IAEA
International Atomic Energy Agency

FISA 2019 • EURADWASTE '19

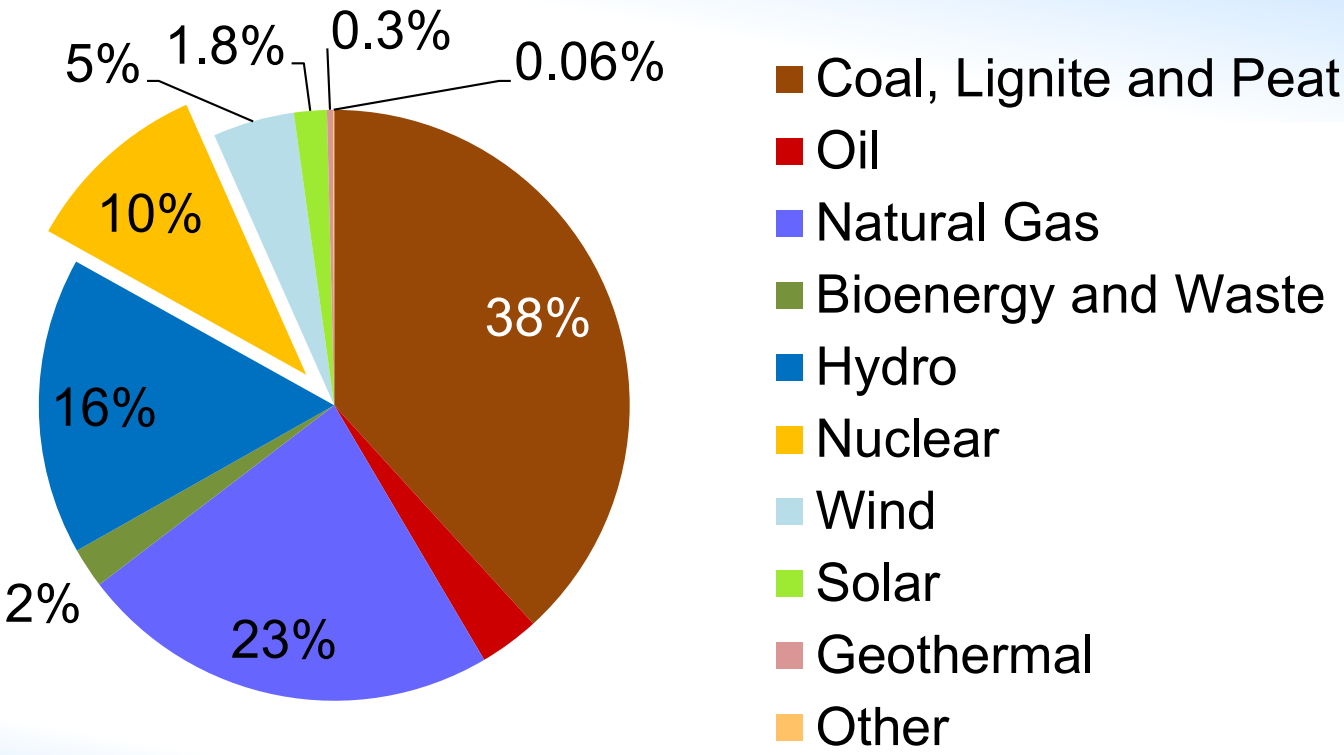
9th European Commission Conferences on EURATOM Research and Training in
Safety of Reactor Systems | Radioactive Waste Management

