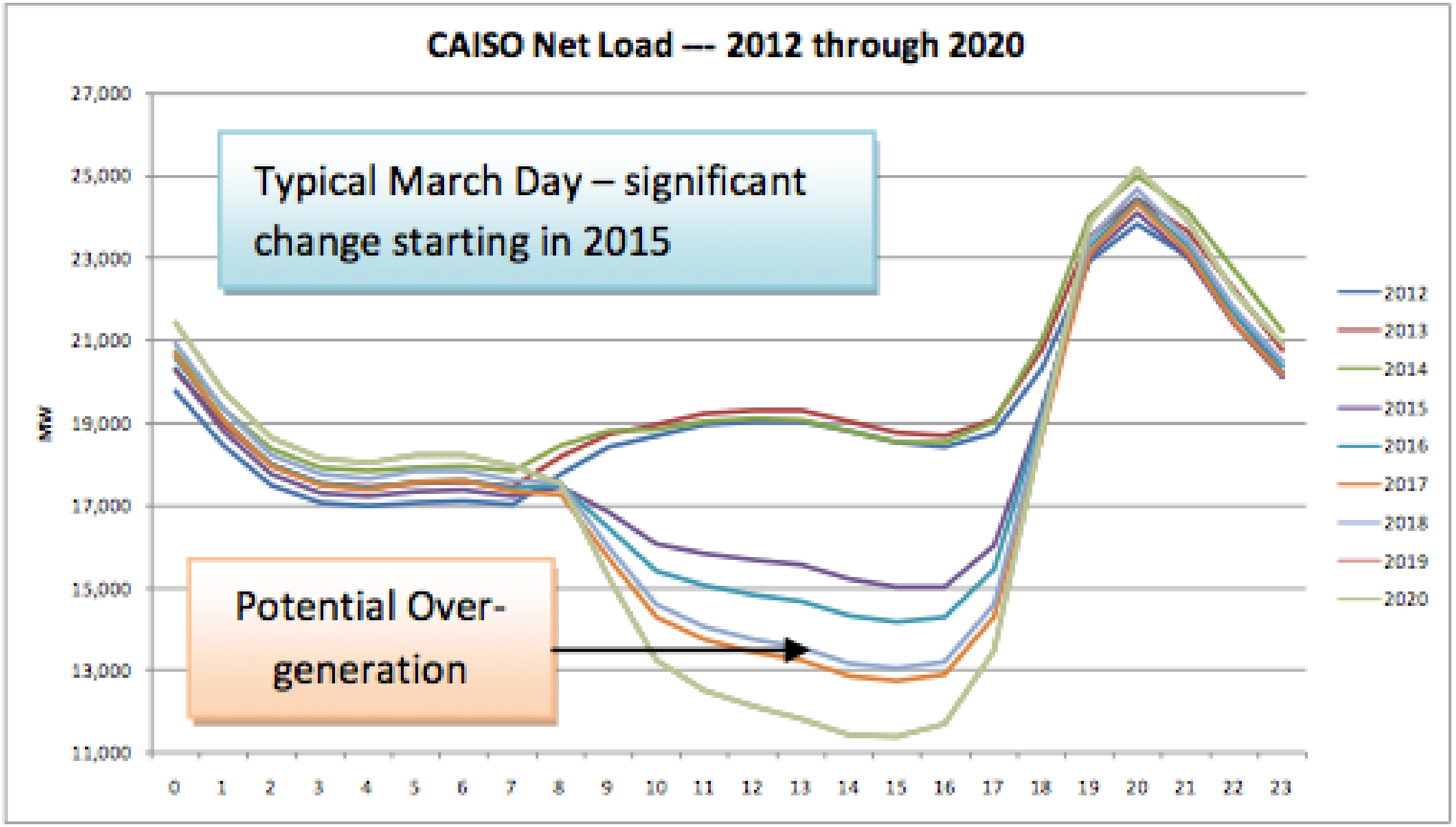
- Market Reasons for SMR
- World players in SMR
- Chinese HTR – Case Study
- American SMR – NuScale and Others
- SMR Economics
- Optimizing Manufacturing – Lessons Learned from Large Reactors and Other Industries
- Summary

Nuclear Energy: A Driving Force in the U.S. Energy Portfolio

Secretarial support:
"Nuclear energy is a critical component of America's energy future, and entrepreneurs are developing promising new technologies that could truly spur a renaissance in the United States and around the world."

Communication to the FERC on resilience pricing: "We must account for the value of on-site fuel storage capability – **for more than 90 days**. Moreover because of the long held time to secure and maintain these resources we must ensure that the technical expertise and materials are readily available."

CA Net Load Pattern Changes 2012-2020



Source: CAISO

Incentives for SMR Deployment

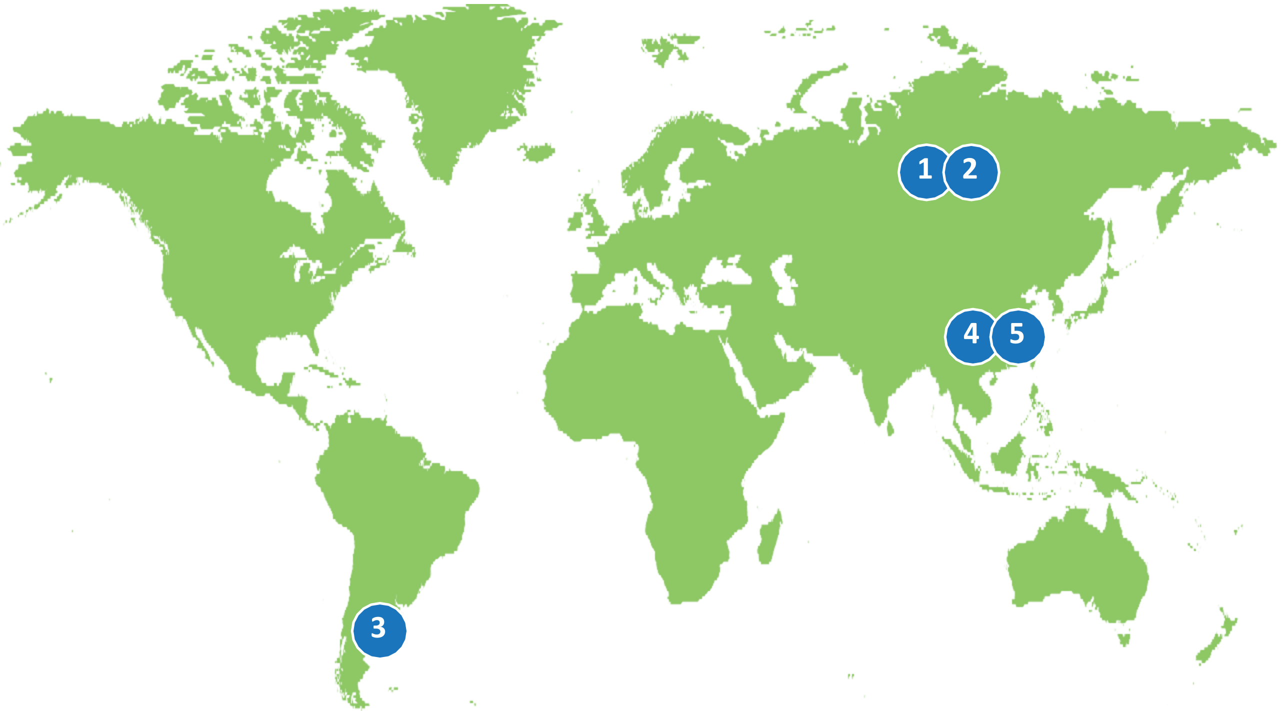
- Reduction of initial investment and associated financial risk
- Improved match to smaller electric power grids
- Effective protection of plant investment from the potential to achieve a reactor design with enhanced safety characteristics
- Possible reduction of the current 10-mile Emergency Planning Zone
- Reduction of transmission requirements and a more robust and reliable grid
- Use of components which do not require ultra-heavy forgings
- Suitability for load following, district heating and desalination

SMRs Under Construction Globally

Small reactor designs under construction

	Name	Capacity	Type	Developer
1	KLT-40S	35 MWe	PWR	OKBM, Russia
2	RITM-200	50 MWe	Integral PWR	OKBM, Russia
3	CAREM-25	27 MWe	integral PWR	CNEA & INVAP, Argentina
4	HTR-PM	2x250 MWt	HTR	INET, CNEC & Huaneng, China
5	ACPR50S	60 MWe	PWR	CGN, China

Source of info: World Nuclear Association www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx



Global SMR market value is approximately 65-86GW by 2035, valued at £250-400bn

Source www.rolls-royce.com/products-and-services/nuclear/small-modular-reactors.aspx?gclid=EAIaIQobChMIzu7s-rrD81glV1wrTCh1jXQUMEAAYASAAEgLWcfD_BwE

SMRs in Advanced Development

	Name	Capacity	Type	Developer
1	**EM-Squared**	265 MWe	HTR	GA, San Diego
2	NuScale	50 MWe	integral PWR	NuScale Power + Fluor, USA
3	SMR-160	160 MWe	PWR	Holtec, USA + SNC-Lavalin, Canada
4	ACP100	100 MWe	integral PWR	NPIC/CNNC, China
5	SMART	100 MWe	integral PWR	KAERI, South Korea
6	PRISM	311 MWe	sodium FNR	GE Hitachi, USA
7	ARC-100	100 MWe	sodium FNR	ARC, USA
8	Integral MSR	192 MWe	MSR	Terrestrial Energy, Canada
9	BREST	300 MWe	lead FNR	RDIPE, Russia
10	SVBR-100	100 MWe	lead-Bi FNR	AKME-engineering, Russia

Source of info: World Nuclear Association www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx

