



Technology Roadmap

Nuclear Energy

2015 edition

2050

2045

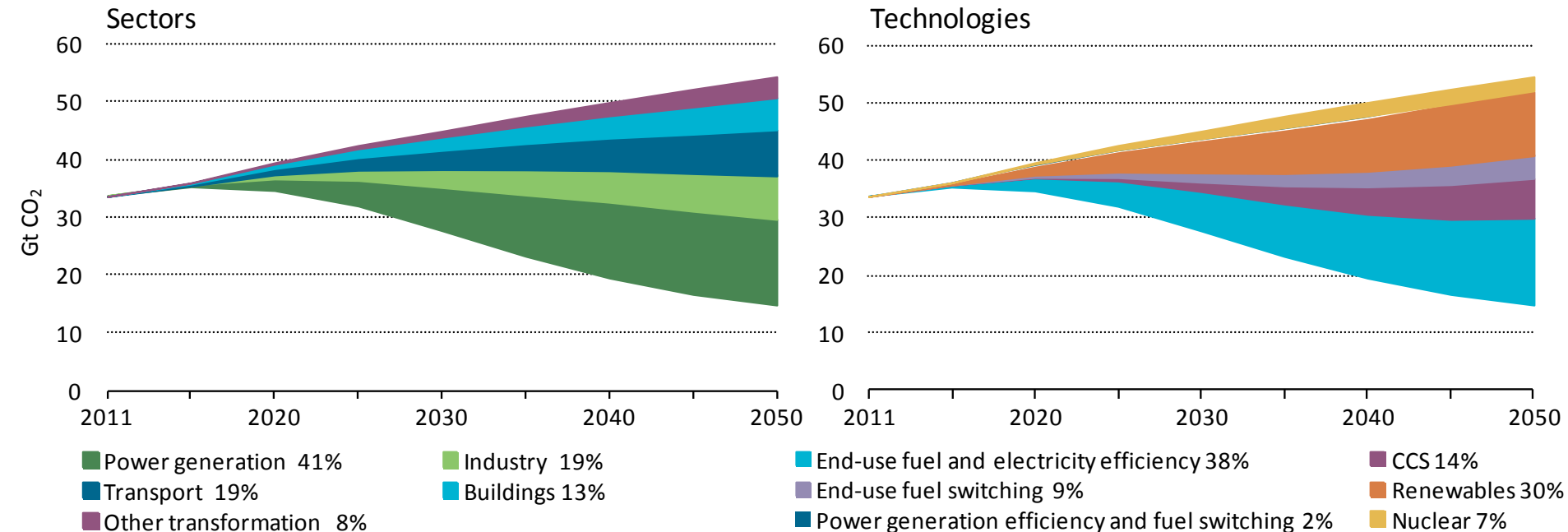
2035

2040



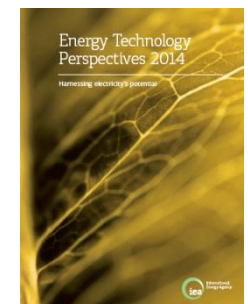


IEA Flagship Publication, Energy Technology Perspectives



Source: Energy Technology Perspectives 2014

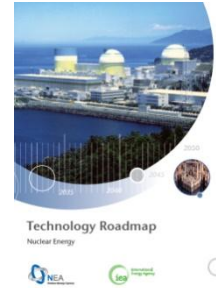
- 6° C Scenario – business-as-usual; no adoption of new energy and climate policies
- 2° C Scenario - energy-related CO₂-emissions halved by 2050 through CO₂-price and strong policies





Nuclear since 2010, update of early roadmap

- **Fukushima Daiichi accident (March 2011)**
 - Impact on energy policies & public acceptance
 - Safety evaluations and upgrades
- **Aftermath of financial crisis (2007-2008) and economic crisis**
- **Uranium market depreciation**
- **Shale gas revolution in the US (and US coal prices↘)**
- **Cost overruns and delays in some FOAK Gen III projects**
- **Lower than anticipated costs for onshore wind and solar PV**