# Global Trends in Nuclear Power: Advanced Reactors Including SMR Integrated in Hybrid Energy Systems

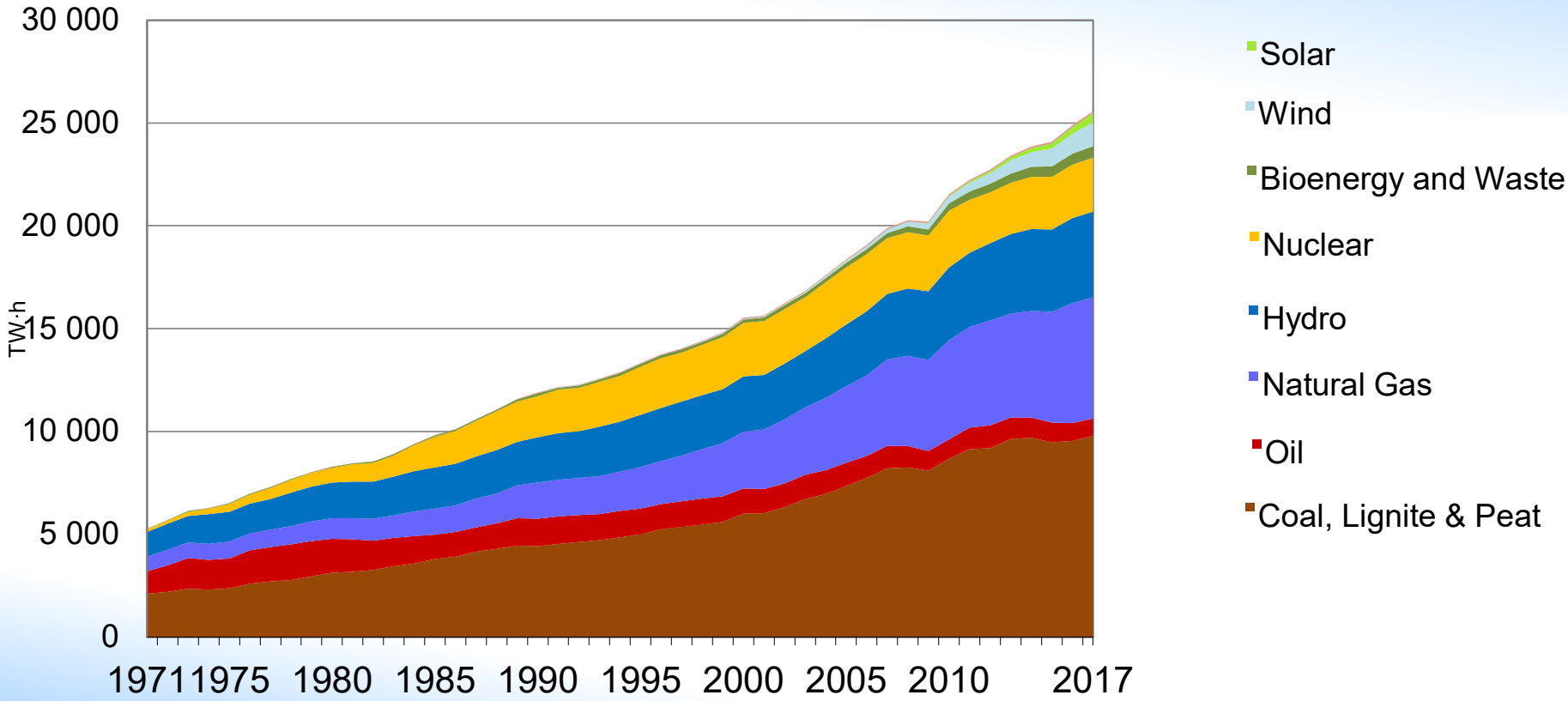
**Stefano Monti**

Head, Nuclear Power Technology Development Section
Division of Nuclear Power, Department of Nuclear Energy
International Atomic Energy Agency

