小型モジュール炉（SMR）研究開発の概要

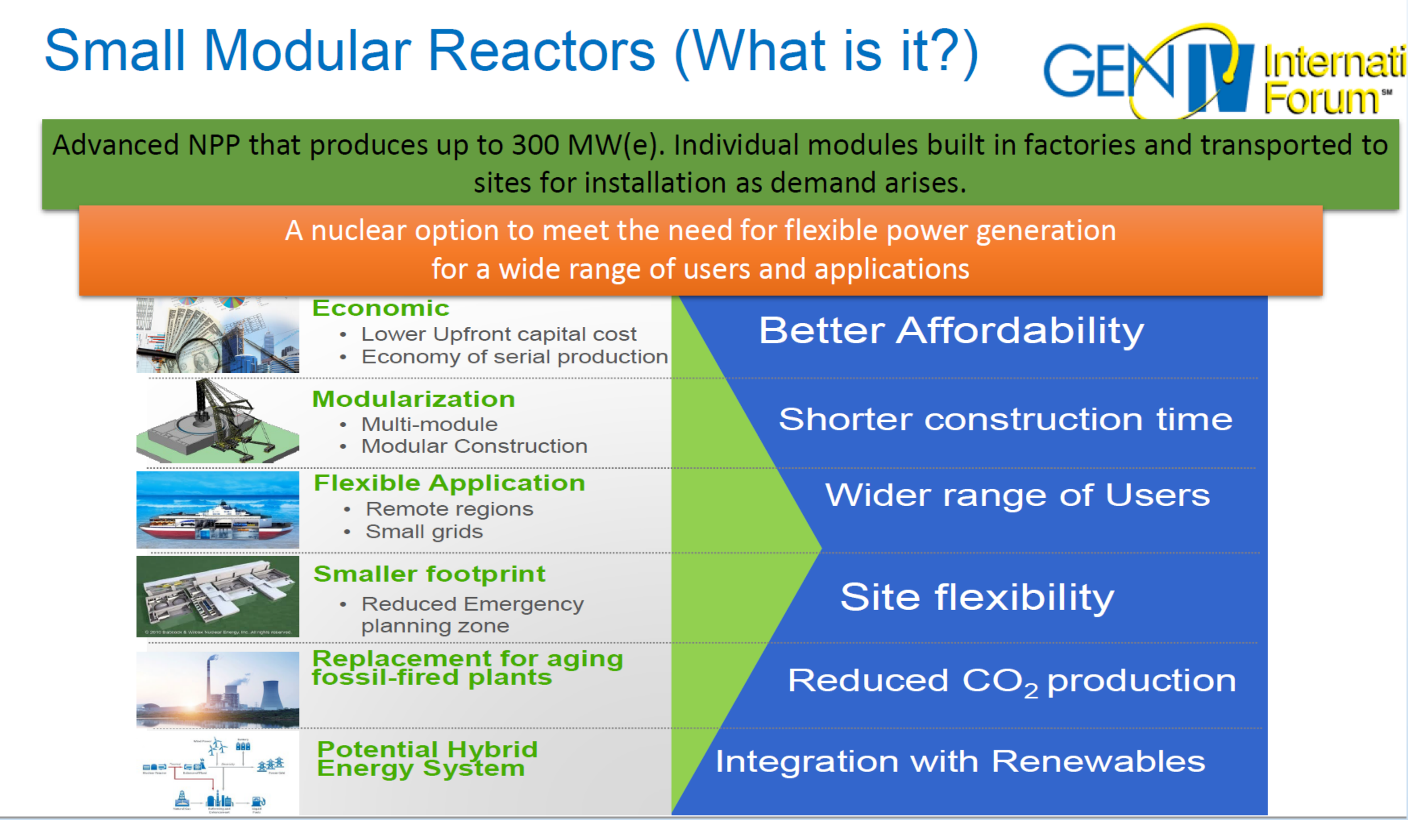
概要 / 目的:

