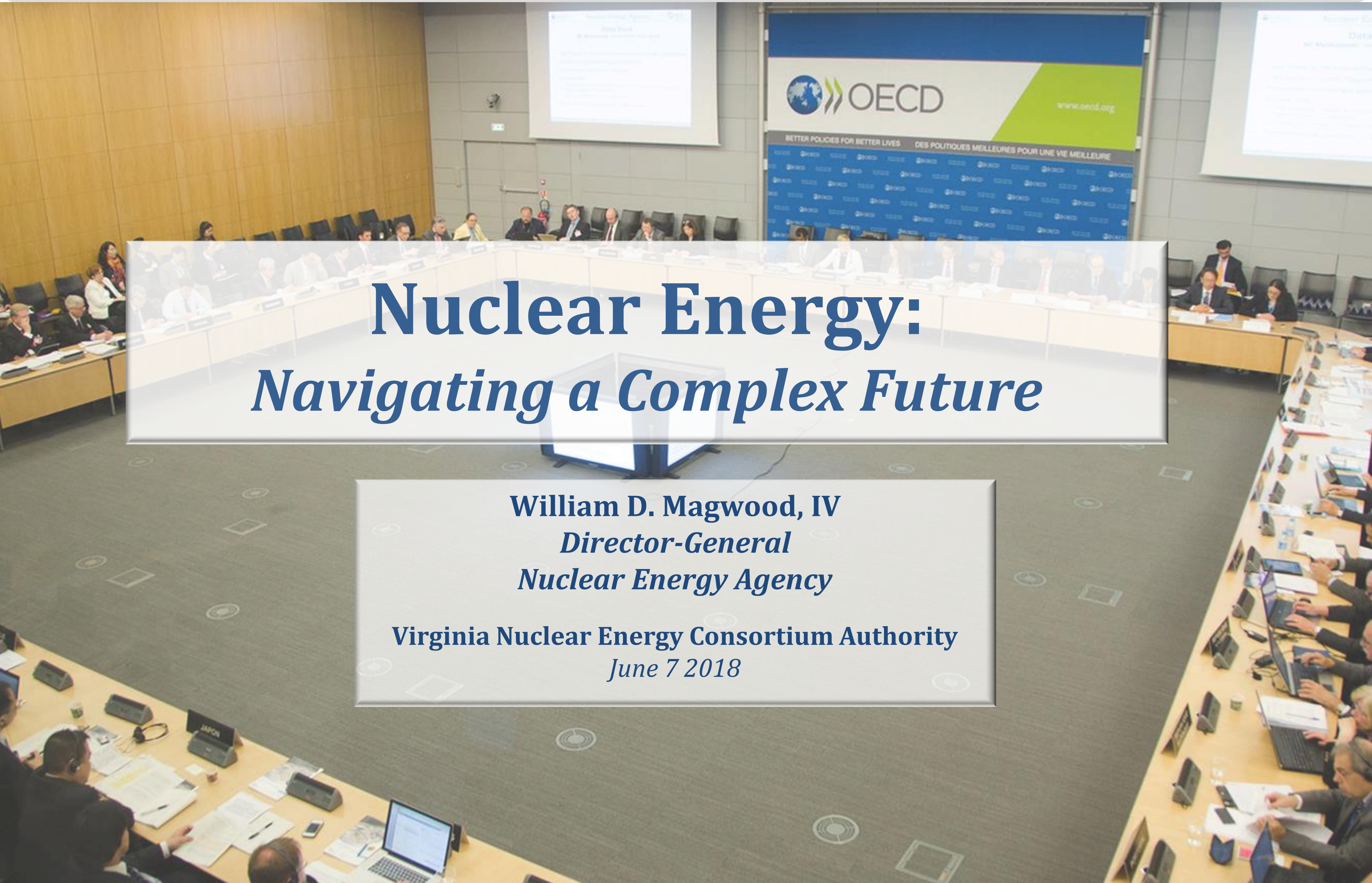


Nuclear Energy:
Navigating a Complex Future

William D. Magwood, IV
Director-General
Nuclear Energy Agency

Virginia Nuclear Energy Consortium Authority
June 7 2018

The NEA: 33 Countries Seeking Excellence in Nuclear Safety, Technology, and Policy

- **33 member countries + strategic partners (e.g., China)**
- **7 standing committees and 72 working parties and expert groups**
- **The NEA Data Bank - providing nuclear data, code, and verification services**
- **22 international joint projects (e.g., the Halden Reactor Project in Norway)**

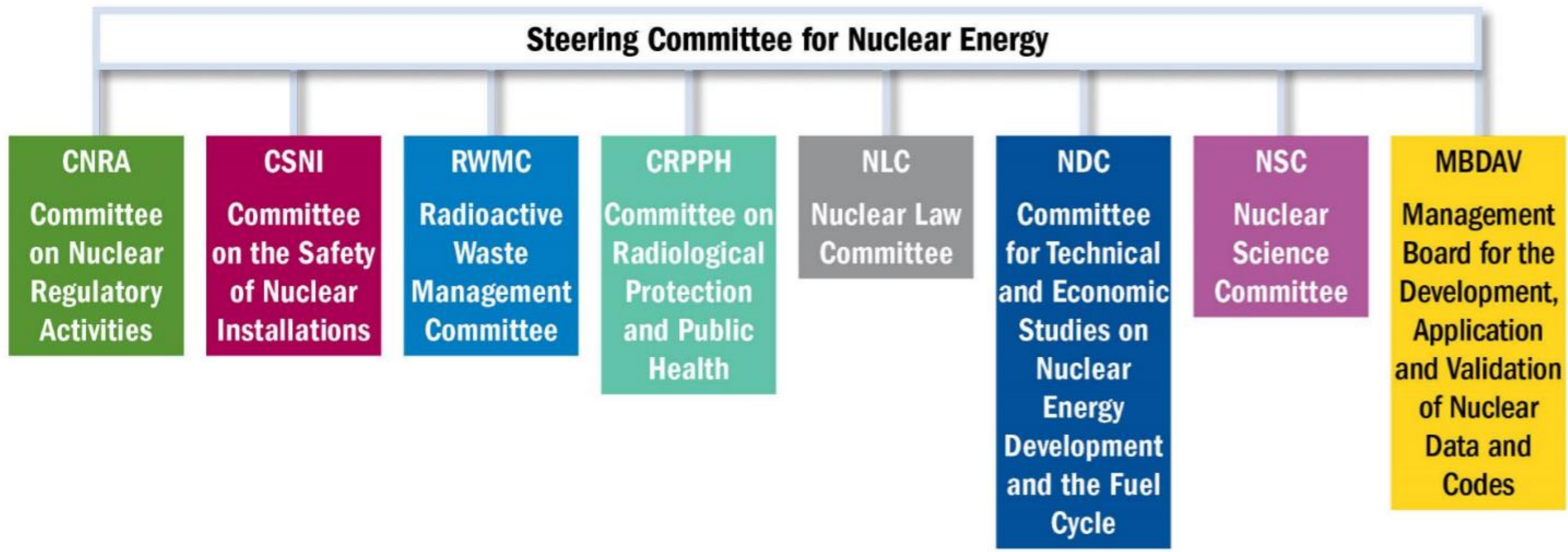
The NEA: A Framework to Address Global Challenges