General Atomics EM-Squared Design

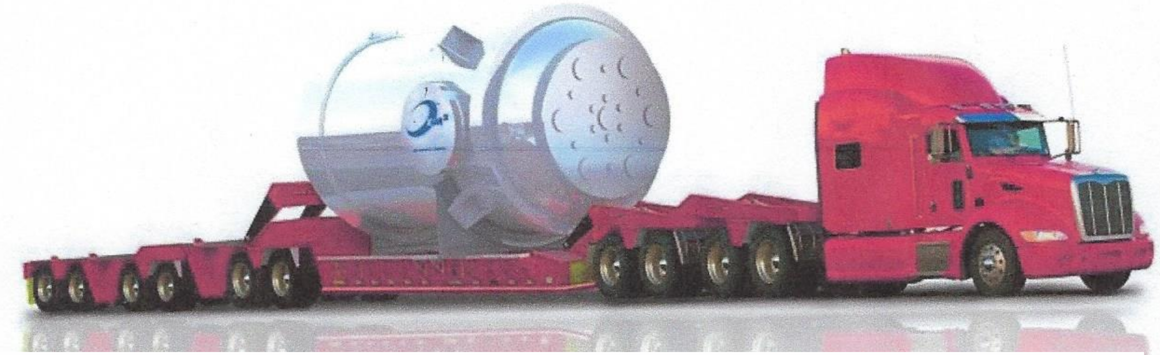
The San Diego Union-Tribune

Log In

SPECIAL SALE | 12 WEEKS FREE

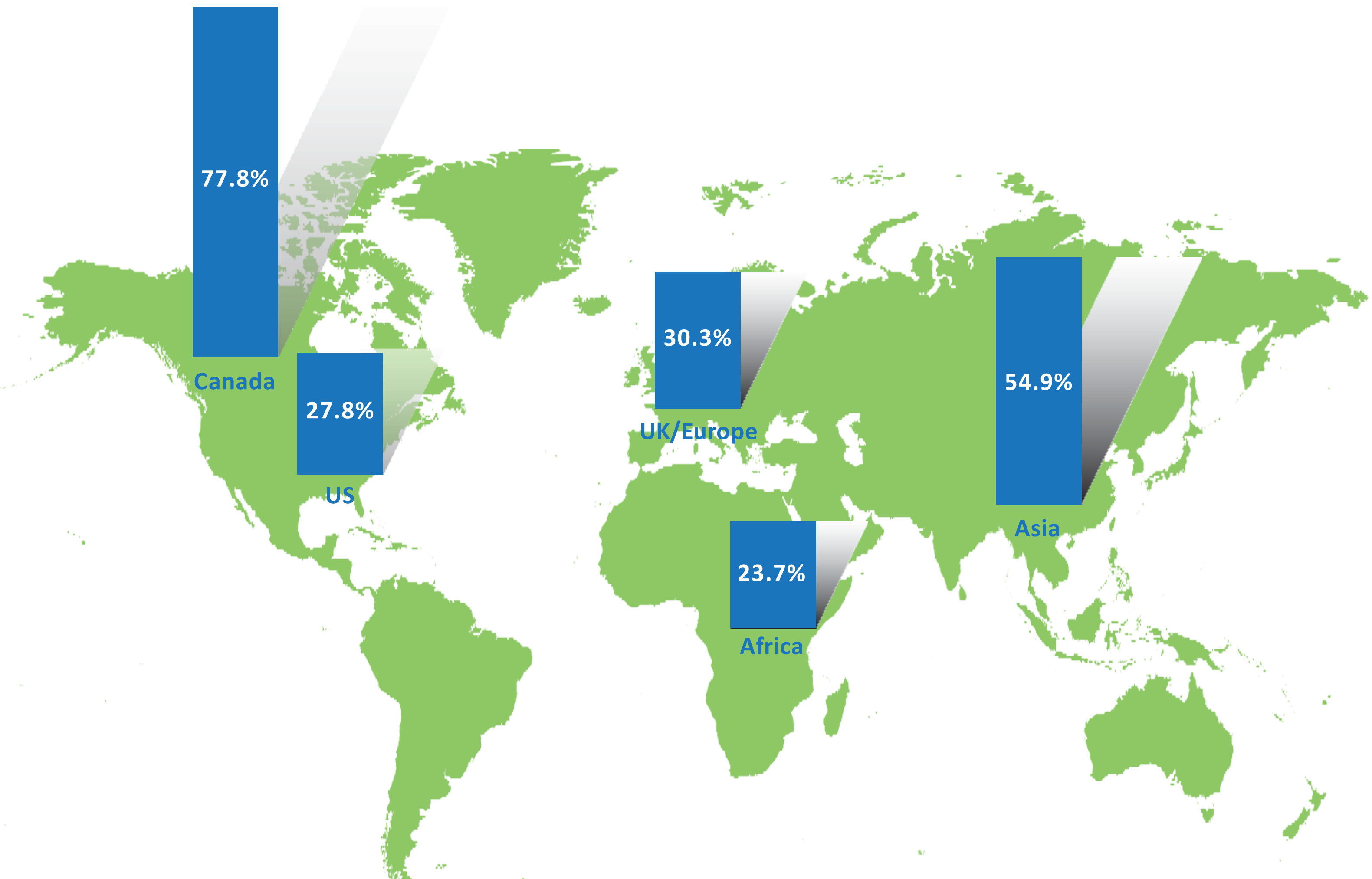
BUSINESS

Focus: For General Atomics, smaller nuclear plants are beautiful



And there are no guarantees the design will work, although Ted Quinn, a former president of the American Nuclear Society who lives in Dana Point, said of the 30 to 40 independent designs underway in the U.S. today, EM^2 is among the most promising.

Nuclear Energy Insider poll: Which markets are most attractive for SMR deployment?



Globally SMRs are being developed rapidly and are likely to reach a projected ~22 GW of installed capacity by 2035

SMR Deployment

Non-Exhaustive

Immediate

- CAREM-25, Argentina
- KLT-40S, Russia
- HTR-PM, China
- SMART, Korea

2015

Medium Term

- EM-Squared, USA
- RITM-200, Russia
- PRISM, USA
- PMBR, S.A.
- 4S, Japan
- ACP100, China
- NuScale, USA
- …

2025

Longer Term

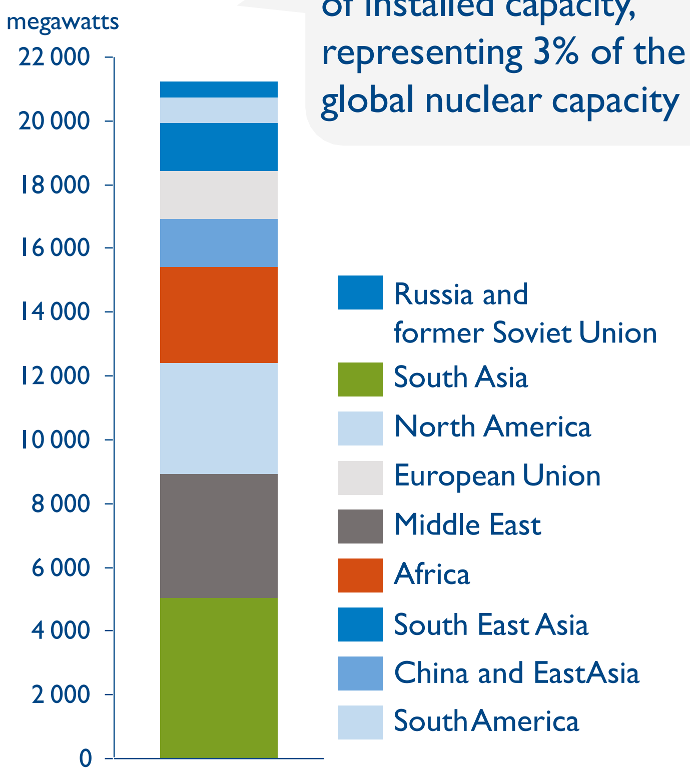
- AHWR300, India
- Flexblue, France
- IMR, Japan,
- G4M, USA
- …

2035

2050+

Estimated SMR Capacity* (2035)

Projected to be ~22 GW of installed capacity, representing 3% of the global nuclear capacity



Source: OECD, NEA, *) Best Case Scenario

However, being a pilot technology there are still several challenges that face SMRs' commercial deployment

Non-Exhaustive

Challenges facing SMR deployment

FOAK vs NOAK

To realize financial benefits SMRs require economies of scale and scalability, which will only be realized by NOAK

Electrical grid network

Electrical grid networks do not have the sufficient infrastructure to accommodate nuclear reactors

Supply Chain

Current supply chain network is geared towards large NPPs leaving SMR material difficult to source

Know-how

There is a lack of technical know-how to manage multi-module plants and meet advanced R&D requirements, current technology not fully compatible with a factory assembly model

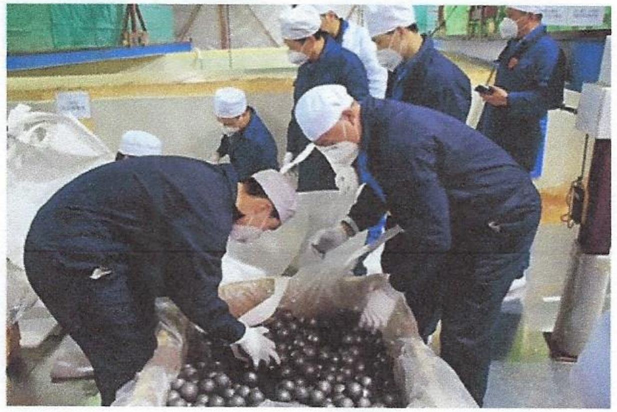
Regulation/Licensing

Lack of SMR regulations governing enhanced passive safety systems and multi-modular deployment and components result in long and onerous licensing process

Source: IAEA,

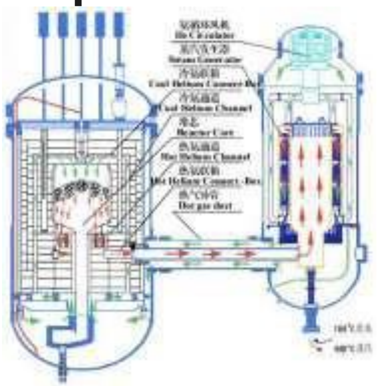
Chinese HTR-PM: a commercial NPP

- High Temperature Gas-cooled Reactor - Pebble-Bed Module
  - Total thermal power: 2*250MWth
  - Rated electrical power: 210MWe
  - Primary helium press: 7MPa
  - Temperature at inlet/outlet: 250/750℃



Workers inspect the spherical moderator elements prior to their loading (Image: CNI23)