原子力発電は、**低出力で小型の原型炉・試験炉から始まりましたが、ニーズの高まり、規模の経済、立地可能なサイトの制限により、比較的早い段階から、発電方式は大型炉による発電に代わりました。しかしここ数年は、小型モジュール炉（SMR）への関心が高まっており、50以上の概念が現在検討されています。**IAEAでは、個々のモジュールの出力が300MWeまでの先進炉をSMRと定義しています。モジュールは工場で製造でき、プラントサイトに輸送、設置されますが、必要に応じて追加することができます。またSMRは先進技術の全て（水冷却、第4世代システム、超小型炉等）と関連付けられ、**受動安全機能の強化、シンプルな設計及び運転、大量生産による経済性、ハイブリッドシステム及び非電気利用に対する柔軟性も兼ね備えています**。このウェビナーでは、SMRの魅力、課題、開発状況、今後の展開に焦点を当て、紹介します。

講演者紹介:

Mr. Frederik Reitsmaは、ウィーンにある国際原子力機関（IAEA）の原子力技術開発部門（NP）で**SMRのチームリーダー**を務めている。約7年前にIAEAに入局し、この分野のプロジェクトの管理、調整、監督を行っている。加盟国と協力して**将来の主要なトレンドと技術開発のニーズを特定**し、技術的およびプログラム的なリーダーシップをとっている。また、以前は、高温ガス冷却炉プロジェクトの責任者を務めていた。多くの技術論文（90以上）を発表し、国際ワークショップや国際会議にスピーカーとして招聘されるほか、国際協力プロジェクト（OECD/NEAやGIFなど）をリードしてきました。原子炉物理学者でもあり、SMRおよび高温ガス炉の核工学と解析に豊富な経験を持ち、炉心の中性子工学設計と安全性の専門家です。南アフリカのPBMRプロジェクトでは、13年間にわたってさまざまな指導的立場にあり、キャリアの最初の10年間は、OSCARの原子炉計算システムの開発に貢献してきました。

SMRは、**導入に伴う経済性、モジュール構造、プラント展開の柔軟性、再生可能エネルギーとの相性**などの観点から関心を集めている。



SMR Designs around the World

Land Based Water Cooled Reactors

CAREM	SMART	RUTA-70	DHR400
ACP100	UNITHERM	NuScale	RITM-200
CAP200	VK-300	mPOWER	NUWARD
IRIS	KARAT-45	W-SMR	BWRX-300
DMS	KARAT-100	SMR-160	HAPPY200
IMR	ELENA	UK-SMR	CANDU SMR

Micro Reactors

IHTR	MMR-5
IMSBR	MMR-10
eVinci	AURORA
U-Battery	MoveluX

Fast Reactors

4S	W-LFR	SSTAR LFR
BREST-OD-300	SEALER	URANUS
SVBR-100	LFR-AS-200	ARC100
EM²	LFR-TL-X	

High Temperature Gas-cooled Reactors

HTR-PM	MHR-100	XE-100	HTTR-30
DPP-200	PBMR-400	A-HTR 100	HTR-10
GT-MHR	HTMR-100	MMR	RDE
MHR-T	SC-HTGR	GTHTR300	StarCore

Marine Based Water Cooled Reactors

ACPR50S	VBER-300
KLT-40S	ABV-6E
RITM-200M	SHELF

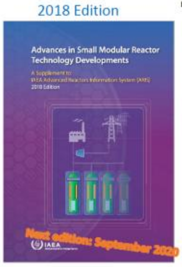
Molten Salt Reactor

IMSR	SSR-WB	CA WB
CMSR	SSR-TS	KP-FHR
THORCON	LFTR REACTOR	MCSFR
FUJI ITMSF	MK1 PB-FHR	

IAEA SMR Booklet

The booklet contains information provided by vendors and designers on their SMRs

2018 Edition



- SMRs are categorized in types based on coolant type/neutron spectrum:
  - Land Based WCRs
  - Marine Based WCRs
  - HTGRs
  - Fast Reactors
  - MSRs
  - Micro reactors
  - Test reactors (to be included with the types above as applicable)
- Design description and main features of ~70 SMR designs being updated (56 in 2018)
- Include information on fuel cycle, decommissioning and final disposal (for the first time)