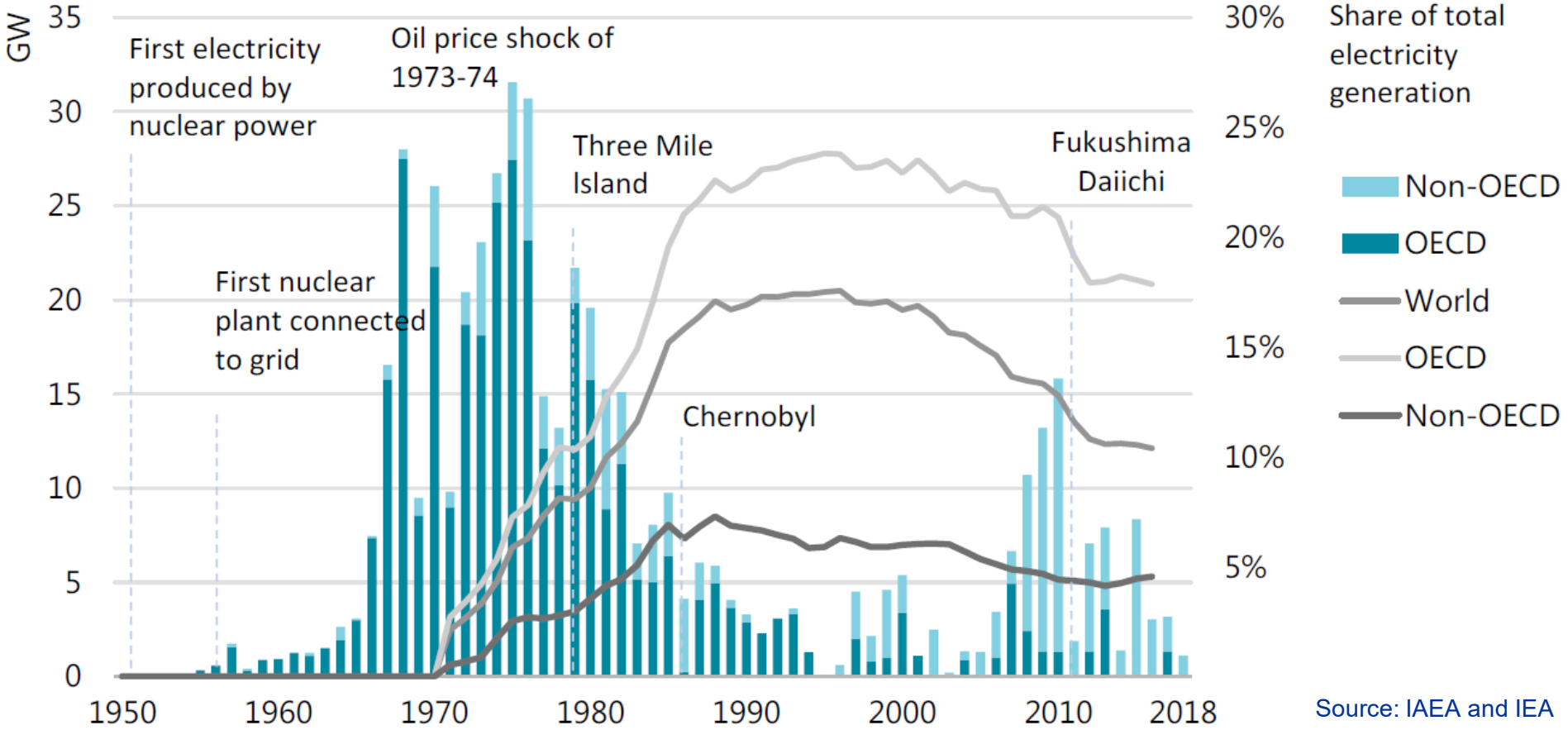
# Electricity Production



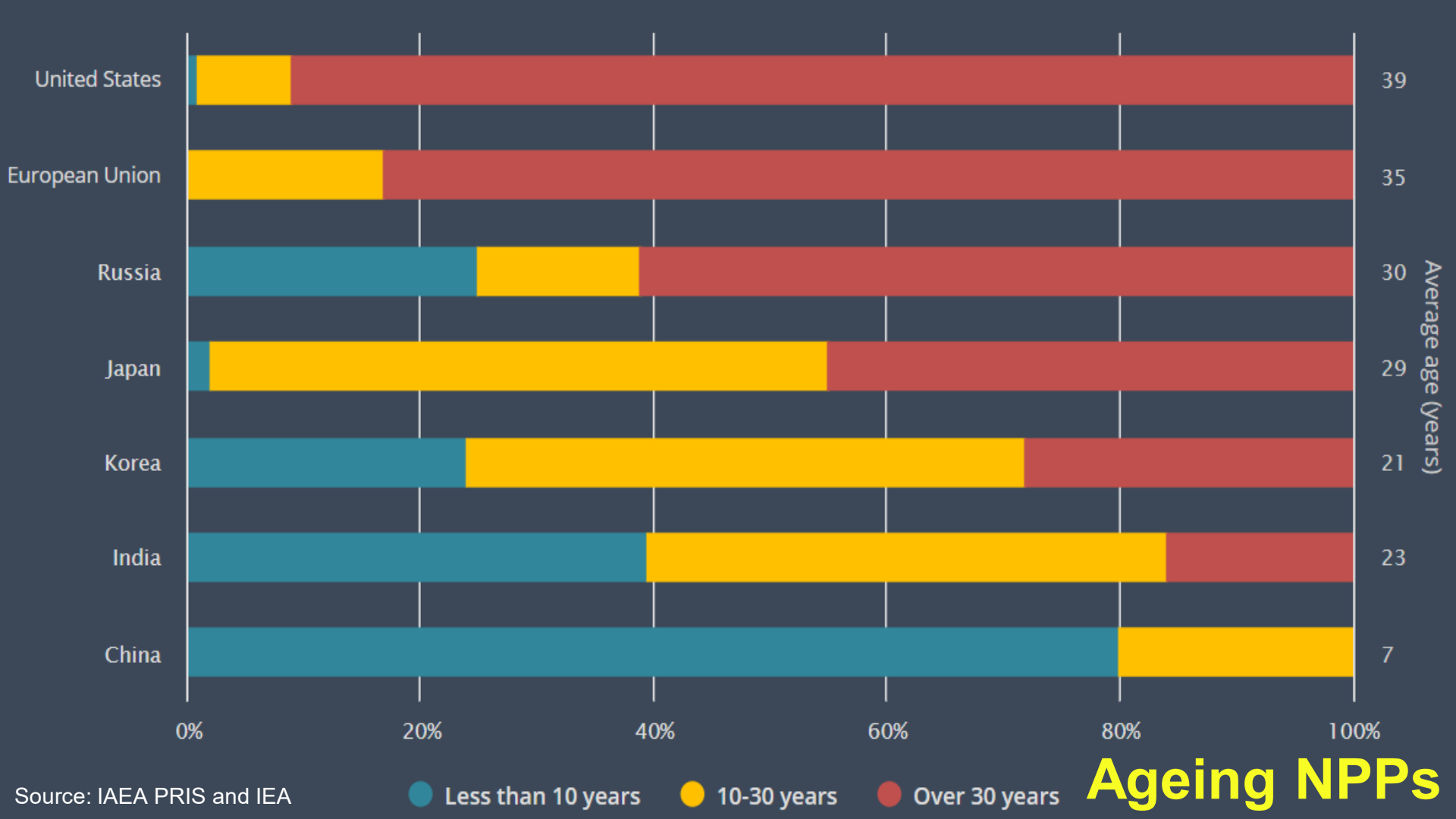
# Electricity Production by Source



# NPPs Deployment & Share in Global Electricity

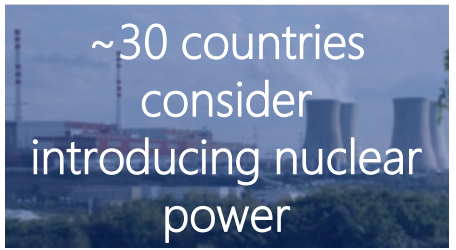



Source: IAEA and IEA


United States
European Union
Russia
Japan
Korea
India
China
39
35
30
29
21
23
7
Average age (years)
0%
20%
40%
60%
80%
100%
Less than 10 years
10-30 years
Over 30 years
Source: IAEA PRIS and IEA
Ageing NPPs