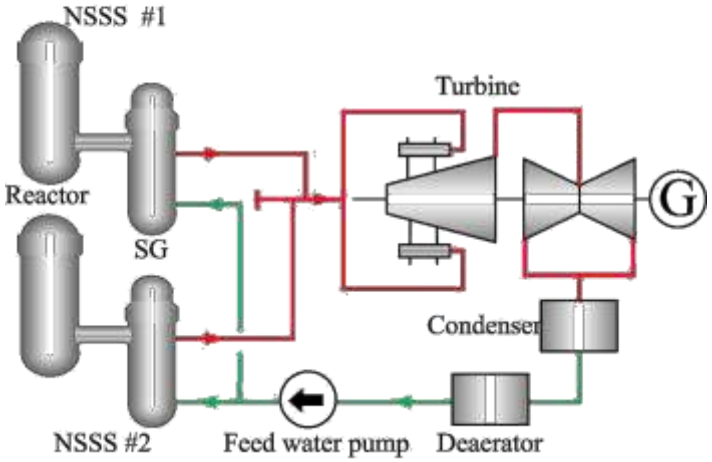
Chinese HTR-PM



HTR-10

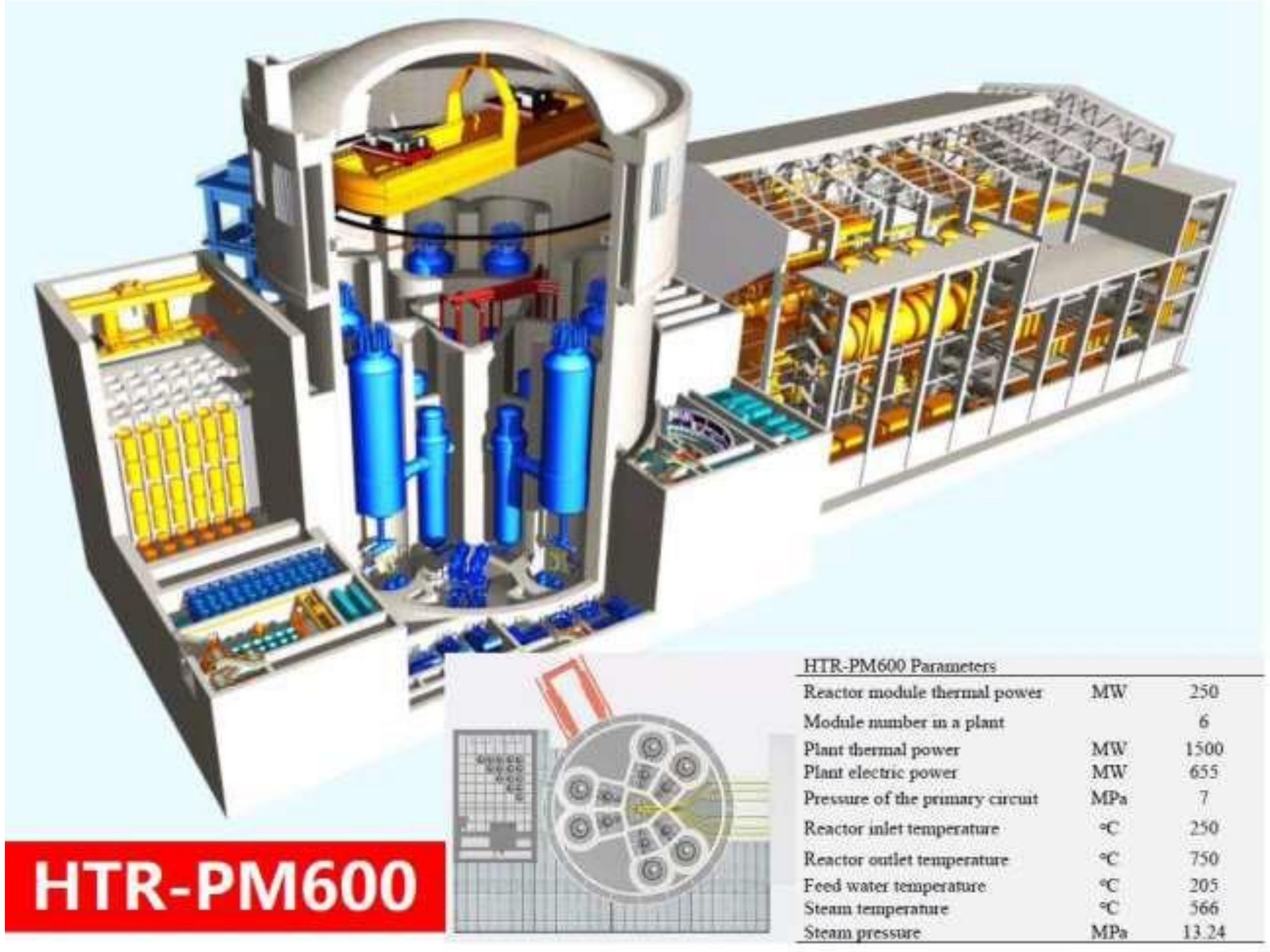
HTR-PM
(One module)

x2



HTR-PM
(Two modules drive one steam turbine)

HTR-PM600 – Next Step



HTR-PM600 Parameters		
Reactor module thermal power	MW	250
Module number in a plant		6
Plant thermal power	MW	1500
Plant electric power	MW	655
Pressure of the primary circuit	MPa	7
Reactor inlet temperature	°C	250
Reactor outlet temperature	°C	750
Feed water temperature	°C	205
Steam temperature	°C	566
Steam pressure	MPa	13.24

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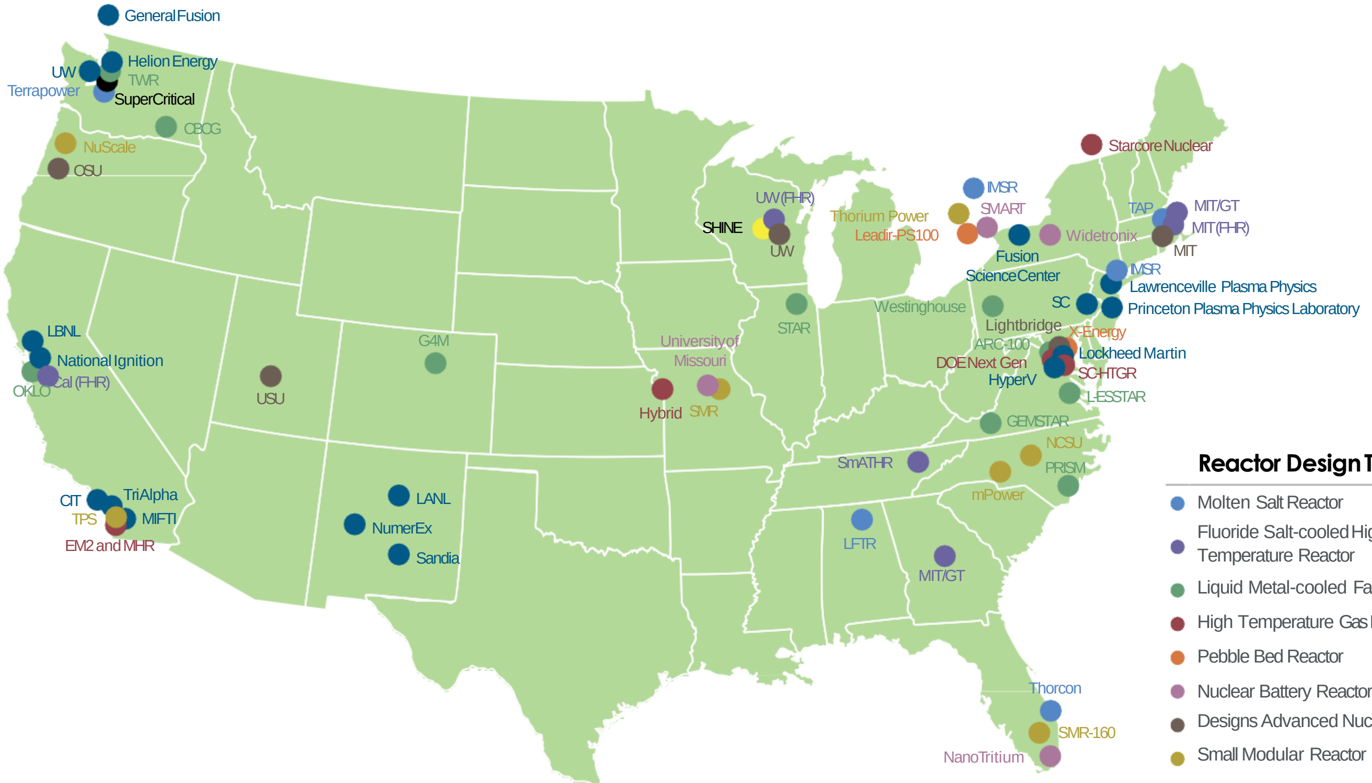
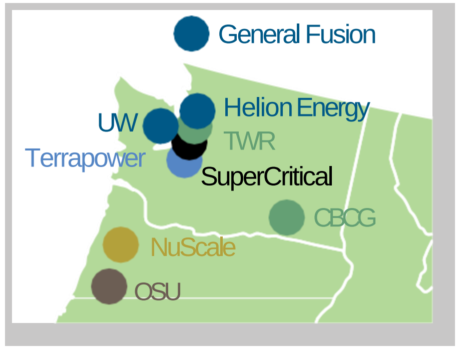
Market spotlight: USA SMR



Reactor Design Types

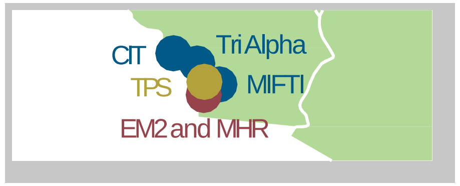
- Molten Salt Reactor
- Fluoride Salt-cooled High Temperature Reactor
- Liquid Metal-cooled Fast Reactor
- High Temperature Gas Reactor
- Pebble Bed Reactor
- Nuclear Battery Reactor
- Designs Advanced Nuclear Fuels
- Small Modular Reactor
- Fusion Reactor
- Super-Critical CO_2 Reactor
- Accelerator Driven System

Pacific Northwest

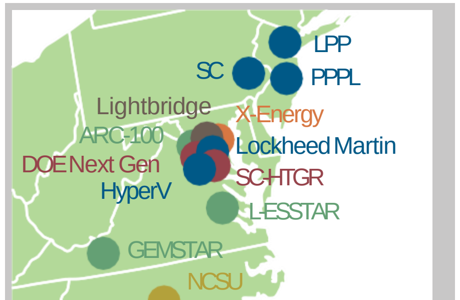


Bay Area

Southern California



Atlantic

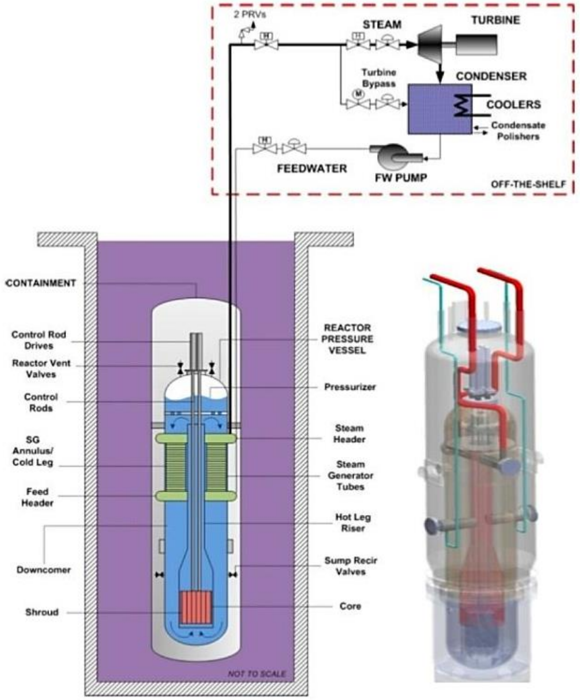


Source: Third Way www.thirdway.org/infographic/the-advanced-nuclear-industry-2016-update

TerraPower "Bill Gates" Reactor Partnered with China – now all U.S.