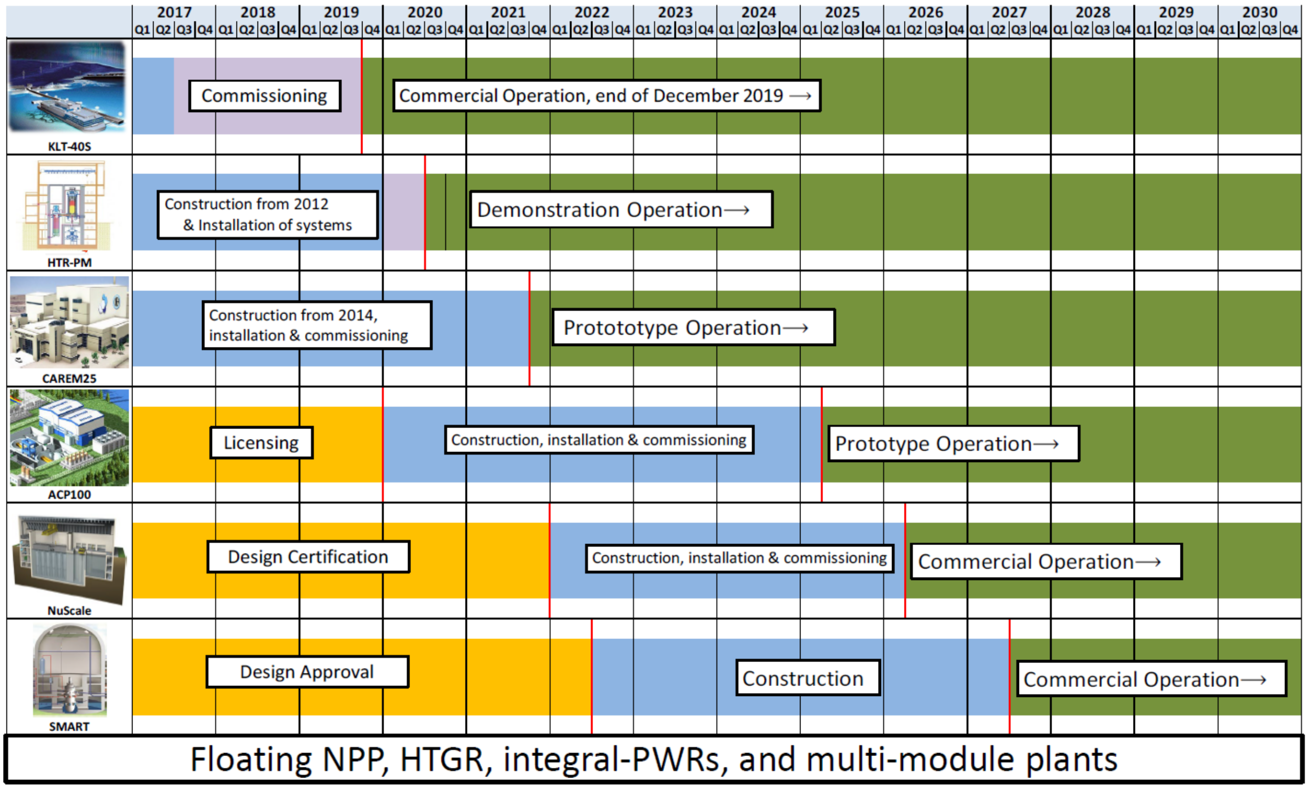
IAEA ARIS Database Includes SMR Designs

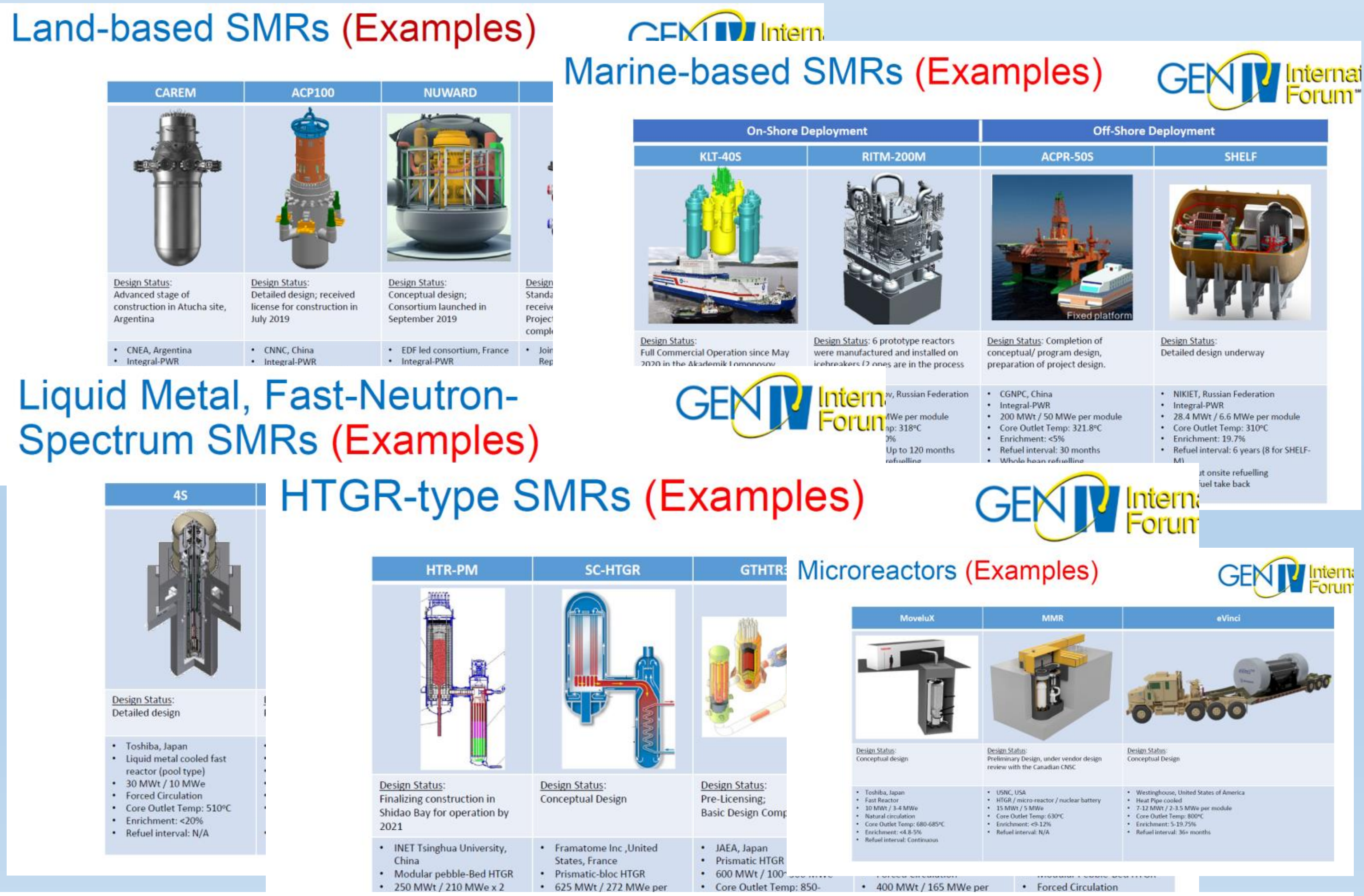
20

IAEAはすでに**SMRブックレット**を発行しており、**ARISデータベース**にはSMRのコンセプトが含まれている。

SMRの開発段階は、既に**ライセンス段階から建設段階へ進んでいる。**

Status of Deployment Timeline as of Spring 2020





水冷式だけでなく、液体金属、ガス、溶融塩冷却方式、そして海洋型から**マイクロリアクター**まで、100近いコンセプトが提案されている。

SMRの設計上の特徴は、**モジュール構造、サイト条件との適合性（柔軟性）、物理的セキュリティの確保方法、防護区域（EPZ）**であり、それらの特徴の紹介がなされている。また、グレーデッドアプローチ（等級別アプローチ）の適用が想定されている。

SMR Site Specific Considerations

- SMRs promise much smaller sites
  - EPZ can possible be reduced
  - Located close to population centers / end users
  - Located next to heat users / industries
- The first SMRs currently built / to be deployed has selected existing NPP / nuclear sites (HTR-PM, CAREM, NuScale plan)
- Important factor is physical security (smaller site and close proximity of other buildings / industries will present new challenges)