# Nuclear Power

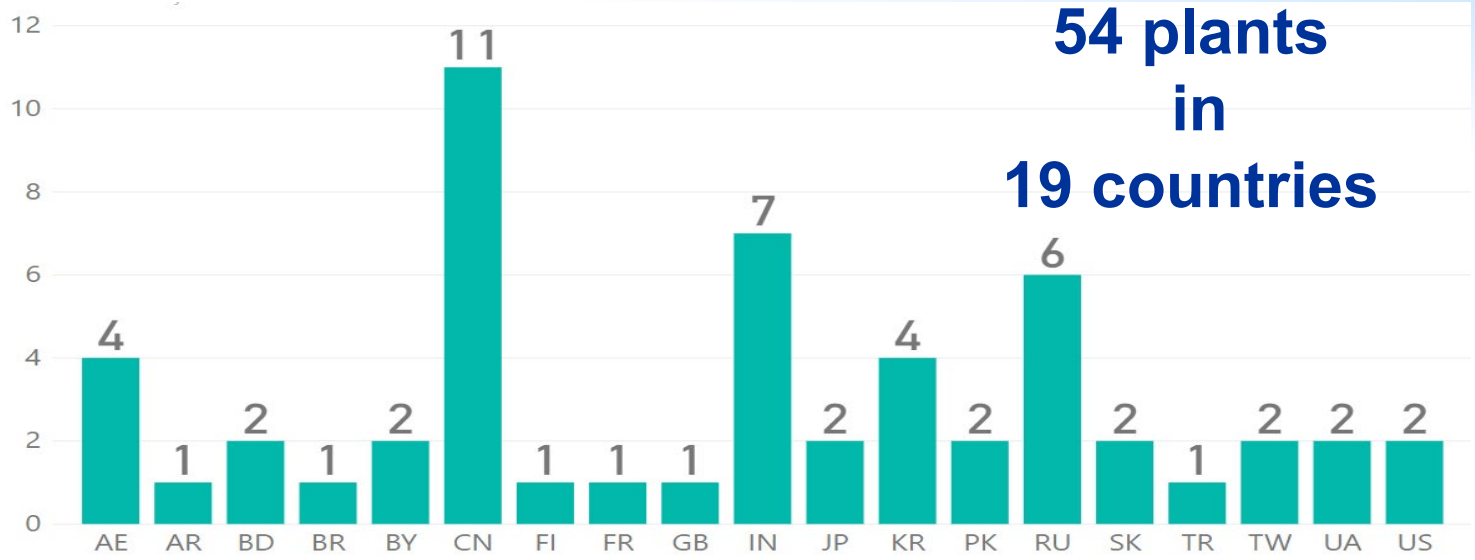




6

# NPPs Under Construction



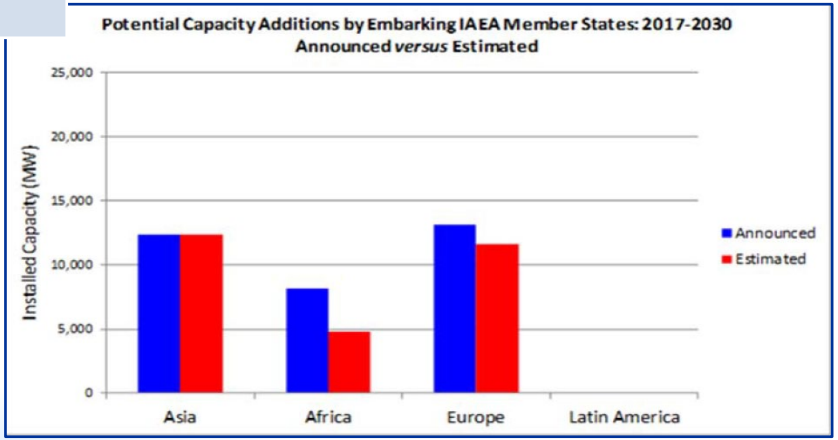

| Economy type | Number of plants | State-owned operator | Private operator – regulated environment* | Private operator – wholesale market |
|---|---|---|---|---|
| Advanced economies | 14 | 7 | 6 | 1 |
| Developing economies | 40 | 40 | 0 | 0 |
| **World** | **54** | **47** | **6** | **1** |

Source: IAEA and IEA

# Newcomers in numbers

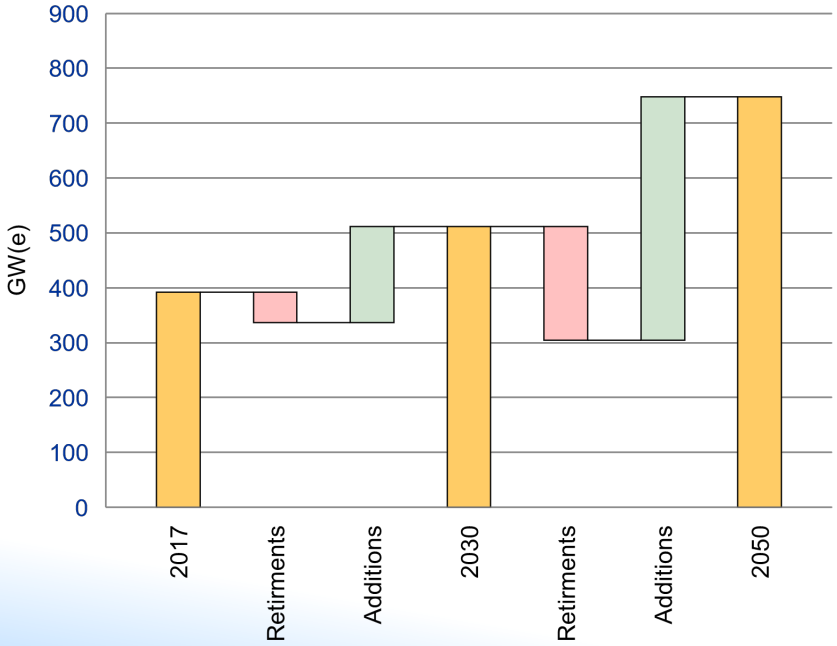
| Country Status (according to the Milestones) | Countries |
|---|---|
| First NPP construction started | 4 |
| First NPP contract under negotiation or signed | 1 |
| Decision made, preparing infrastructure | 4 |
| Active preparation for final decision | 9 |
| Considering nuclear power programme | 9 |

Construction: UAE, Bangladesh, Belarus, Turkey

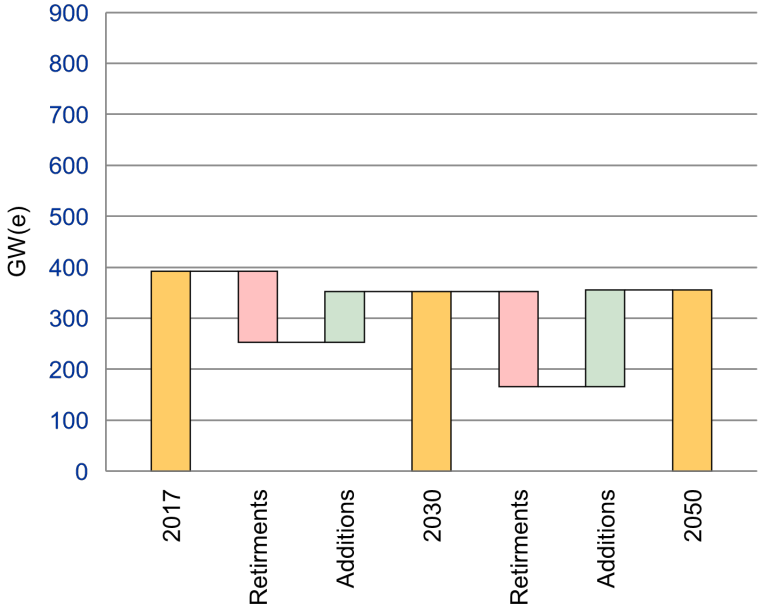


# World Nuclear Capacity: Actual, Retirements and Additions, High and Low Cases

## High Case




## Low Case




Source: Energy, Electricity and Nuclear Power Estimates for the Period up to 2050 – RDS 1, 2018