Small Modular Reactors – U.S.

- NuScale
  - Design Certification Application (DCA) submitted to NRC on January 12, 2017
  - NRC accepted the application and announced that there would be a 46 month review
- NuScale/UAMPS Siting
  - Site use agreement for a site on the INL reservation
  - Selected a site on INL reservation
  - NuScale and UAMPS are conducting internal business analyses to inform a Decision to Proceed for Combined License Application (COLA) activities in 2018
- TVA Siting
  - Submitted an Early Site Permit application to NRC May 12, 2016
    - NRC review has begun
- TVA is exploring technology options and plans to begin COLA development activities in 2018



Market Spotlight: USA

NuScale Power

Designer: NuScale

Output: 50 MWe

Type: integral PWR

Partner: Fluor

August 2015: DOE Awards NuScale with $16.7 million award to prepare a combined construction and operating license application (COLA)

February 2016: US Dept. of Energy issued a Site Use Permit to UAMPS CFPP granting it access to the INL site to identify potential locations for the NuScale Power Plant

August 2016: NuScale Power announces campaign to select fabrication partners

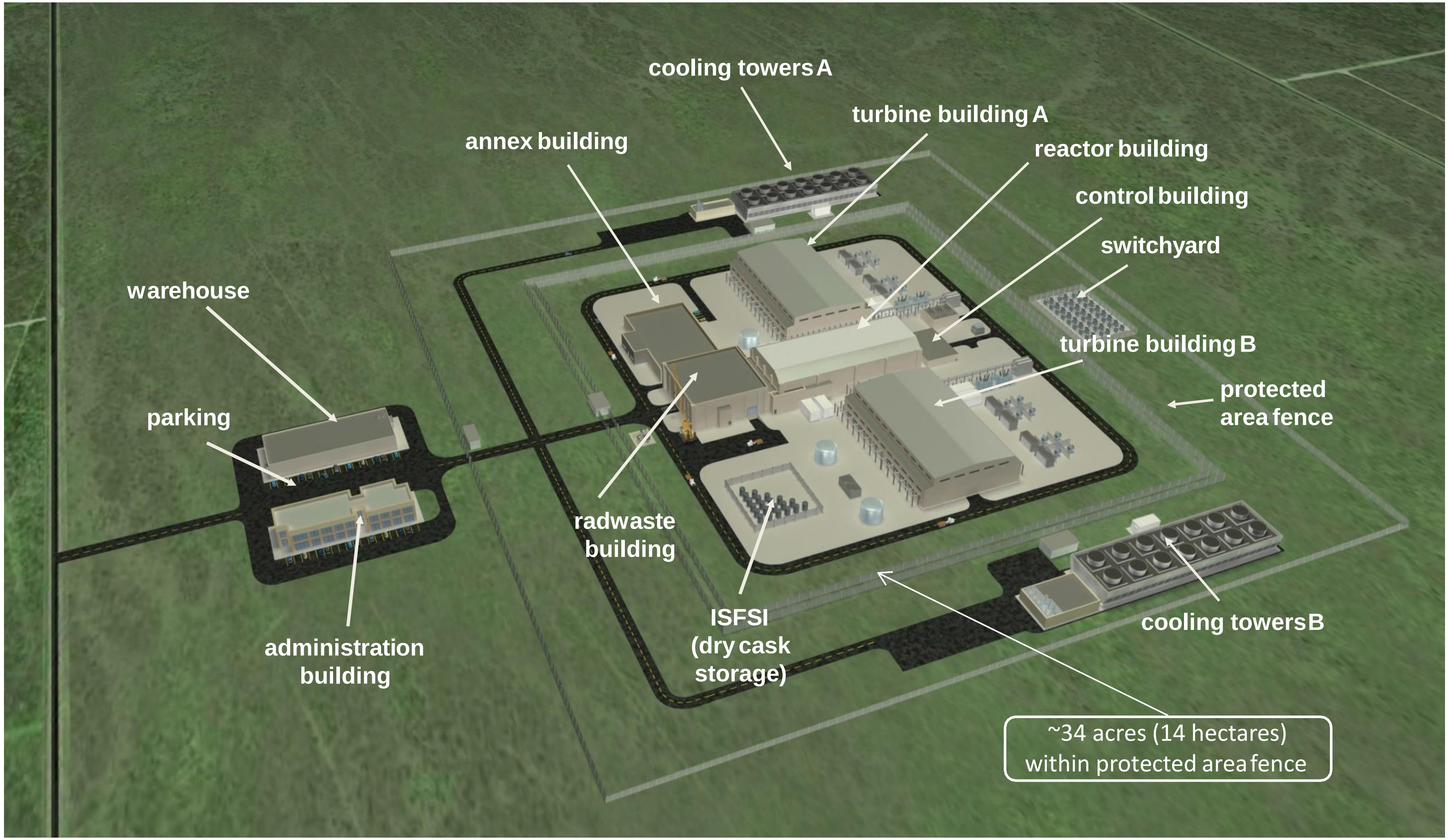
December 2016: NuScale asks the US Nuclear Regulatory Commission to approve the company's SMR commercial power plant design

February 2017: NuScale and UK-based Ultra Electronics, Nuclear Control Systems, successfully conducted the acceptance testing of the module protection system to be used by NuScale

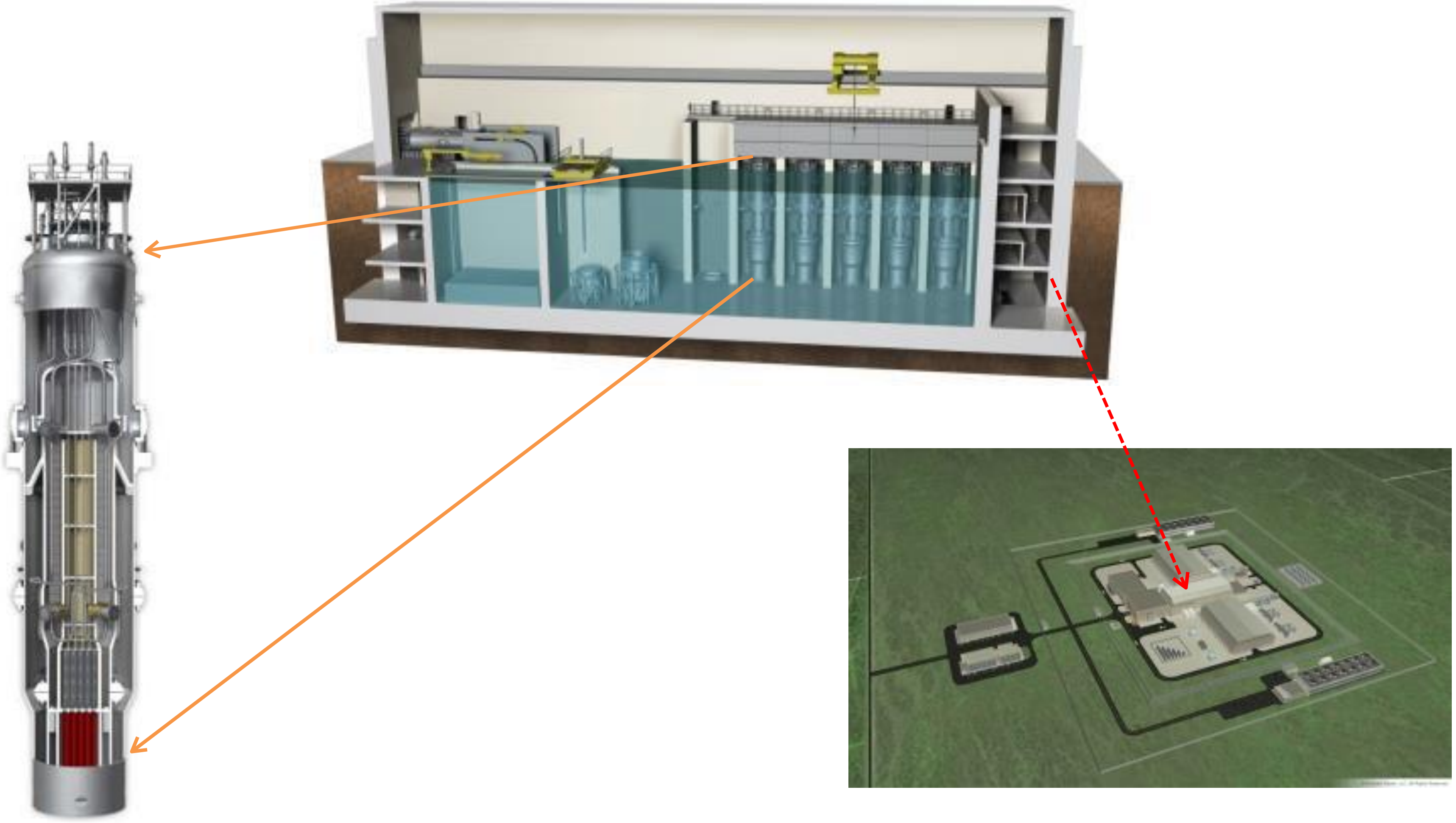
September 2017: NuScale sets out five-point UK SMR action plan to achieve 2020s deployment