The Role of the NEA is to:

- Foster international co-operation to develop the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes.
- Develop authoritative assessments and forge common understandings on key issues as input to government decisions on nuclear technology policy.
- Conduct multinational research into challenging scientific and technological issues.

NEA countries operate about 86% of the world's installed nuclear capacity

NEA Standing Technical Committees



The NEA's committees bring together top governmental officials and technical specialists from NEA member countries and strategic partners to solve difficult problems, establish best practices and to promote international collaboration.

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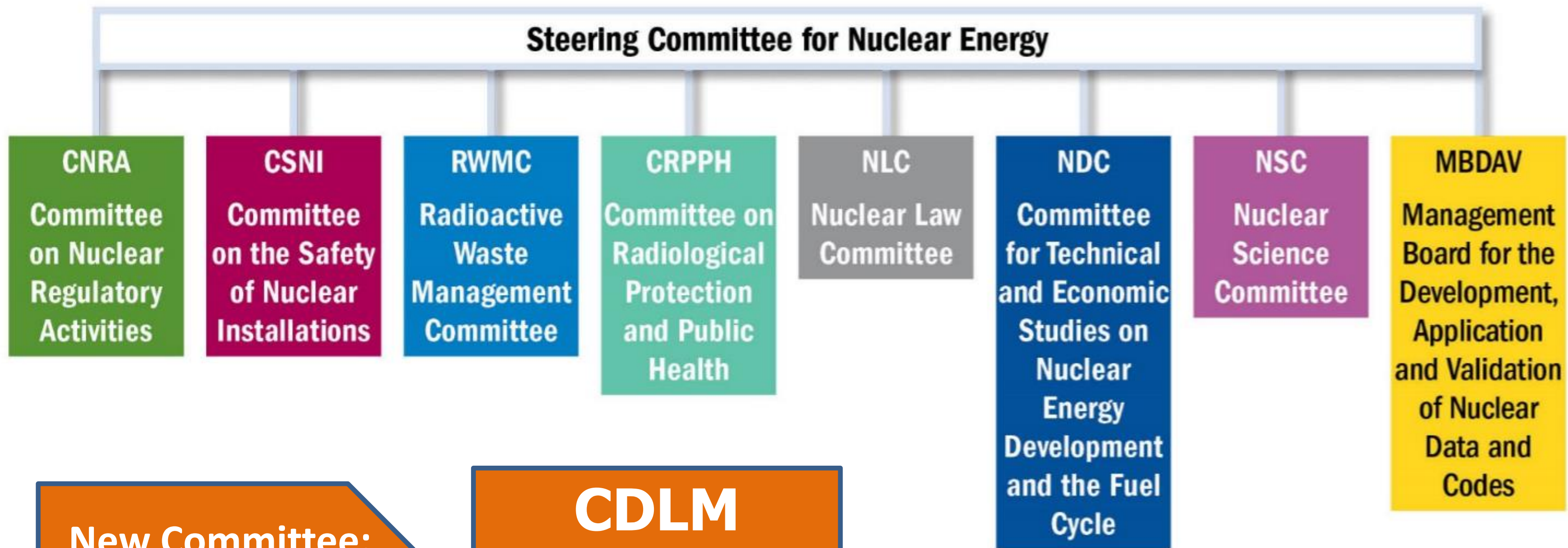

New Committee: Approved 19 April 2018

CDLM

Committee on Decommissioning of Nuclear Installations and Legacy Management

The NEA's committee ... governmental officials and technical specialists from NEA member countries and strategic partners to solve difficult problems, establish best practices and to promote international collaboration.

NEA Nuclear Science Activities

Nuclear Science Committee (NSC)

Expert Group on Improvement of Integral Experiments Data for Minor Actinide Management (EGIEMAM-II)

Expert Group on Multi-physics Experimental Data, Benchmarks and Validation (EGMPEBV)

Expert Group on Accident-tolerant Fuels for LWRs (EGATFL)

Working Party on International Nuclear Data Evaluation Co-operation (WPEC)

- High Priority Request List for Nuclear Data

Working Party on Scientific Issues of the Fuel Cycle (WPFC)

- Heavy Liquid Metal Technologies
- Fuel Recycling Chemistry
- Advanced Fuel Cycle Scenarios
- Innovative Structural Materials
- Innovative Fuels
- Benchmarking of Thermal-hydraulic Loop Models for Lead-alloy-cooled Advanced Nuclear Energy Systems

Working Party on Multi-scale Modelling of Fuels and Structural Materials for Nuclear Systems (WPMM)

- Validation and Benchmarks of Methods
- Multi-scale Modelling Methods
- Structural Materials Modelling
- Multi-scale Modelling of Fuels
- Primary Radiation Damage