# Improving sustainability of the existing fleet of NPPs through innovation

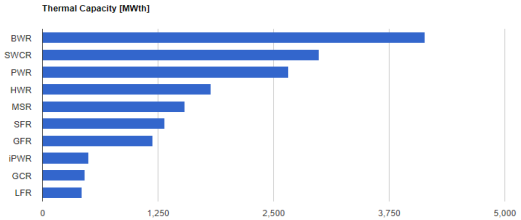
- Ensure the key contribution of NP to decarbonization of the energy sector
- Ensure their availability to bridge the nuclear industry to a future that includes the routine deployment of:
  - SMRs & microreactors
  - Innovative reactor technologies (GIF technologies)
  - Tightly coupled hybrid energy systems
  - Non-electric applications of NP

# ARIS

*enables users to easily get an overview of the current reactor technologies being developed and deployed by giving access to the designers' reactor descriptions*

IAEA

## Characteristics of Advanced Reactors




Thermal Capacity | Operating Temperature | Power Density | Plant efficiency | Discharge burnup

(Click on type for more reactors)

## Advanced Reactors Information System(ARIS)

Overview | General data | Nuclear Steam Supply System | Reactor Coolant System | Reactor Core | Core Materials | Reactor Pressure Vessel

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type | All | PWR | BWR | HWR | SCWR | iPWR | GCR | GFR | SFR | LFR | MSR | FR | SMR |
| Country | All | Canada | China | EU | France | India | Japan | Rep. of Korea | Russia | USA | Other | | |
| Status | All | On Hold | Under Design | Licensed | Construction | In Operation | | | | | | | |
| Purpose | All | Commerical | Demonstration | Experimental | Prototype | | | | | | | | |

(Click on acronym for more information)

OVERVIEW

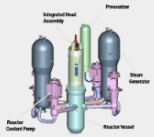
| Acronym | Full name | Design Org. | Coolant | Moderator | Design Status | Country | Type | Purpose |
|---|---|---|---|---|---|---|---|---|
| 4S | Super-Safe, Small and Simple Reactor | Toshiba | Sodium | No Moderator | Under Design | Japan | SFR | Commerical |
| ABWR | Advanced Boiling Water Reactor | GE-Hitachi | Light Water | Light Water | In Operation | USA | BWR | Commerical |

IAEA | ARIS Advanced Reactors Information System

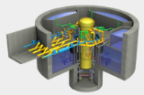
Technical Data | Characteristics | Publications | Glossary | About ARIS

ADVANCED REACTORS

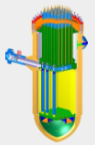
WATER COOLED TECHNOLOGY



PWR

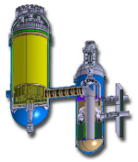


BWR



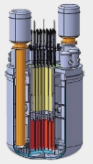
SCWR

GAS COOLED TECHNOLOGY



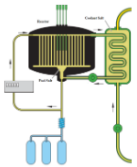
GCR

MOLTEN METAL COOLED TECHNOLOGY

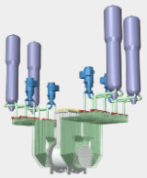


SFR

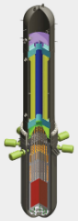
MOLTEN SALT COOLED TECHNOLOGY



MSR

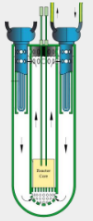


HWR



iPWR

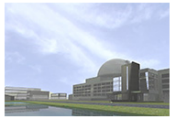
GFR



LFR

SMR

ARIS



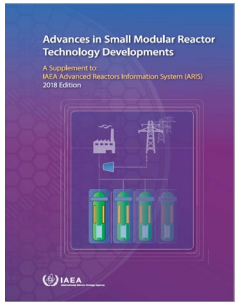
### The Database on Advanced Nuclear Power Reactors

The Advanced Reactor Information System (ARIS) is a database designed and maintained by the IAEA's Nuclear Power Technology Development Section (NPTDS) since 2009. The most important content of ARIS are the design descriptions of evolutionary and innovative advanced nuclear reactors. ARIS enables users to easily get an overview of the current reactor technologies being developed and deployed by giving people access to the designers' design descriptions. Read more »

NPTDS

The goal of the Nuclear Power Technology Development Section (NPTDS) is to foster information exchange and collaborative research in the area of advanced nuclear reactor technologies to ensure a sustainable, secure, stable and safe energy future for Member States.
NPTDS Website

# SMR Technology Development




**RUSSIA**
ELENA | VK-300 | KLT-40S | SVBR-100 | BREST300-OD | VBER-300 | VVER-300 | RITM-200 | ABV6-M | MHRs | UNITERM | SHELF | RUTA-70

**CANADA**
IMSR

**USA**
mPower
NuScale
W-SMR
SMR-160
EM²
GT-MHR
SUPERSTAR
Xe-100
SC-HTGR
W-LFR

**DENMARK**
CMSR
CA WB

**LUXEMBOURG**
LFR-AS-200

**UK**
UK SMR
SSR

**FRANCE**
SMR

**SWEDEN**
SEALER

**ITALY**
IRIS

**KOREA**
SMART

**JAPAN**
DMS
4S
IMR

**CHINA**
HTR-PM | ACPR50S
ACP100 | CAP150

**INDONESIA**
ThorCorn

**SOUTH AFRICA**
AHTR-100
HTMR-100
PBMR-400

**ARGENTINA**
CAREM-25

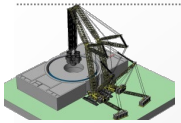
# SMR: definition & rationale for development

Advanced Reactors with an installed capacity up to 300 MW(e), built in factories and transported as modules to sites for installation as demand arises.