Source: NuScale Power www.nuscalepower.com/about-us/history

NuScale Power Plant Layout

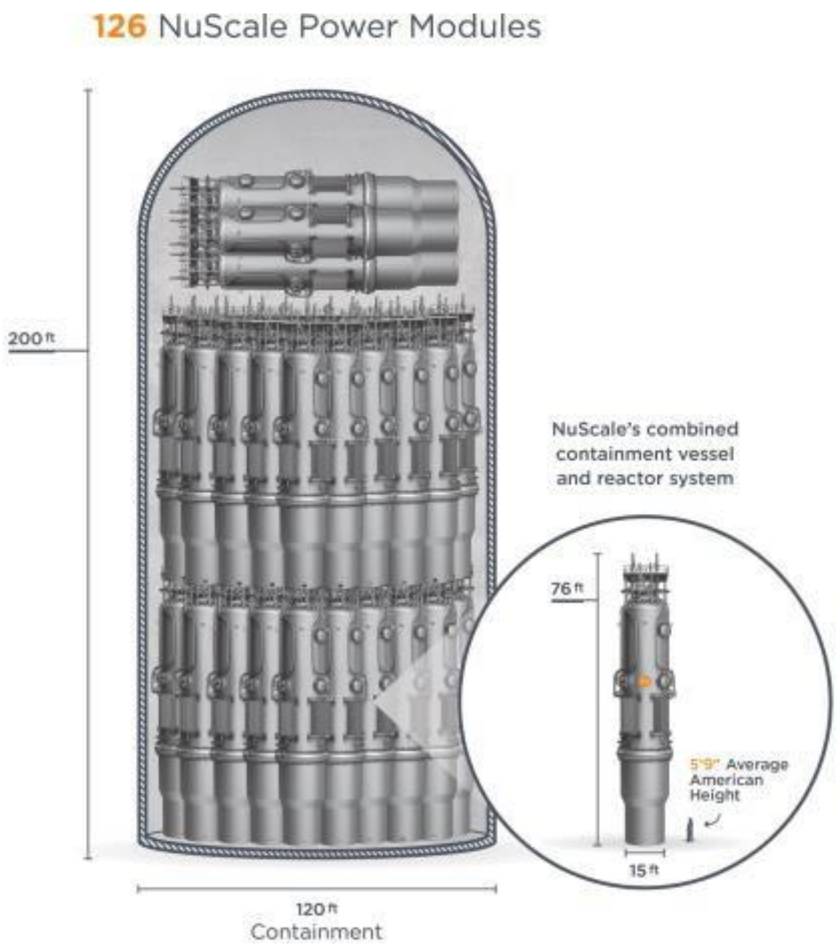


NuScale Power Plant - Overview

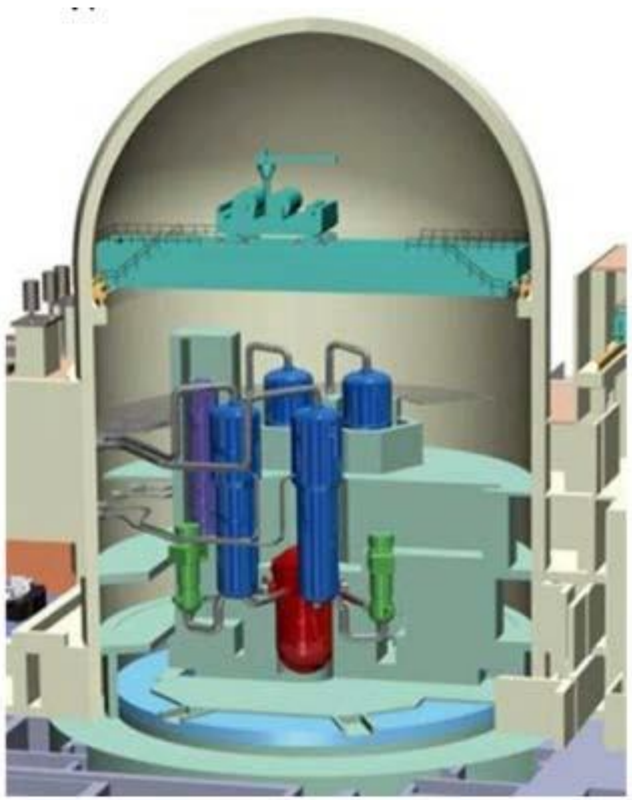


Size Comparison

Comparison size envelope of new nuclear plants currently under construction in the United States.



Typical Pressurized Water Reactor

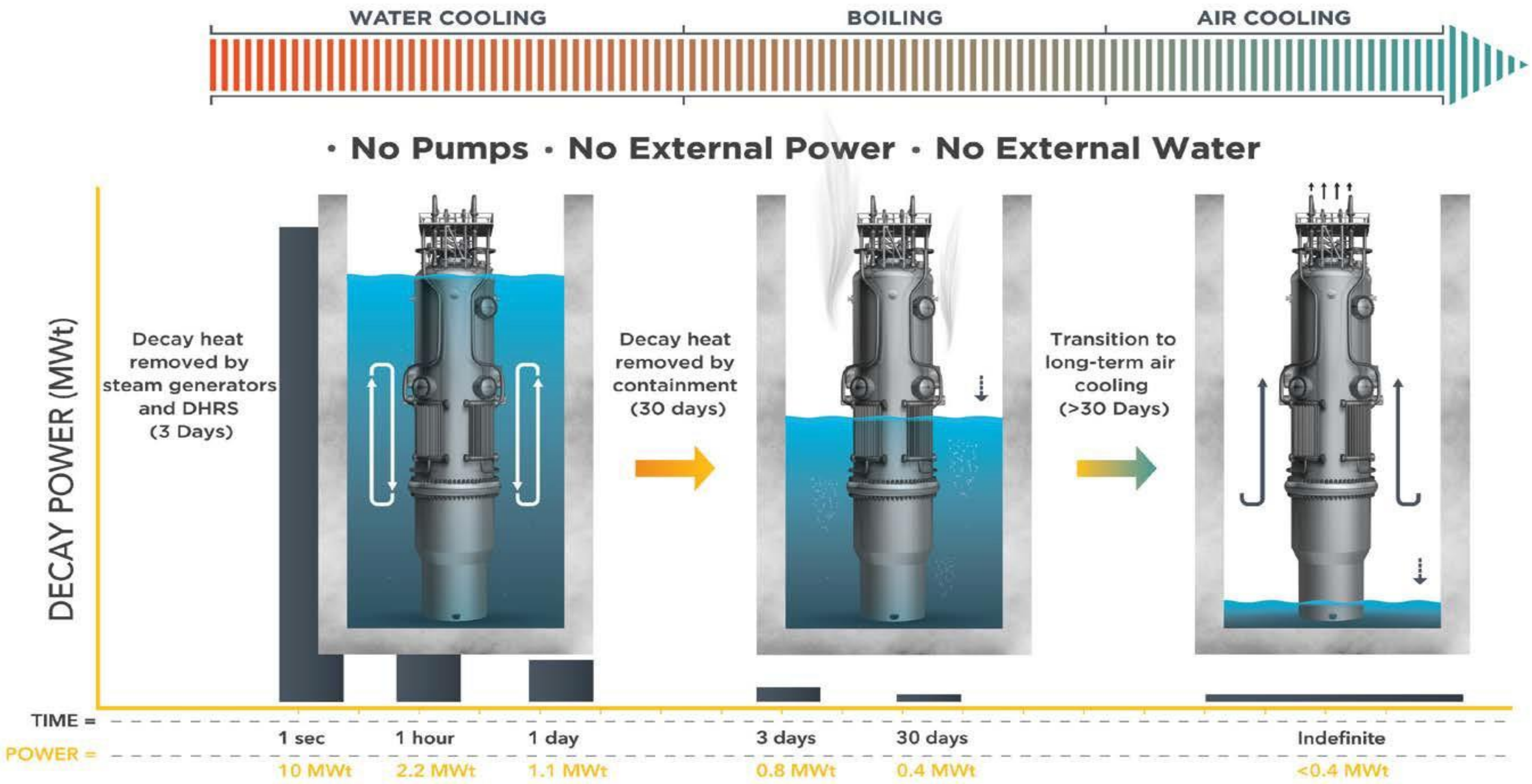


*Source: NRC

*Source: U.S. NRC

Innovative Advancements to Reactor Safety

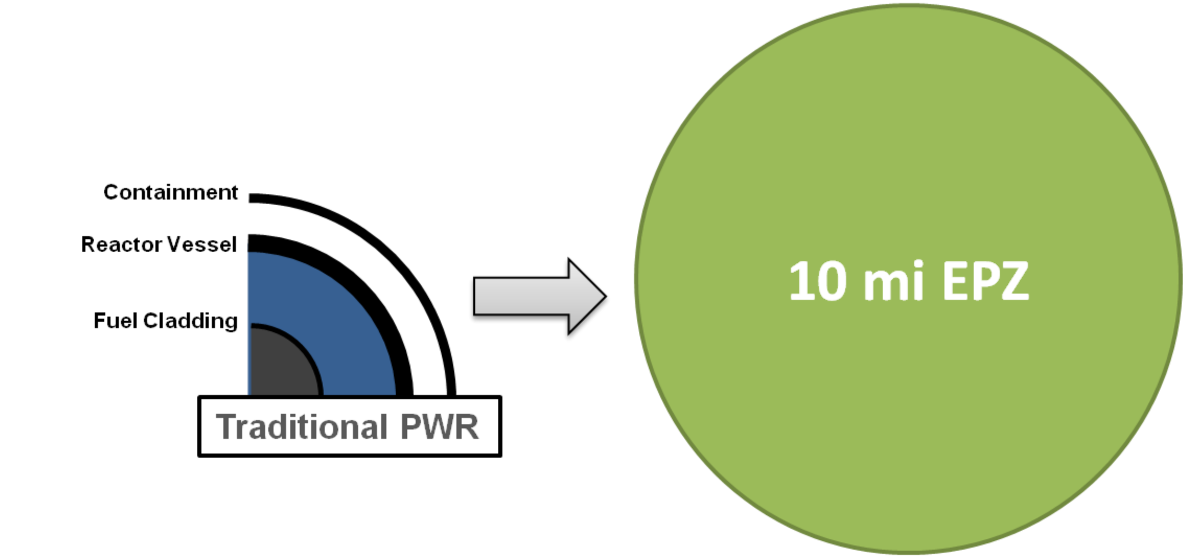
*Nuclear fuel cooled indefinitely without AC or DC power**



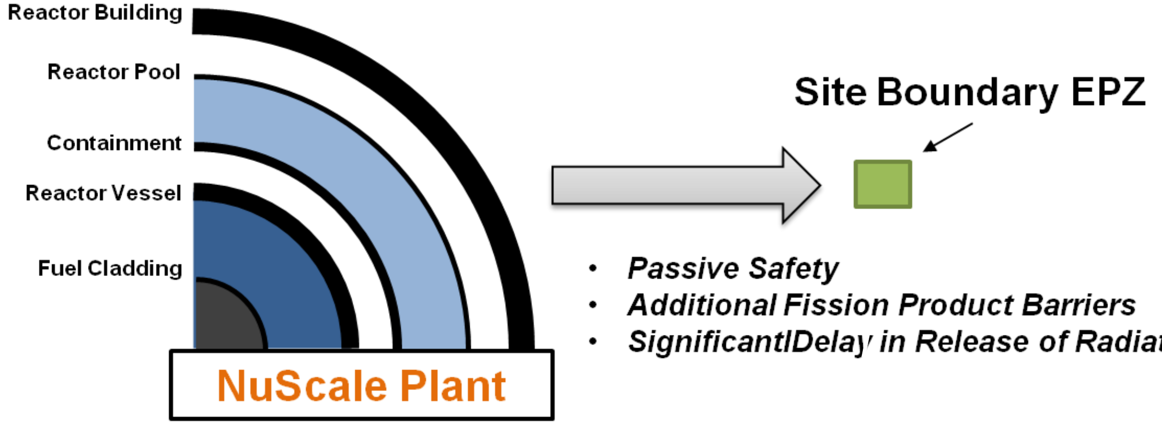
- ***30 days is a minimum based on very conservative estimates.***

****Alternate 1E power system design eliminates the need for 1E qualified batteries to perform ESFAS protective functions – Patent Pending***

Strong Safety Case - Smaller EPZ



The licensee must have pre-determined protective action plans in place for a large publicly accessible area.