Working Party on Nuclear Criticality Safety (WPNCS)

- Advanced Monte Carlo Techniques
- International Criticality Safety Benchmarks Evaluation Project
- Criticality Excursions Analyses
- Assay Data of Spent Nuclear Fuel
- Uncertainty Analyses for Criticality Safety Assessment

Working Party on Scientific Issues of Reactor Systems (WPRS)

- Reactor Physics and Advanced Nuclear Systems
- Uncertainty Analysis in Modelling
- Reactor Fuel Performance
- Radiation Transport and Shielding

NEA joint project in the nuclear science area:

Thermodynamics of Advanced Fuels – International Database (TAF-ID) Project

NEA joint projects in the nuclear science area under development:

Thermodynamic Characterization Of Fuel debris and Fission products based on scenario analysis of severe accident progression at Fukushima Daiichi NPP **(TCOFF)**

NEA Education and Skills & Technology **(NEST)** Framework

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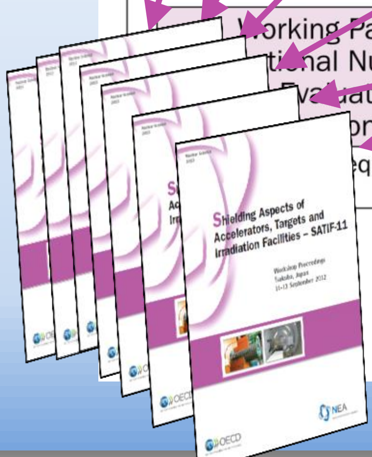


Nuclear Science Work Areas
- ***State-of-the-art reviews***
- ***Benchmark studies***
- ***Sensitivity & Uncertainty Analyses***
- ***Workshop/Seminar/Conference proceedings***

Major NEA Separately Funded Activities

NEA Serviced Organisations

- **Generation IV International Forum (GIF)** with the goal to improve sustainability (including effective fuel utilisation and minimisation of waste), economics, safety and reliability, proliferation resistance and physical protection.
- **Multinational Design Evaluation Programme (MDEP)** initiative by national safety authorities to leverage their resources and knowledge for new reactor design reviews.
- **International Framework for Nuclear Energy Cooperation (IFNEC)** forum for international discussion on wide array of nuclear topics involving both developed and emerging economies.

23 Major Joint Projects

(Involving countries from within and beyond NEA membership)

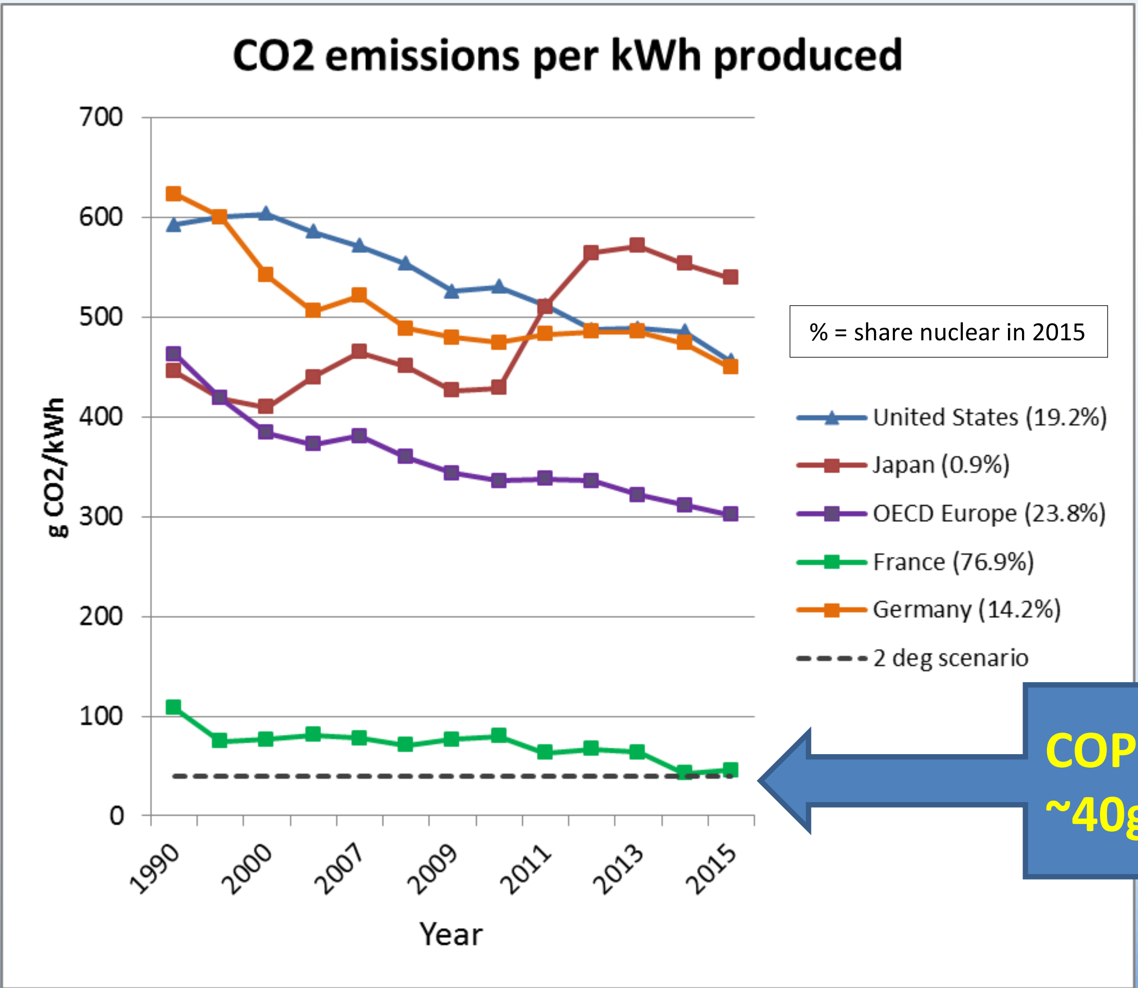
- **Nuclear safety research** and experimental data (e.g., thermal-hydraulics, fuel behaviour, severe accidents).
- **Nuclear safety databases** (e.g., fire, common-cause failures).
- **Nuclear science** (e.g., thermodynamics of advanced fuels).
- **Radioactive waste management** (e.g., thermochemical database).
- **Radiological protection** (e.g., occupational exposure).
- **Halden Reactor Project** (fuels and materials, human factors research, etc.)