The HTR-PM - (Two-reactor unit) = 210MWe
The Vogtle 3 and 4 Nuclear power plant USA - 2 units = 2220 MWe

Progress made in applying a graded approach

- Nuclear Regulatory Commission staff agreed with the Tennessee Valley Authority that scalable emergency planning zones (EPZs) for small modular reactors are feasible

world nuclear news

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US regulators discuss smaller SMR emergency zones

28 August 2018

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CLARIFICATION: NRC staff have concluded the TVA methodology can be used in the future to determine if a reduced emergency planning zones is justified, and has not made a decision on EPZ criteria for small modular reactors.

The US Nuclear Regulatory Commission (NRC) has concluded that Tennessee Valley Authority's (TVA's) methodology can be used in the future to determine if a reduced emergency planning zone is justified for small modular reactors, a spokesman for the Commission told *World Nuclear News* today. It has not yet agreed that an EPZ around small modular reactors can be scaled to reflect their reduced risks rather than the mandatory ten-mile EPZ required for the USA's current light-water reactor fleet.

SMRと再エネの相性は良好であるため、コージェネレーションを含むハイブリッド概念に注目が集まっている。

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Role of SMRs in Climate Change

SMR Renewables Hybrid Energy System to Reduce GHG Emission

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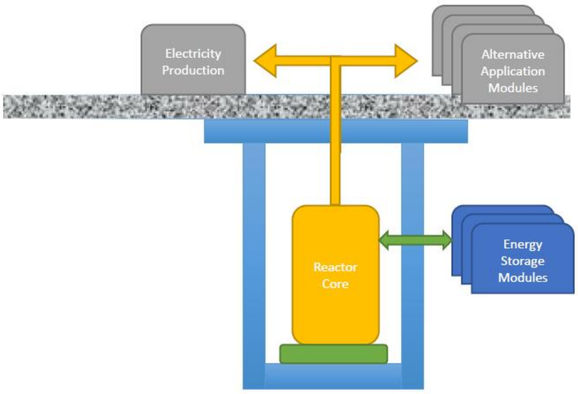
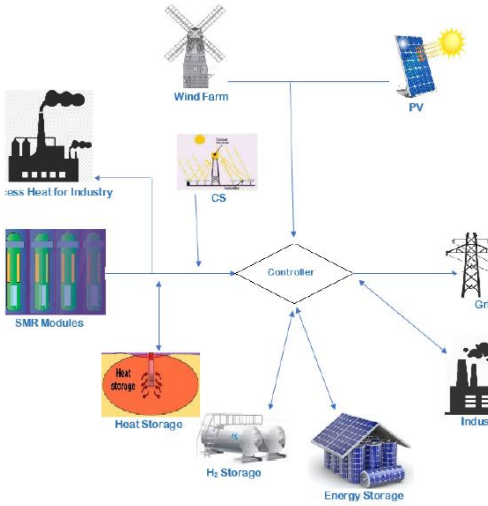
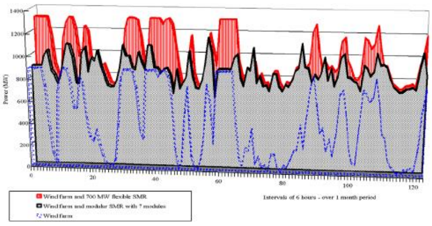


Modules:
- Electricity production
- Process heat
  - Petro-chemical industry
  - Desalination plant
  - Oil and gas reforming
  - Hydrogen production
  - Ammonia production
  - District heating / cooling
  - Waste reforming
- Energy storage
- Load follow capabilities
  - Switch between applications