A nuclear option to meet the need for flexible power generation for wider range of users and applications

**Economic**
- Lower Upfront capital cost
- Economy of serial production

→ Better Affordability



**Modularization**
- Multi-module
- Modular Construction

→ Shorter construction time

**Flexible Application**
- Remote regions
- Small grids

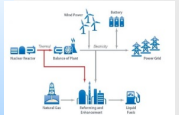
→ Wider range of Users

**Smaller footprint**
- Reduced Emergency planning zone

→ Site flexibility

**Replacement for aging fossil-fired plants**

→ Reduced $CO_2$ production



**Potential Hybrid Energy System**

→ Integration with Renewables

# Advantages, Issues & Challenges

**Technology Issues**
- 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

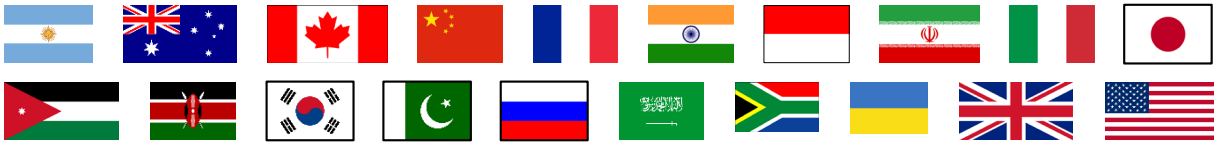
**Non-Techno Issues**
- Fitness for smaller electricity grids
- Options to match demand growth by incremental capacity increase
- Site flexibility
- Reduced emergency planning zone
- Lower upfront capital cost (better affordability)
- Easier financing scheme

**Technology Issues**
- Licensability (FOAK designs)
- Non-LWR technologies
- Operability and Maintainability
- Staffing for multi-module plant; Human factor engineering;
- Supply Chain for multi-modules
- Advanced R&D needs

**Non-Techno Issues**
- Economic competitiveness
- Plant cost estimate
- Regulatory infrastructure
- Availability of design for newcomers
- Physical Security
- Post Fukushima action items on institutional issues and public acceptance

# International Technical Working Group on SMR

- To advice and support IAEA programmatic planning and implementation in areas related to technology development, design, deployment and economics of SMRs
- 20 Member States and two International Organizations: European Commission and OECD-NEA as invited observers:



- Three technical subgroups established:
  - **SG-1:** Development of Generic Users Requirements and Criteria (GURC)
  - **SG-2:** Research, Technology Development and Innovation; Codes and Standards
  - **SG-3:** Industrialization, design engineering, testing, manufacturing, supply chain, and construction technology
- TWG will also address SMR for Non-Electric Applications and coupling with renewables
- 1st TWG Meeting for SMR held on 23 - 26 April 2018 in Vienna
- 2nd Meeting scheduled for 8 – 11 July 2019 in Vienna

# IAEA acting as the Secretariat for

- Canada
- China
- Finland
- France
- Korea
- Russian Federation
- Saudi Arabia
- United Kingdom
- United States


# Safety of nuclear installations – Regulatory issues

- SMR Regulators' Forum:
  - Pilot Phase (2015-2017) with 3 Working Groups: graded approach; defence in depth and emergency planning arrangements
  - Phase 2 (2018-) with three new Working Groups: licensing; design safety and safety analysis; manufacturing, commissioning and operation
  - Next meeting planned for Q4 2019

- Capacity Building for SMRs (Planned Workshops)
  - Siting and External Hazards Evaluation
  - Design safety and safety assessment
  - Principles for Emergency Preparedness & Response
  - Regulatory framework and licensing issues

# Emergency preparedness and response

- TM on Next Generation Reactors and EPR
  - Scheduled to take place in March 2020
  - Follow-up of a similar TM held in 2017
  - To be focused not only in SMR but also Generation IV reactors

- Based on the materials developed by the CRP on Emergency Planning Zones, technical guidance (EPR Series publications) is expected to be developed by 2021