COP 21 and Energy Production

- UN-sponsored meeting concluded with 195 countries agreeing to develop approaches to limit global warming to below 2°C.
- Energy represents 60% of global CO_2 emissions - ¾ of global electric power production today is based on fossil fuels.
- Many countries – including China and India indicate that nuclear will play a large role.

Electricity Mix and Carbon Emissions

(g CO_2 per kWh produced)



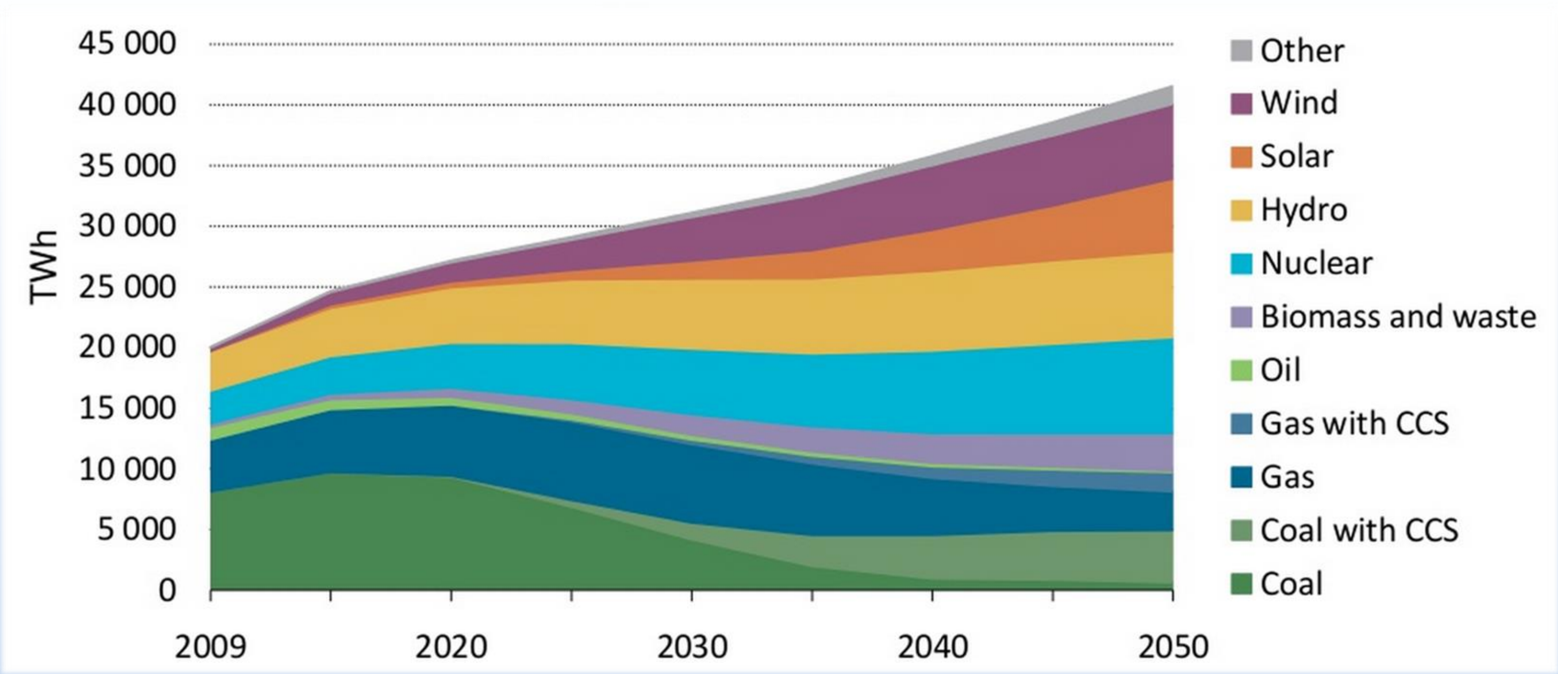
Main trends:

- US: coal to gas switch, ↗ RES
- Japan: nuclear ↘↘↘, fossil ↗↗↗
- France: fossil ↘, RES ↗
- Germany: nuclear ↘↘, RES ↗↗