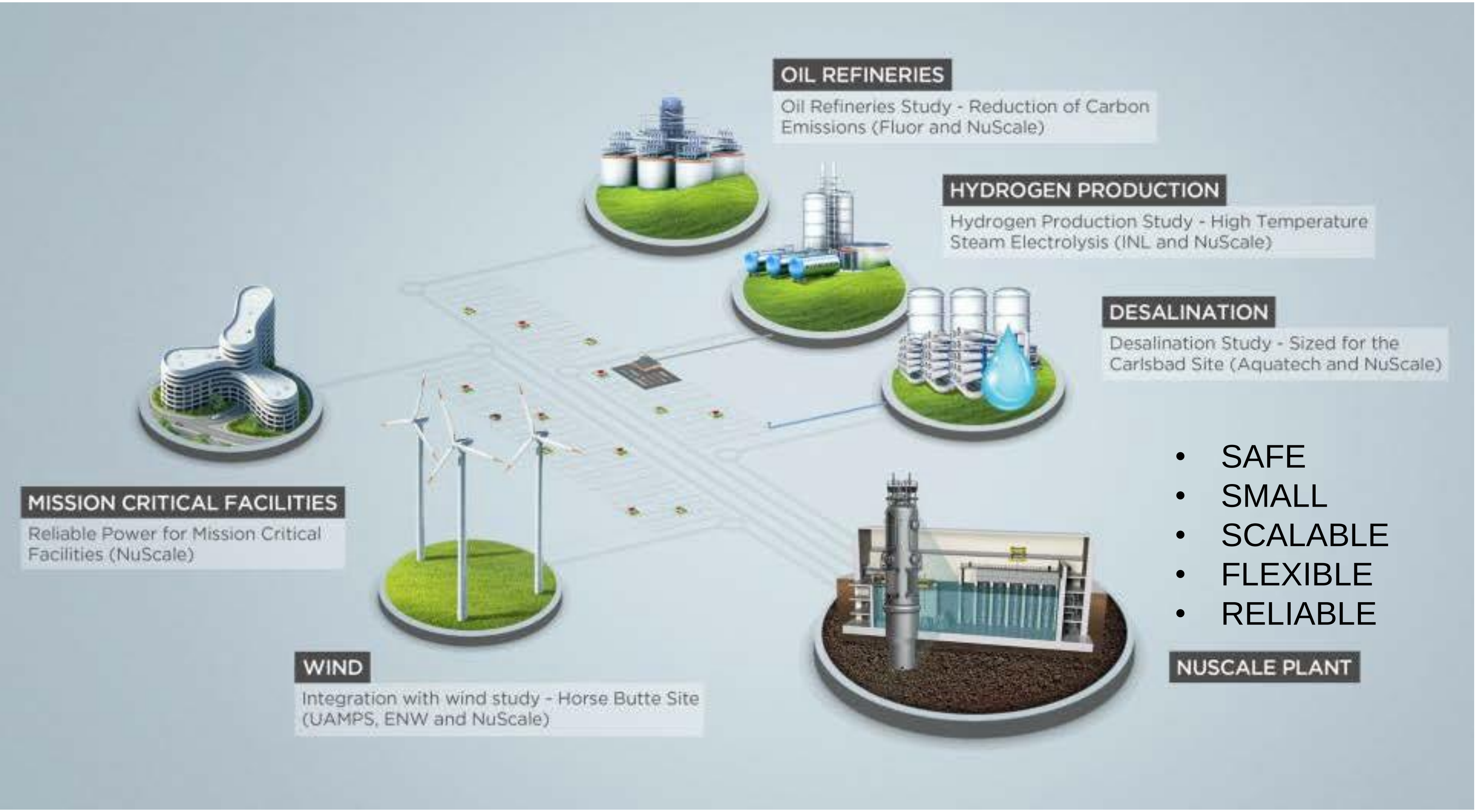


- ***Passive Safety***
- ***Additional Fission Product Barriers***
- ***Significant Delay in Release of Radiation***

Virtually no publicly accessible area is subject to protective action planning by the licensee.

NuScale Control Room Simulator

NuScale Diverse Energy Platform (NuDEP) Initiative



- SAFE
- SMALL
- SCALABLE
- FLEXIBLE
- RELIABLE

Economics – Front and Center

- Simplicity of design provides competitive levelized cost of electricity compared to other low carbon options.
  - Lower up-front cost and lower operating cost as compared to large light-water nuclear reactors
    - Competitive overnight capital cost compared to large advanced nuclear
    - First plant target LCOE - $65/MWh
- Up to 12 modules can be added to a facility incrementally, in response to load growth, reducing initial capital costs
- First module in situ can generate and bring in revenue immediately
- NuScale Power Modules fabricated in an off site facility, bringing cost savings associated with repetitive manufacture
  - Realize benefits of factory fabrication

Construction Cost Summary (U.S.)

Overall EPC Overnight Plant Costs For First Plant ($1,000,000)

ITEM	2014 Dollars
Power Modules (FOAK Cost plus Fee, Transportation, & Site Assembly)	$ 848
Home Office Engineering and Support	$ 144
Site Infrastructure	$ 60
Nuclear Island (RXB, RWB, MCR)	$ 538
Turbine Island (2 buildings with 6 turbines each)	$ 350
Balance of Plant (annex, cooling towers, etc)	$ 225
Distributables (Temp. Bldgs., Field Staff, Const. Equip., etc.)	$ 545
Other Costs	$ 185
Total Overnight Price	**$ 2,895**

$ 5,078 per kWe net

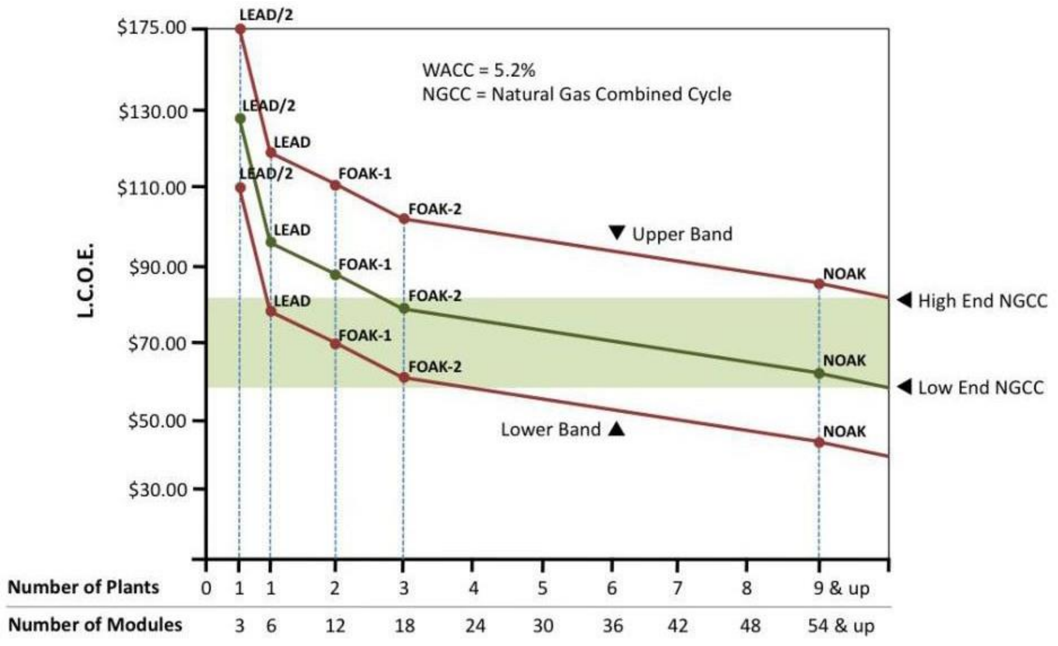
Note: NuScale website's latest estimate with uprated 60MWe modules is $3B for 12 module 684MWe net output with 54 month mobilization and 32 month critical path to commercial operation. ($4,385/kw)

The electricity cost of SMR is expected to drop drastically driven by the learning achieved from repetitive construction and standardization of designs