# SMR: Support to Member States through TC

### Ongoing SMR/HTGR Missions

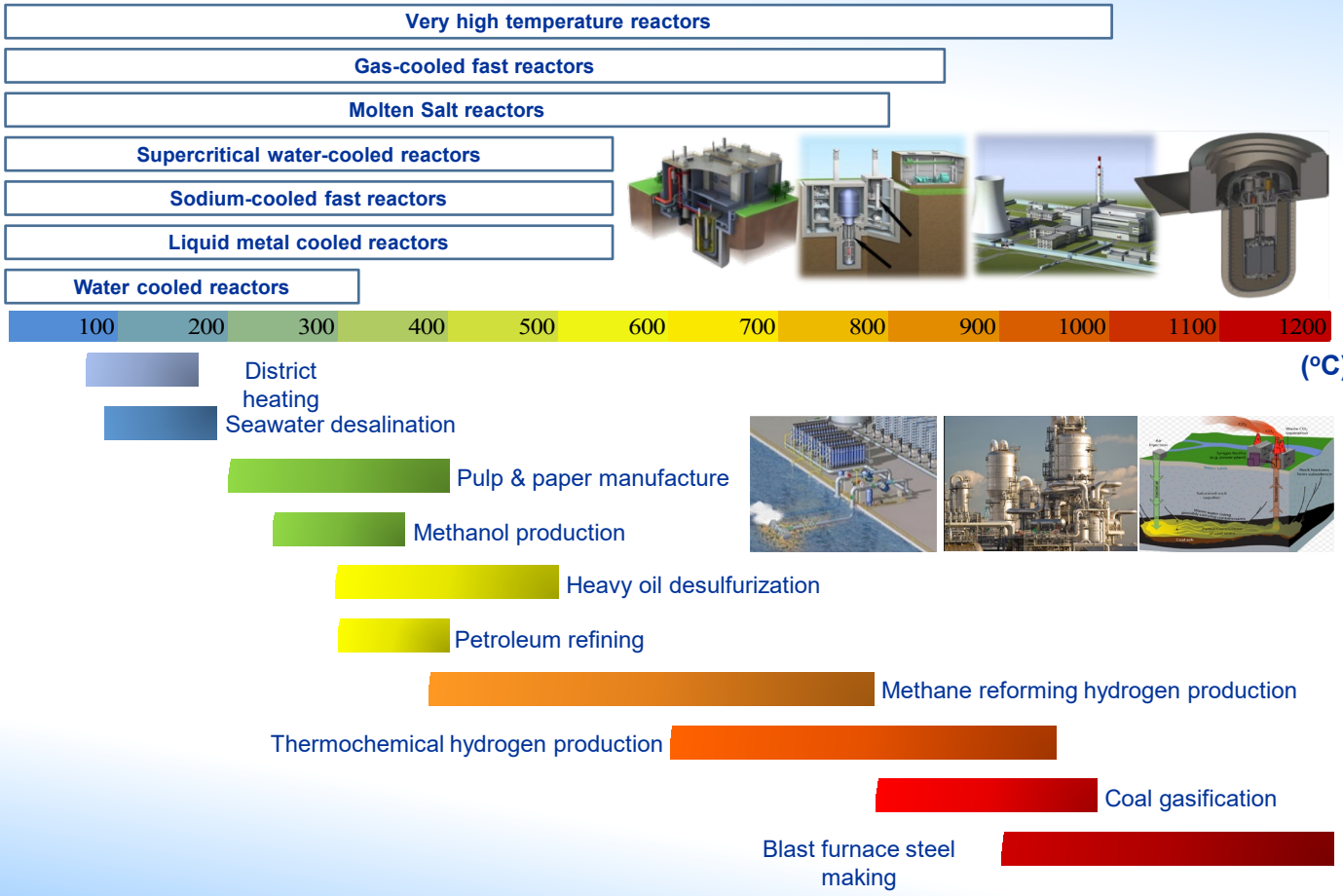
- Indonesia
- Jordan
- Saudi Arabia

### Technical Cooperation Project: Europe/Eurasia

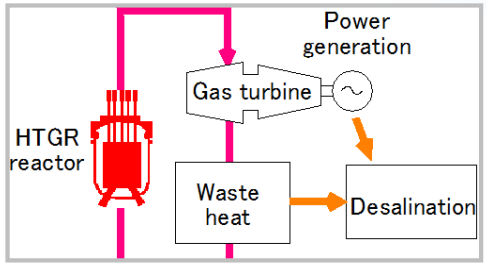
- Armenia
- Azerbaijan
- Croatiaa
- Czechia
- Hungary
- Lithuania
- Poland
- Romania
- Russia
- Slovakia
- Tajikistan
- Ukraine

- Design and technology status of water-cooled SMRs / non-water cooled SMRs
- Non-electric nuclear applications, options, technology readiness and toolkits
- Technology Assessment training
- Infrastructure, economic and financing aspects of SMRs
- Design Specific Issues on Engineering Project, Construction and Industrial Supply Chain for Small Modular Reactor Deployments
- Siting of SMRs
- SMR deployment scenarios in global energy portfolio
- Design safety and safety assessment of SMRs
- Principles for Emergency Preparedness & Response for SMRs
- SMR fuel cycles and waste management (specifically also for HTGRs)