COP 21 Objective: ~40g CO_2 /kWh

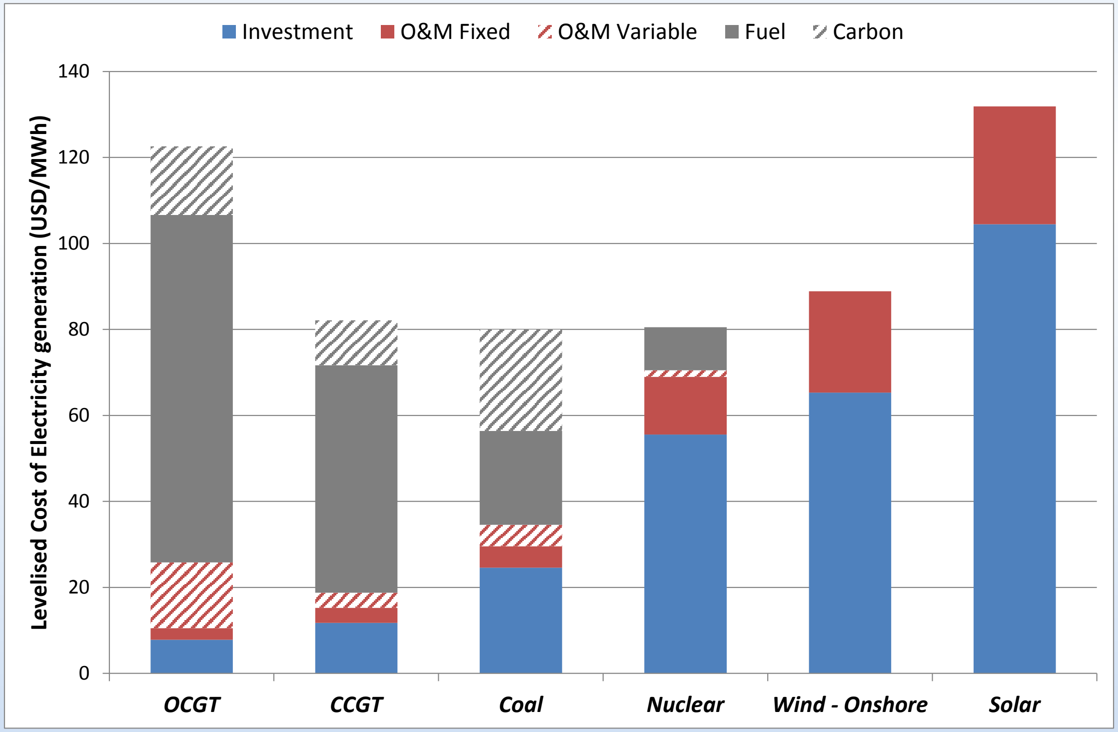
Source: IEA data (CO2 emissions from fuel combustion 2017, Electricity Information 2017)

IEA 2°C Scenario:
Nuclear is Required to Provide the Largest Contribution to Global Electricity in 2050



Source: IEA

But is Nuclear Cost Competitive?

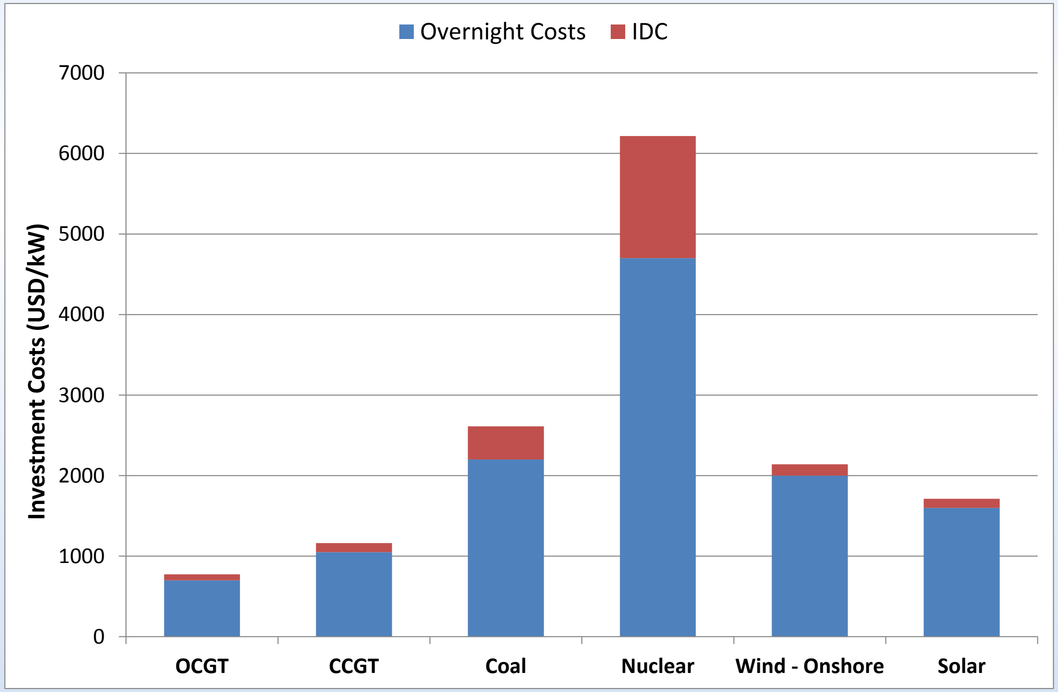


Levelized Cost for Plants Built in 2020

- Today's nuclear energy plants are a very competitive source of long-term electricity supply.
- Costs of renewables are dropping but, without subsidies, are still high.
- Costs of natural gas still sets the pace for the market and are generally low.

Source: NEA

But is Nuclear Cost Competitive?