Costs Evolution of SMR and Natural Gas Plants

Case Study

Expected Cost of SMR and NGCC After Several Constructions



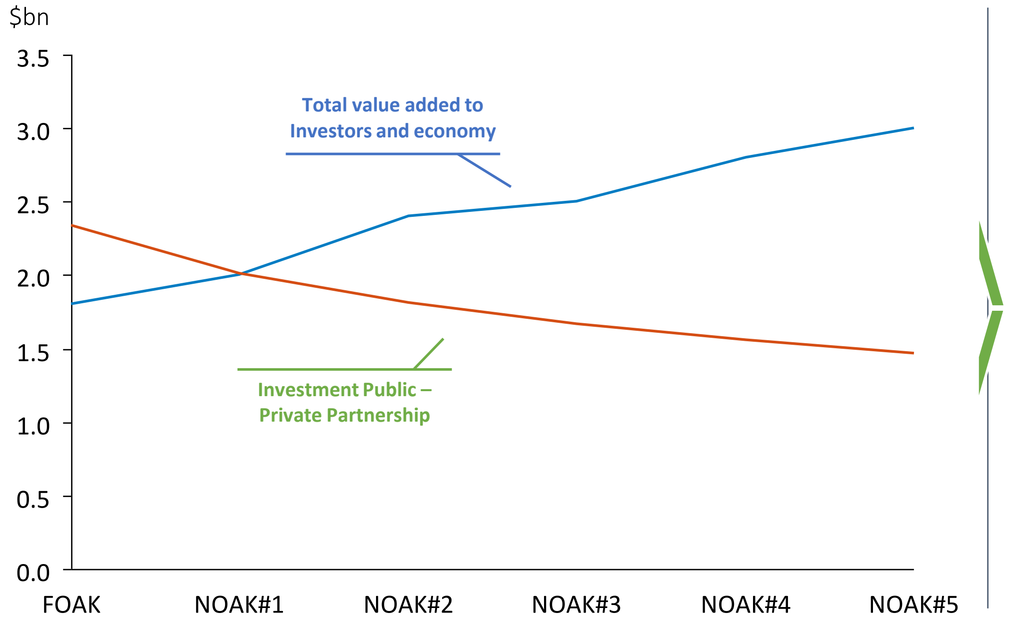
Source: Small Modular Reactors – *Key to Future Nuclear Power Generation in the U.S*

Comments

- The learning process will drive down costs through repetitive construction and manufacturing of standardized designs
- The upper and lower bound for prices reflect the uncertainties about learning rates
- The cost of electricity by building SMR after several repetitions is expected to be equal to or lower than the costs of electricity using Natural Gas Combined Cycle
- The prices considered, factor in owner's costs, contingencies, interest during construction, fuel, operations and maintenance costs

INITIAL INVESTMENT VERSUS NET VALUE FOR SMR DEPLOYMENT

Net value added to USA economy from SMR Deployment



- Funding cost for initial FOAK comes from direct equity injection into VENDOR owner and from investors and govt and from lifetime NPV of VENDOR owner's funding gap (PPA tariff – LCOE)
- Total value added to economy derived from direct, indirect and induced benefits from SMR production and deployment
- Breakeven in net value added reached with NOAK#2 (3rd site)
- Net value added to USA economy can reach up to $ 1.5 bn by deployment of NOAK#5 (6th site)

- Options:
  - "Step of Faith"
  - State involvement – Fed help

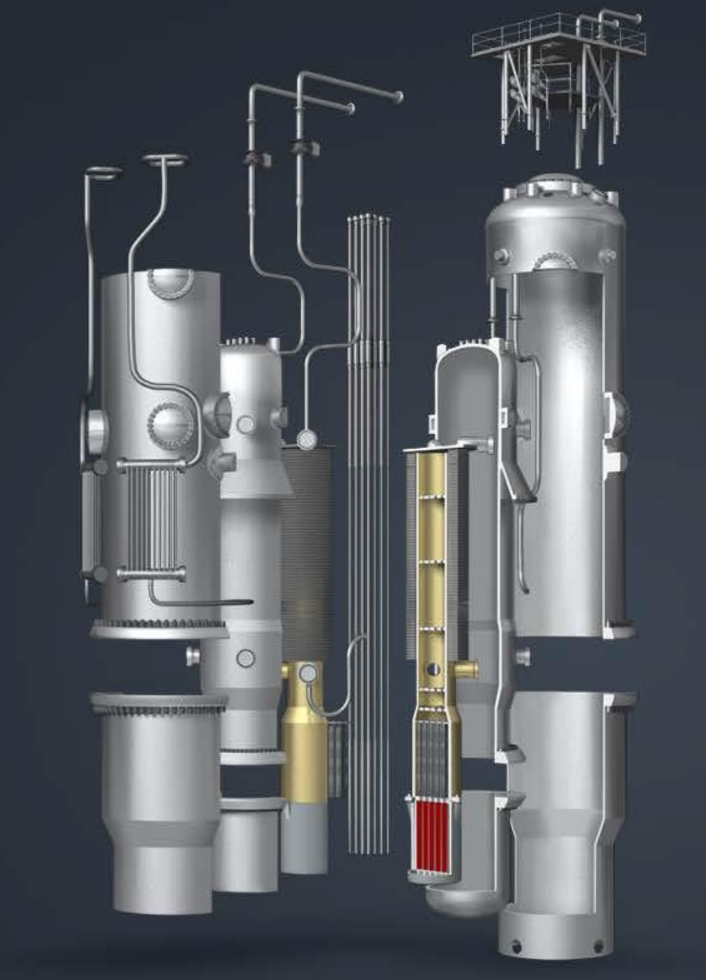
LCOE Reduction

- Control room and licensed operators
  - For 12 reactors, NRC requirements would result in multiple control rooms and many licensed operators
  - NuScale and NRC are aligned on information and regulatory path that will allow single control room and six licensed operators
  - Reduces construction and O&M costs for life of plant
- Site boundary emergency planning zone (EPZ)
  - TVA is seeking NRC approval of a site boundary and 2-mile EPZ for the Clinch River site
  - NuScale recently provided analysis that demonstrates technical criteria for site boundary EPZ can be met by the NuScale design
  - NRC estimates site boundary EPZ saves hundreds of millions of dollars over the life of a plant relative to a 10-mile EPZ
- Security staffing initiative
  - NuScale is collaborating with TVA on security staffing
  - Staffing reductions based on security considerations integrated into design
  - Expectation is that number of security staff necessary will be substantially reduced
  - Reduces O&M cost for life of the plant`

Advanced Manufacturing for Nuclear

Model T Ford

Holtec Advanced Manufacturing Facility



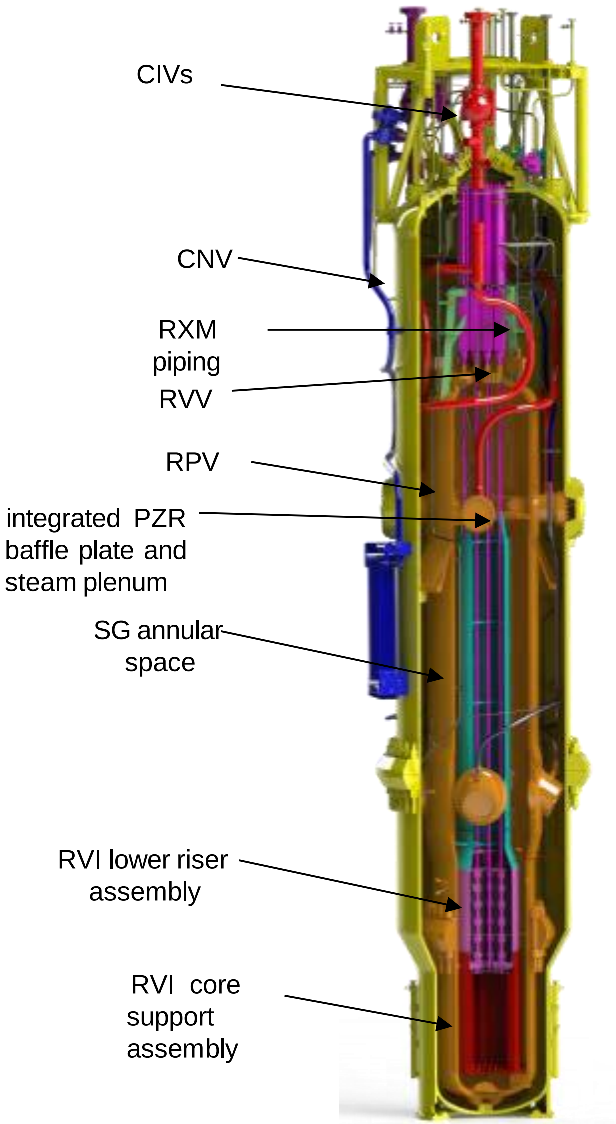
Reducing Manufacturing Risk

NUFAB™
PARTNERING FOR FABRICATION

- Teaming with World Class Manufacturers
- *100 attendees from 83 companies attended the NuFAB supplier’s Day event on November 3, 2016*

Supplier Scope - Base

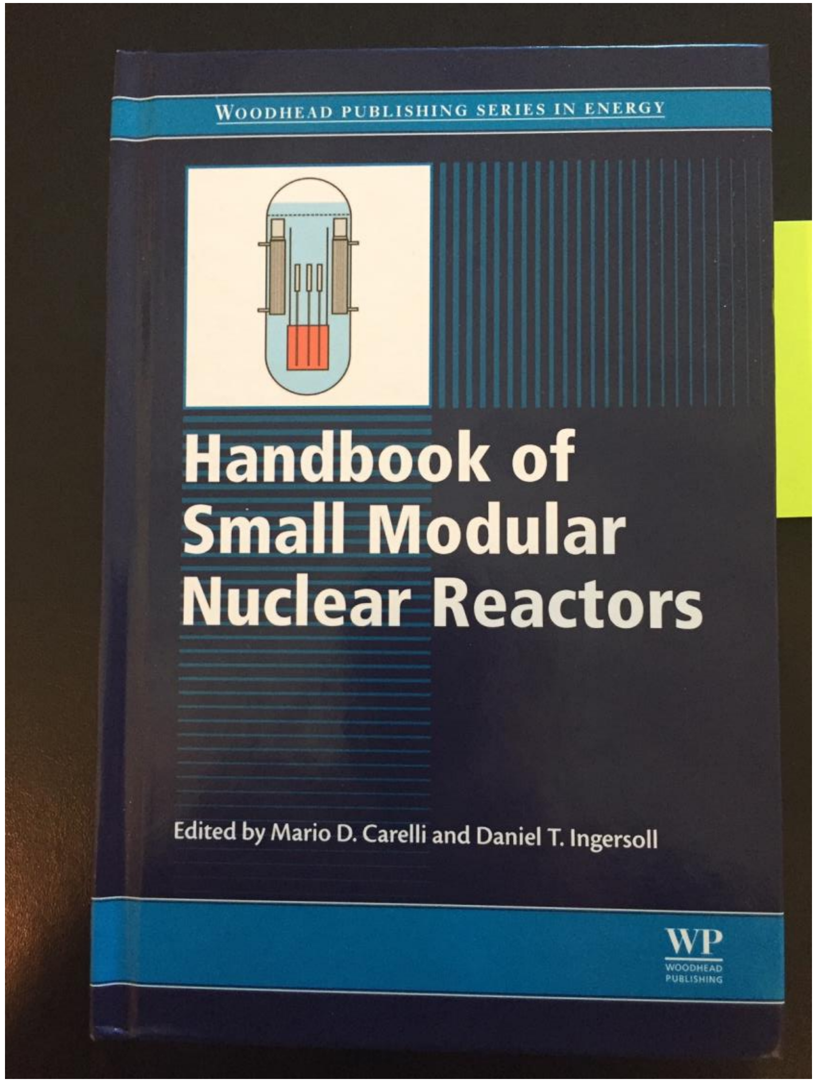
- Refine the design for manufacturability, assembly and transportability
- Prepare for fabrication
- Fabricate 12 NuScale Power Modules
  - Containment Vessel
  - Reactor Vessel
  - Reactor vessel internals and piping
  - Steam Generator
  - Assembly and testing, including ITAAC support
  - Install equipment from other OEMs