# SMR for Non-Electric Applications

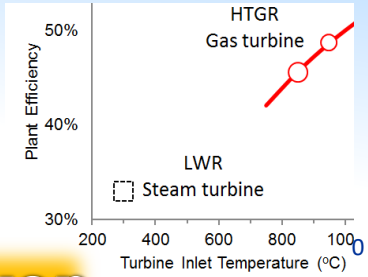


# Optimizing the use of nuclear reactors

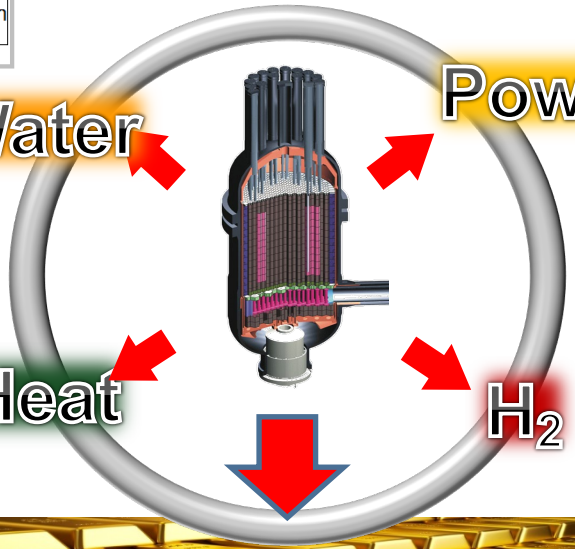


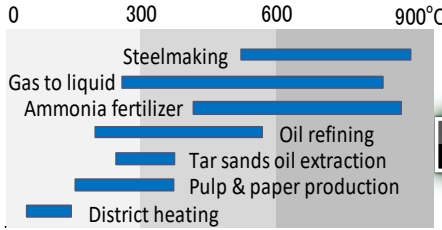

**50 000 m3/day**
**Seawater desalination**

**Reactor outlet coolant 850-950°C**

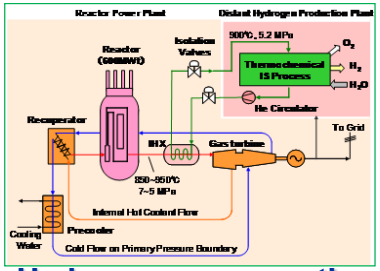



**High efficiency power generation**



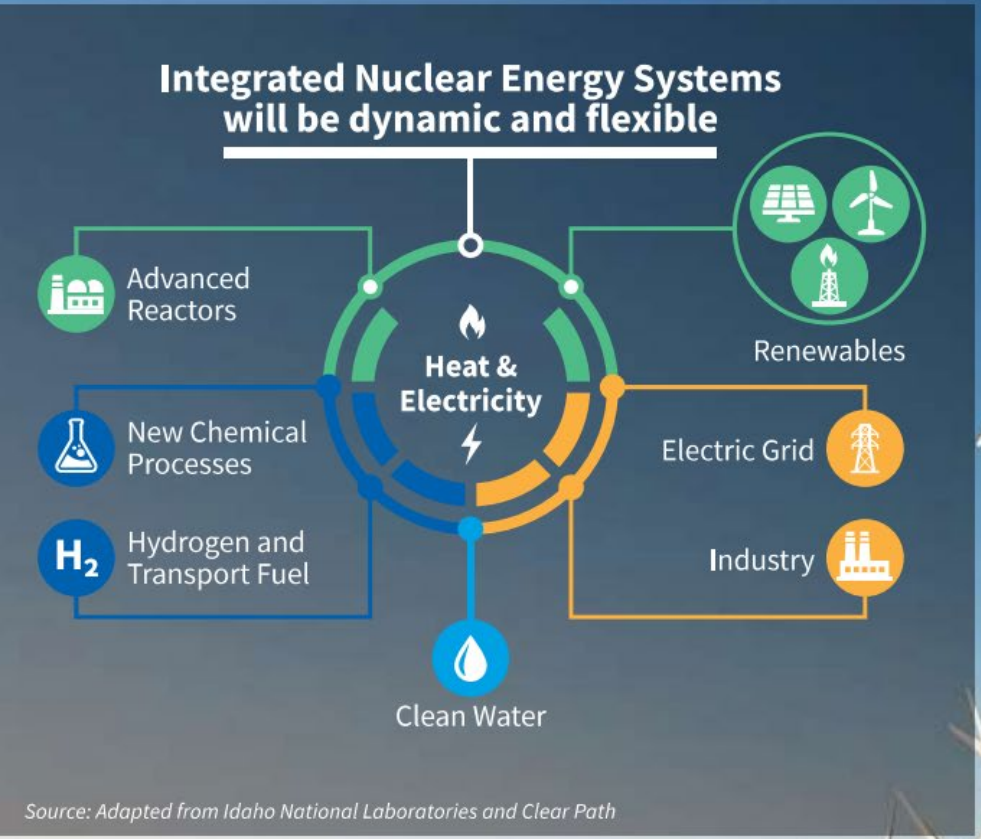

**Industrial heat applications**




**Hydrogen cogeneration**


Nuclear Co-generation

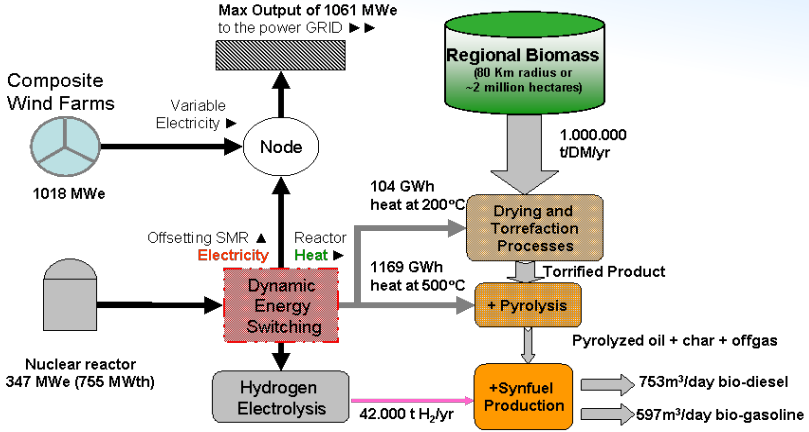
# Nuclear-Renewable hybrid energy systems




Innovative nuclear energy technologies are being developed to complement the deployment of wind and other renewables in integrated energy systems.

Credits: NICE future

# Fully Integrated Hybrid Energy Systems



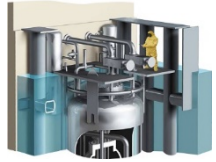

- Combined heat and electricity reactors can support low-carbon goals while providing stability in production and cost
- Can replace existing fossil powered cogeneration plants
- Alternatively Hybrid-nuclear systems / switching between heat and electricity production; can support demand following

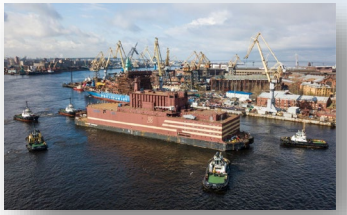
Options:

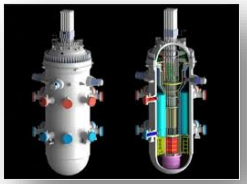
- Supporting heat needs to large industrial complexes
- Supporting desalination, production of biofuel feed stock, district heating and cooling
- Heat storage

# INPRO Dialogue Forum 17 in Coordination with NPTDS

- **INPRO Dialogue Forum (DF) 17 on "Opportunities and Challenges in Small Modular Reactors"**
- Venue: Ulsan, Republic of Korea, Jul 2019
- Opening, Technical Plenaries, Wrap Up and Closing Sessions
- Plenary Technical Sessions:
  - Market Opportunities
  - Design Requirements
  - Research & Technology Development
  - Near Term Deployment Designs (presented by design authorities – designs in licensing, construction or recent deployment)







- Technology Exhibition Space
- Technical Tours to local nuclear sites and industry
- Over 130 current expressions of interest for participation (DFs are usually less than 100 participants)

# Conclusions

- Nuclear power has an important role to play to achieve UN Sustainable Development Goals and Paris Agreement targets
- Innovation applied to the current NPP fleet and R&TD supporting advanced NES are key for the expanded role of nuclear power
- IAEA is addressing growing interest of Member States regarding advanced/innovative reactors, non-electric applications as well as loosely and tightly coupled hybrid energy systems
- The broad variety of advanced reactors (in particular SMR) requires an integrated holistic approach to develop guidance regarding RWM, SNF and decommissioning considerations during the design phase of new reactors, fuel types and advanced fuel cycles


25

8 December 1953

1 to 23 October 1957

11 December 1957

1959

10 December 2005


1958 to 1979

23 August 1979

# *Thank you for your attention!*

**Contact:**
**Stefano MONTI**
S.Monti@iaea.org

*Atoms for peace and Development…*