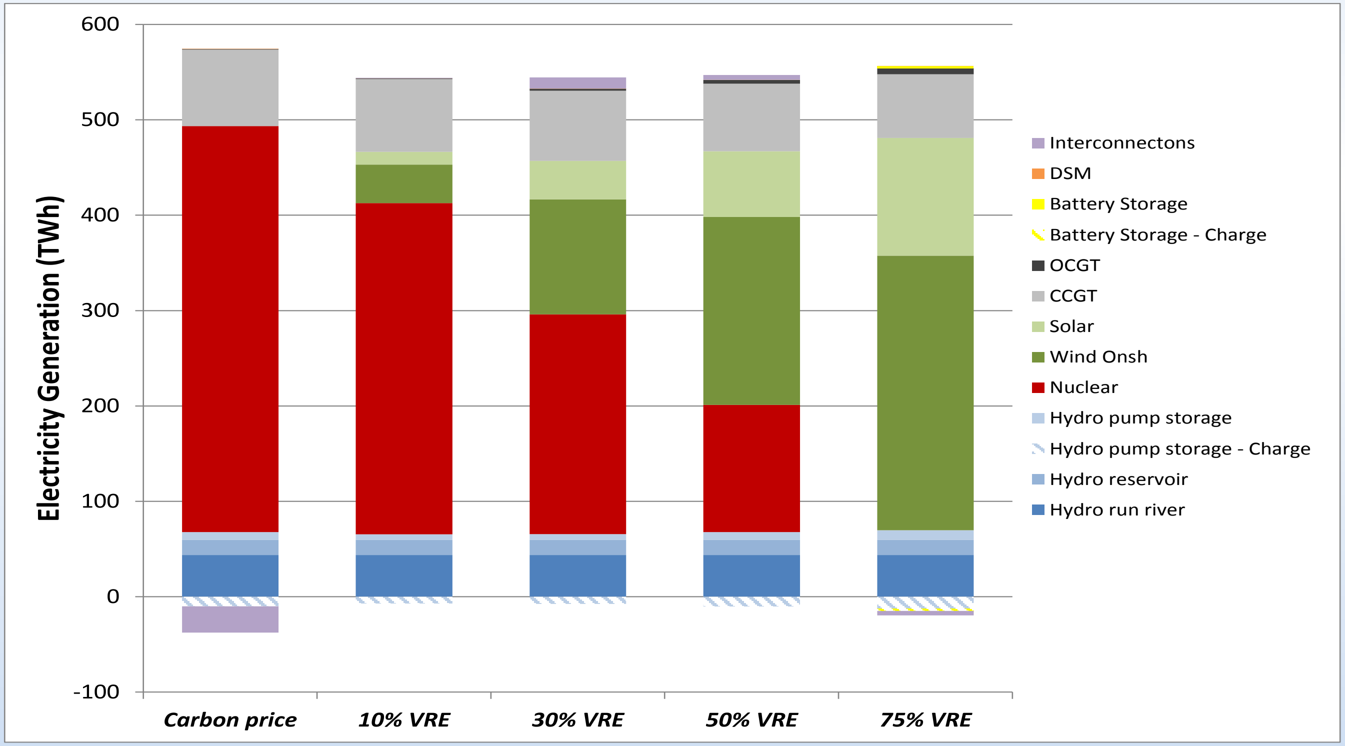


Overnight Construction Costs for Plants Built in 2020

- In today's market, the capital cost of nuclear power is a major issue.
- Lack of construction experience and weak supply chains make construction costs uncertain.
- As the costs of alternatives drop, these high costs become unsustainable.

Source: NEA

How Does Nuclear Fare Against VREs in a Low Carbon Scenario?

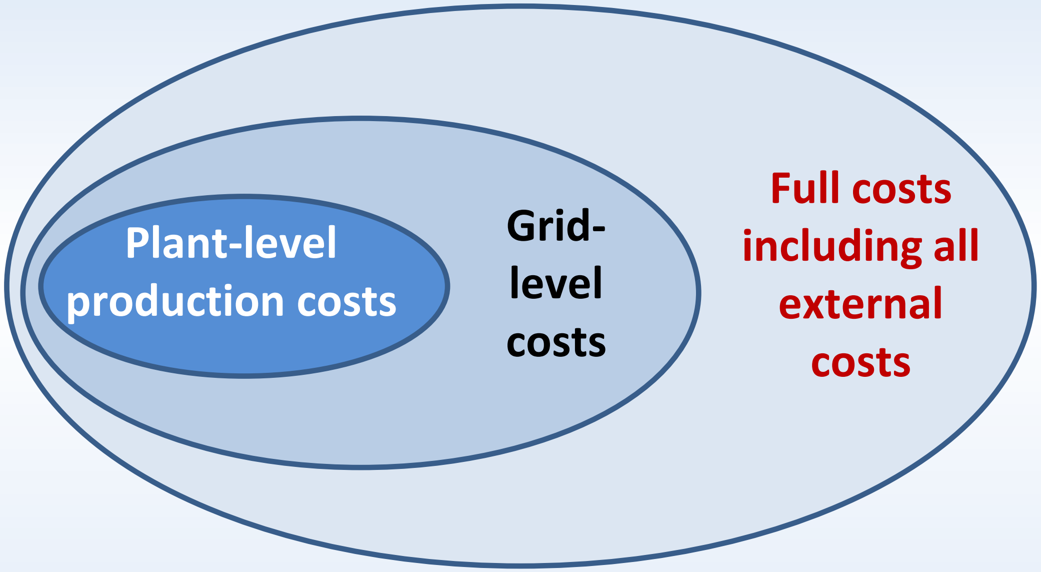


Largely because of high capital costs, current nuclear generation is displaced by VRE as their penetration level increases.

Source: NEA

All Costs Should be Reflected in Decisions

- **Electricity production, transport and consumption affect every facet of life.**
- **Market prices and production costs account for an important share of the overall impacts of electricity.**



- **However, the market value of electricity is not the whole story:**
  - System or "Grid-level" Costs
  - Atmospheric pollution, climate change risks and land-use
  - Impacts on security of supply, cost of major accidents, innovation and employment
- **The price of electricity in today's markets does not accurately reflect the FULL COSTS of electricity, which include the impacts on society and the environment.**

An Example of Social Cost Estimates

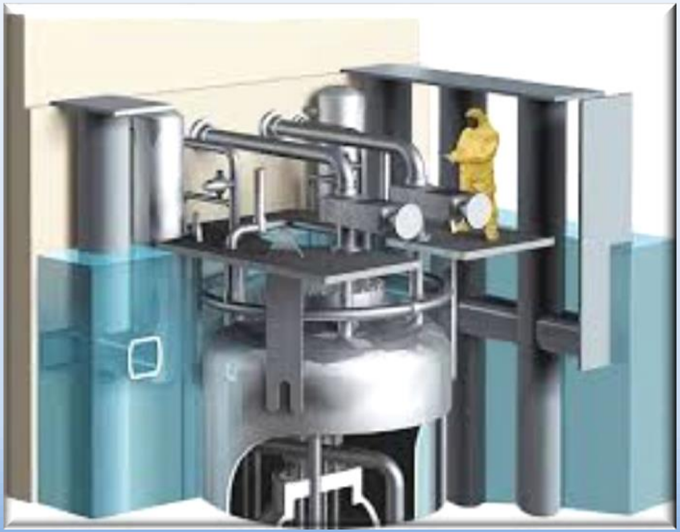
European CASES Project (Euros per MWh)