Methods of Reduction in Total Cost Must Address:

- Total capital costs
- Financing needs
- Manufacturing costs
- Transportation costs
- Construction costs
- Operating costs
- Maintenance costs

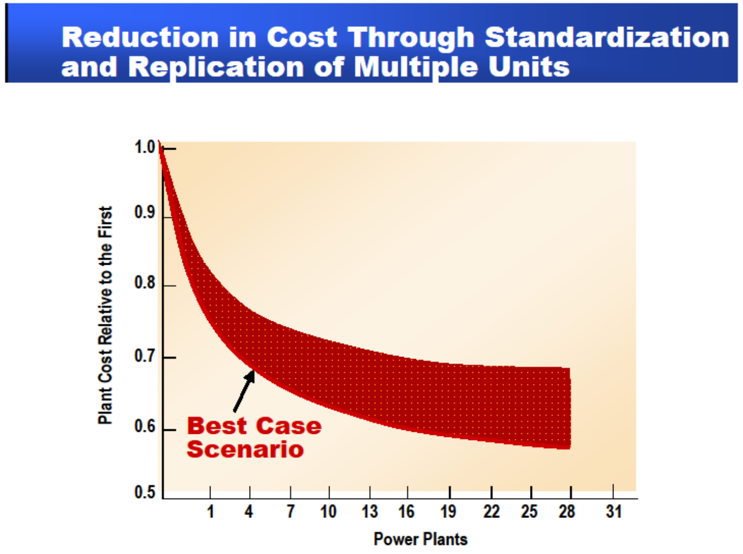
Many References to SMR Manufacturing

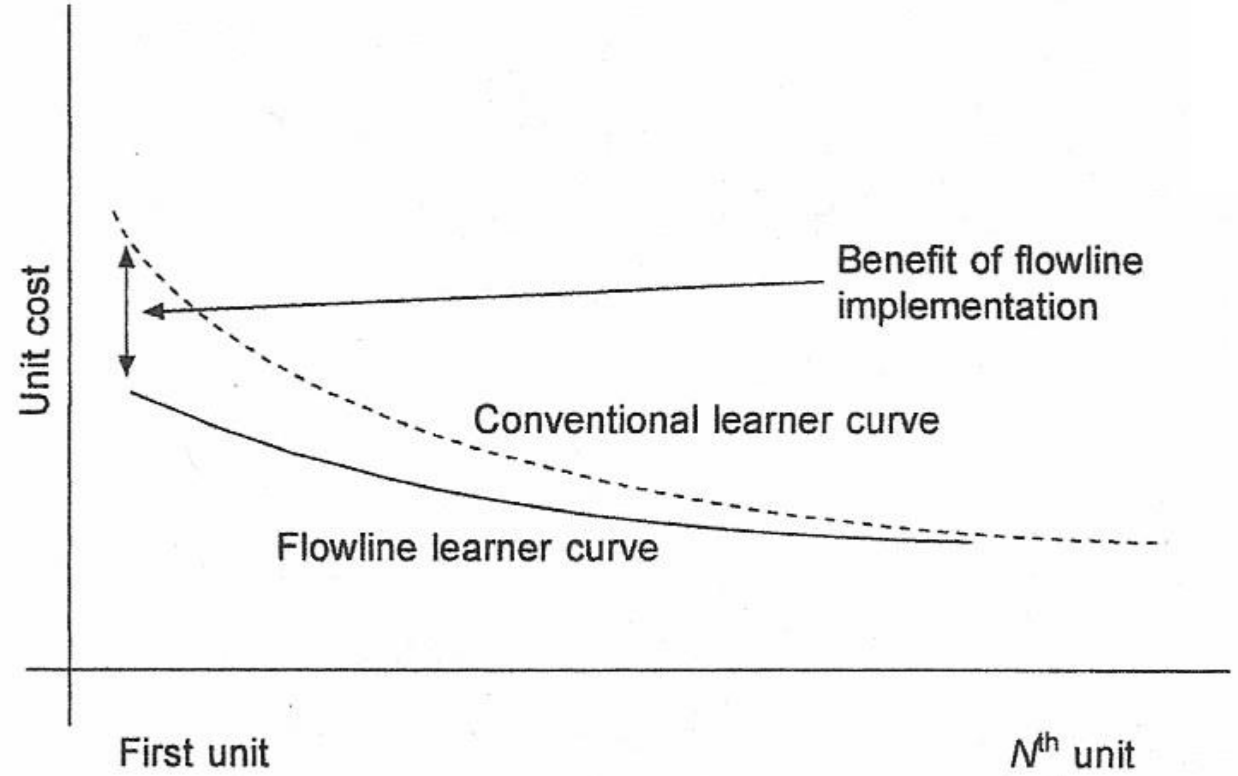


SMR Advanced Manufacturing – CANM, PA

- Role of standardization
- Full production line
- Flowline concept
- Additive Manufacturing
- Casting
- Cybersecurity for Manufacturing
- FOAK prototyping

Flowline Concept



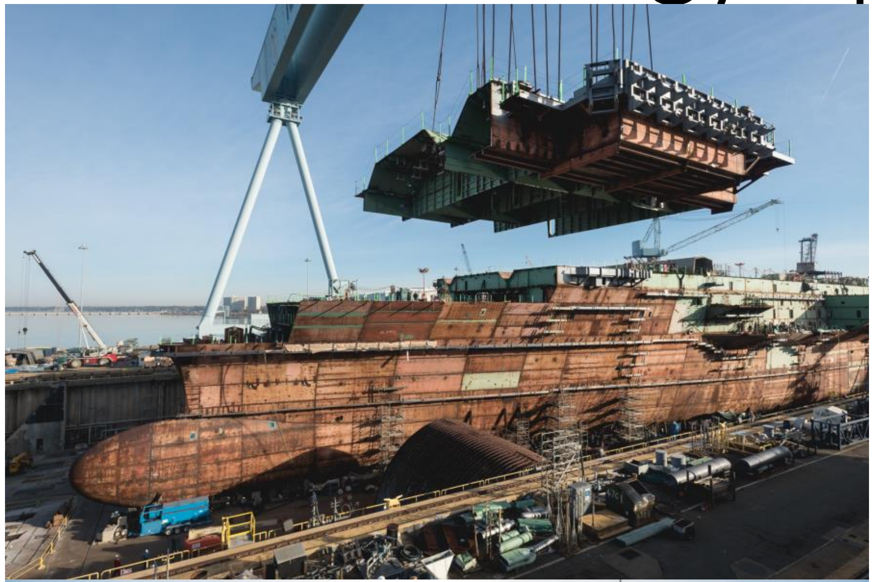


12.5 Illustrative graph of cost benefit of early incorporation of flowline concept.

Flowline concept Benefits-Requirements

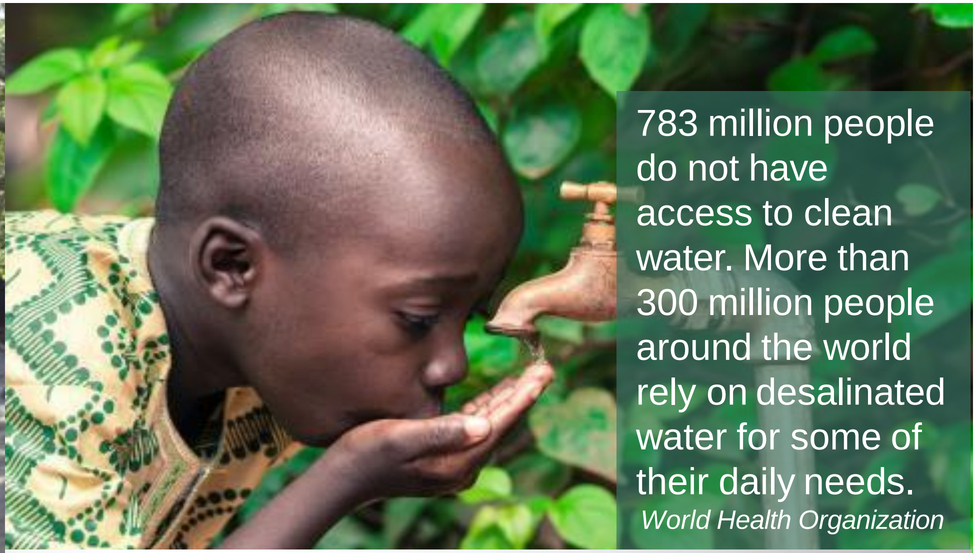
- Benefits
  - Fits in between batch and assembly line manufacturing – hybrid manufacturing method that sits between mass batch production and production line. Has been successfully applied in a number of high technology, high integrity, intermediate volume businesses.
- Requirements
  - Single product family
  - No rework
  - Stable supply of parts/assemblies/kits
  - High reliability of workstation equipment, tools, etc

Flowline Technology Applications -Ships



Flowline Technology Applications - SpaceX

The Global Reality



Summary

Nuclear power has a major role to play in meeting our future energy needs in the U.S. and around the world

To be an economically attractive alternative, SMR's need to have a very strong modular construction methodology and deployment.

Goals for SMR Technology Advancement – U.S. and World

- Deploy SMRs in mid-2020's
- Develop and deploy advanced reactor non LWR technologies in the 2030's

Paper Reactors, Real Reactors

- **Characteristics of an Academic Plant**
  - It is simple
  - It is small
  - It is cheap
  - It is light
  - It can be built very quickly
  - It is very flexible in purpose.
  - Very little development is required. It will use mostly off the shelf components.
  - The reactor is in the study phase – it is not being built now.
- **Characteristics of a Practical Reactor Plant**
  - It is being built now.
  - It is behind schedule.
  - It is requiring an immense amount of development on apparently trivial items. Corrosion, in particular, is a problem.
  - It is very expensive
  - It takes a long time to build because of the engineering development problems.
  - It is large
  - It is heavy
  - It is complicated

(By Admiral Hyman Rickover, 1953)