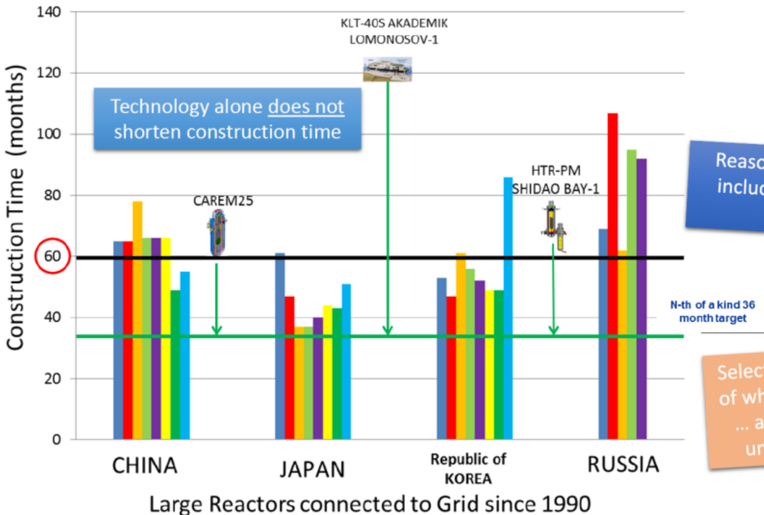
Example of load follow with renewables

TECDOC:
Options to Enhance Energy Supply Security using Hybrid Energy Systems based on SMR;
being finalised in 2020

Capital costs for SMRs

GEN IV International Forum[SM]

Key Topics	Prospects	Impediments
Capital component of levelized cost of power	Potential decrease in case of large scale and serial production	Require large initial order *(e.g. 50 – 80 modules)*
Comparison of material quantities	Design saving	Standardization of new structure, system, components and materials
Impact of local labour and productivity	○ Reduced construction time for proven design ○ Lesser work force required with modular construction (case by case)	FOAK deployment of multi-module plant with modular construction technology versus stick-build
Cost of licensing	Based on LWRs technology - easier licensing, but still could take long in established nuclear regulators	First of a kind; Time required for modifying the existing regulatory and legal frameworks
Ensuring all necessary equipment is included in the cost estimate, e.g. there is no 'missing equipment'	Learning curve: the higher the number of SMR built on the same site is, the better the cost effectiveness of construction activities on site	Cost impact by delayed component delivery or defect during shipping
Assurance of reliable estimates of technology holder equipment prices	Similar among vendors	Manufacturing of FOAK components



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We will only know after we build and operate SMRs

これまで**経済性評価に影響を及ぼす因子の摘出**が行われ、多くの経済性に関する議論が行われている。
ただし、モジュール化の効果については、不確定要素が多く、建設されるまで、その評価は定まらないであろう。

課題と挑戦：
多くのチャレンジすべき課題はあるものの、メリットも多く指摘されており、
そのため開発対象として着目されている。

Key Barriers/Challenges to Deployment

- Limited ***near-term commercial availability***
- Technology developers ability to secure investors for design development and deployment: *first domestically, then international markets*
  - *may be an opportunity to cooperate*
- **Economic** competitiveness
  - Need economy of numbers (vs economy of scale) …
- Regulatory, licensing and **safety issues**.
  - *FOAK, passive features, integrated designs, different technologies*
- Technology Maturity
  - Water cooled SMRs (iPWR and BWRs) based on mature technology
  - HTGR mature technology (with steam generator and Tout < 850 °C)
  - MSR has limited operation experience –some challenges to be solved

NEED GOVERNMENT COMMITMENT TO REALIZE DEMONSTRATIONS PROJECTS!

Advantages, Issues & Challenges

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Technology aspects
- Shorter construction period (modularization)
- Potential for enhanced safety and reliability
- Design simplicity
- Suitability for non-electric application (desalination, etc.).
- Replacement for aging fossil plants, reducing GHG emissions

Non-Techno aspects
- Fitness for smaller electricity grids
- Options to match demand growth by incremental capacity increase
- Site flexibility
- Reduced emergency planning zone
- Lower upfront capital cost (better affordability)
- Easier financing scheme

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Technology issues
- Licensing of FOAK designs, particularly non-LWR technologies
- Prove of operability and maintainability
- Staffing for multi-module plant;
- Supply Chain for multi-modules
- Optimum plant/module size
- Advanced R&D needs

Non-technology issues
- Time from design-to-deployment
- Highly competitive budget source for design development
- Economic competitiveness: affordability & generation cost
- Availability of *off-the-shelf* design for newcomers
- Operating scheme in an integration with renewables