	Nuclear	Coal IGCC	Lignite IGCC	Gas CCGT	Hydro (dam)	Wind ON	Wind OFF	Solar PV	Biomass (straw)	Biomass (wood)
Human Health	1.55	8.35	3.84	4.24	0.57	0.75	0.72	6.58	15.55	4.64
Loss of Biodiversity	0.09	0.79	0.32	0.52	0.02	0.04	0.03	0.34	2.94	0.49
Crops (N, O_3, SO_2)	0.02	0.15	0.04	0.12	0.01	0.01	0.01	0.07	0.10	0.13
Materials (SO_2 , NO_x)	0.03	0.11	0.03	0.07	0.01	0.01	0.01	0.09	0.12	0.07
Radionuclides	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Climate Change	0.43	17.6	19.57	8.97	0.16	0.21	0.17	1.81	1.46	1.20
TOTAL	**2.14**	**26.96**	**23.80**	**13.93**	**0.76**	**1.03**	**0.94**	**8.88**	**20.17**	**6.54**

Source: FEEM (2011)

Key Observations

- Renewables **will be deployed** in significant quantities and are now dramatically altering electricity markets.
- **Natural gas prices are at historic lows** in many markets and are expected to remain low for many years – if not decades.
- Nuclear energy is the only expandable, large-scale, dispatchable source of zero-emission energy. It can have a large role in the future – but **the technology must adapt**.



Water-Cooled Reactors: *Success and Challenges*

Global Successes

- Well-understood technology, can be built at large scale
- Despite 3/11, excellent record of safe operation around the world
- Provides highly reliable, dispatchable, zero-emission energy

Ongoing Challenges

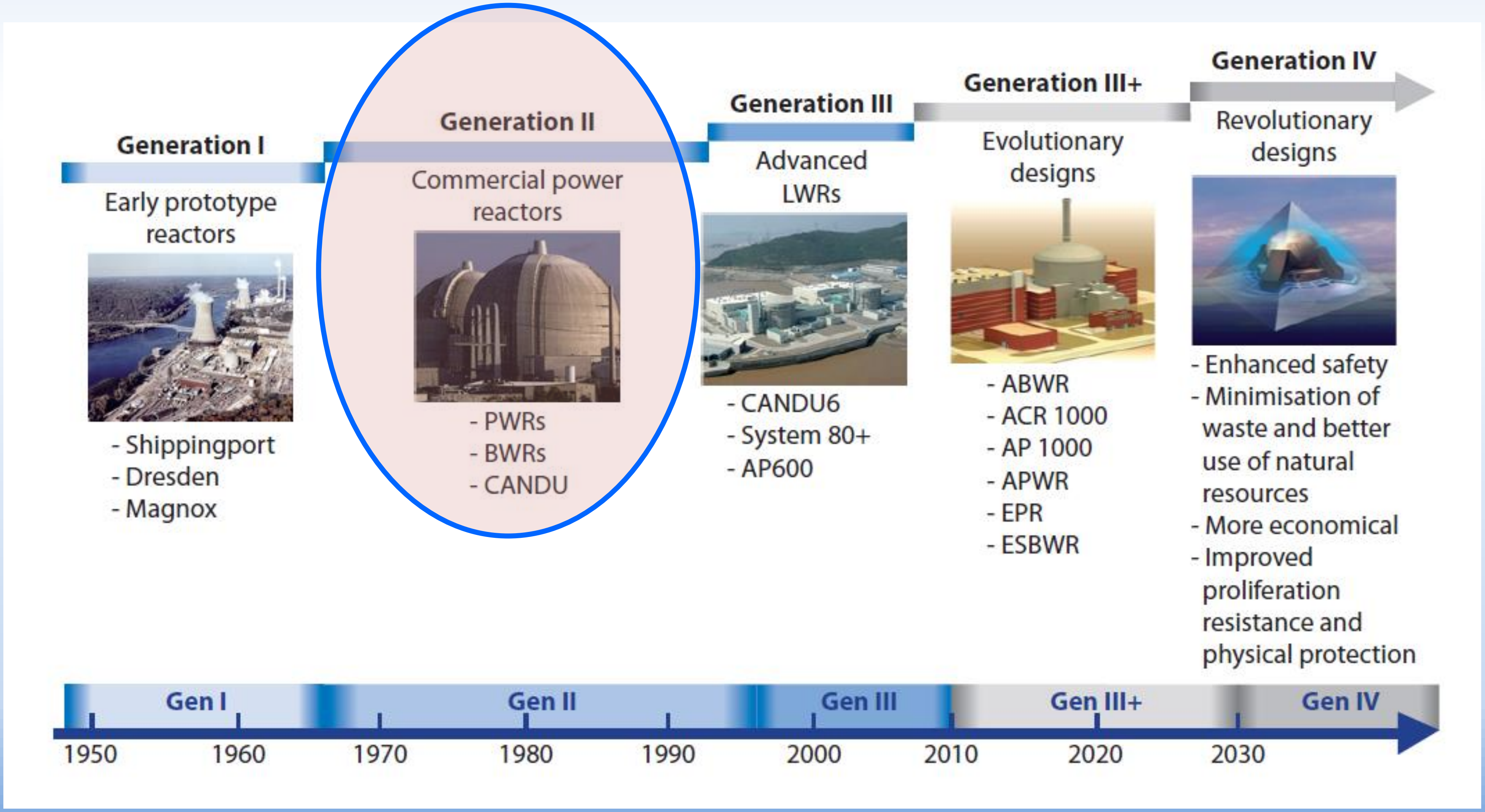
- Safe design and operation and effective regulation is expensive compared to other energy sources
- Nuclear waste disposal
- Persistent public concerns about safety in some countries

Innovation is Needed to Assure the Long-Term Role of Nuclear Energy

- **Improving cost effectiveness and flexibility**
- **Enabling further enhancements to safety at lower cost**
- **Assuring a sustainable, long-term fuel cycle while addressing policymaker concerns about nuclear proliferation**
- **Resolving questions about nuclear waste and environmental impacts**
- **In general: It is necessary to assure that nuclear fits in the future, as yet uncertain, global energy framework.**

But the global capacity to develop and deploy nuclear energy technology innovations is contracting at a time of greatest need

Generation IV:
20 Years of R&D Activity But No Demonstrations



Nuclear Innovation Headwinds:
Little Progress in the Last 25 years

INFRASTRUCTURE

- **Unlike many other areas of innovation, nuclear technology often requires the availability of special facilities (test reactor, hot cells, test loops, etc.) and nuclear-skilled workers.**
- **Tests using fissile materials require appropriate facilities, trained workforce, security and licencing.**
- **Much of the global infrastructure was built more than 40 years ago and is shrinking steadily.**

REGULATORY

- **The job of today's nuclear regulatory organisations is to assure public safety, not to promote innovation.**
- **Maintaining public confidence is essential for all nuclear regulators.**
- **Regulators in most countries will not actively participate in technology development – but will wait for the finished technology to be presented for approval.**
- **Regulators are often viewed by researchers and industry as a barrier to innovation.**

COST

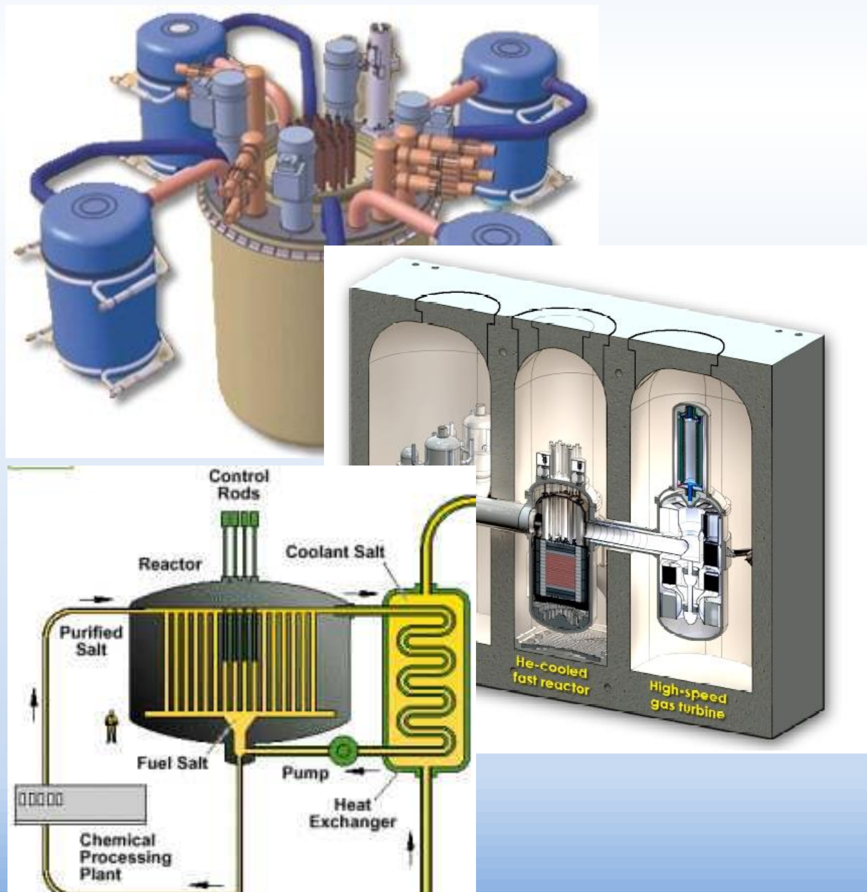
- **Nuclear technology research budgets have been declining in most countries for the last decade or are designed to avoid costly long-term commitments.**
- **Nuclear technology often requires an order-of-magnitude increase in funding to transition between research and engineering-scale demonstration.**
- **The cost and risk of nuclear technology innovation has become prohibitive in many countries.**

The Vision Thing:
Our Biggest Technology Challenge

AEC Chair Glenn Seaborg and NASA Administrator James Webb – July 1961

- **Early 1950s: AEC and NASA started with little; limited infrastructure, limited proven industrial support.**
- **Over about 15 years – both experienced tremendous growth and both made incredible technological progress.**
- **1970s – both initiated bold steps into the future that proved difficult and costly.**
- **1980s-1990s – public support and interest waned and resources reduced.**
- **Today – little significant progress being made and direction is unclear. Bold initiatives have been largely left to private ventures.**

Nuclear Innovation 2050:
Pursuing Global Agreement on the Nuclear R&D Needs for the Future



- What technologies will be needed in 10 years? 30 years? 50 years?
- What R&D is needed to make these technologies available?
- Is the global community doing the R&D needed to prepare for the future?
- Can we cooperate to do more?

NI2050 Targets for Innovation

SHORT TERM — MEDIUM TERM — LONG TERM

- Ageing Management and Long Term Operation
- Decommissioning Technologies
- Advanced Manufacturing and Construction
- Waste Management & Disposal
- Nuclear Process Heat/Cogeneration (550/1000 C)
- Hybrid Systems
- (Gen IV) Adv Mat /Fuels /Components
- Advanced Recycling
- ATF
- Passive Safety
- Severe Accident Knowledge and Management

ENABLERS: Life Cycle Management/Modelling and Simulation/Robotics and I&C

R&D Infrastructures and Demos

Major Questions for the Future

- Will countries really take substantive action to limit carbon emissions?
- Is VRE penetration above 40-50% realistic, practical, and desirable?
- What role will storage play in the future?
- Will nuclear energy adapt to the evolving markets and policy environment?

Concluding Thoughts

- To meet energy and environmental requirements, water-cooled reactors are likely to be needed in many countries for decades to come.
- Some light-water SMR designs are excellent steps in the right direction toward more cost-competitive, flexible nuclear energy.
- But for the longer-term future, we will need fission energy technology that can be built and operated at costs comparable to other energy technologies.
- Fission energy technology needs to evolve or its peak use may already be behind us in OECD countries.
- The time is **NOW** for us to take the next substantive steps in developing and deploying fission energy for the 21st Century.

Thank you for your attention

More information @ www.oecd-nea.org

All NEA reports are available for download free of charge.

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