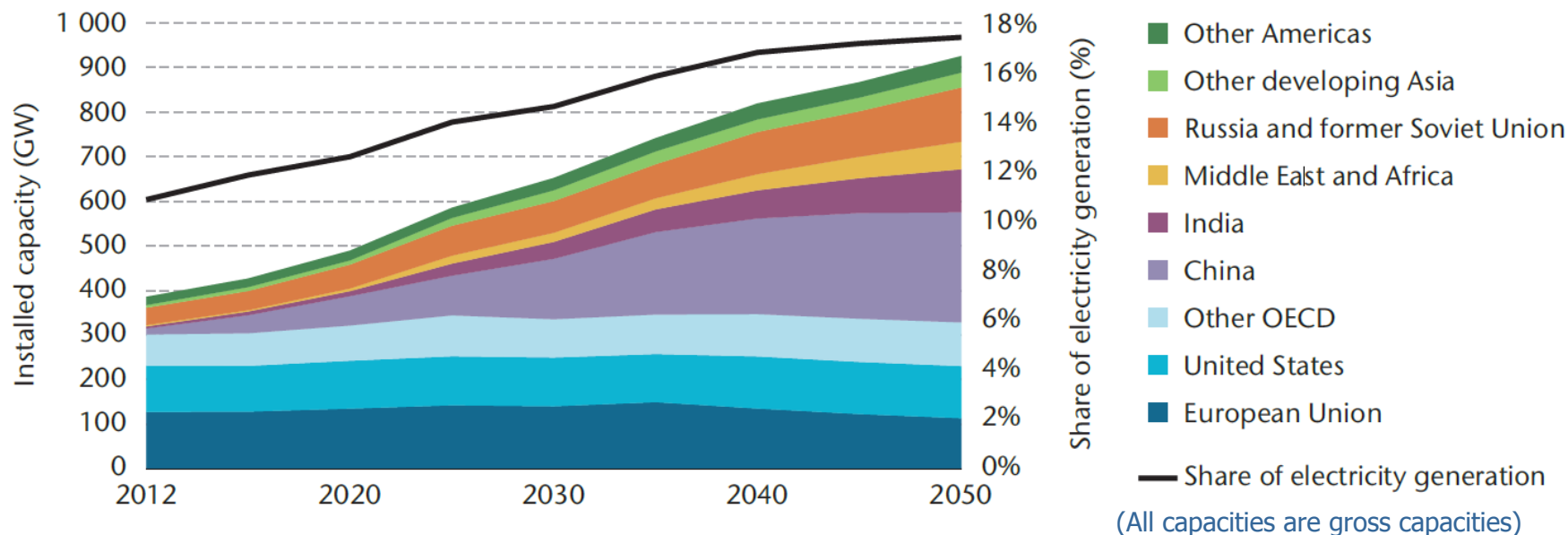
Objectives of the roadmap update

- Provide an overview of nuclear energy today, and areas of potential growth (regional analysis)
- Identify key technological milestones and innovations that can help support ambitious growth in nuclear energy
- Identify barriers to nuclear development
- Recommendations to policy-makers on how to reach milestones & address barriers
- Case studies developed with experts to support recommendations





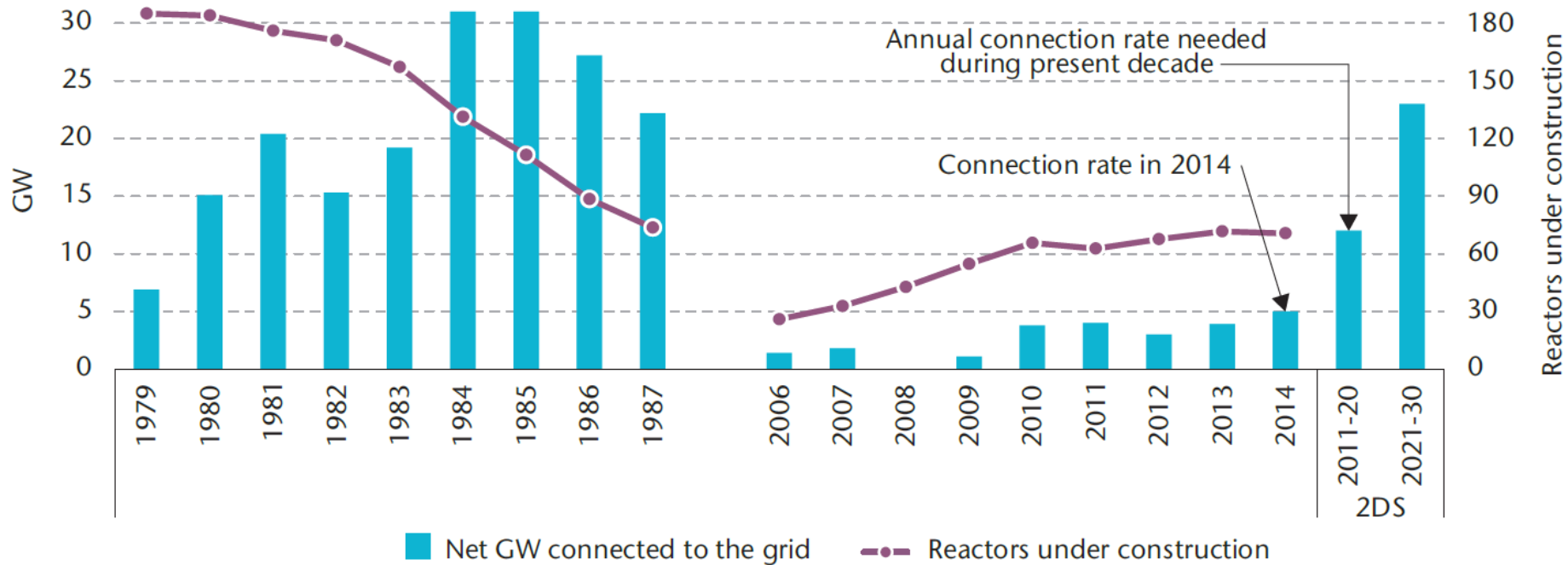
Nuclear in the 2°C Scenario (2DS)



- **930 GW by 2050 (down from 1200 GW)**
- **17% share electricity (down from 24%)**
- **But still a formidable challenge (multiply current capacity by 2.3 in 35 years)**



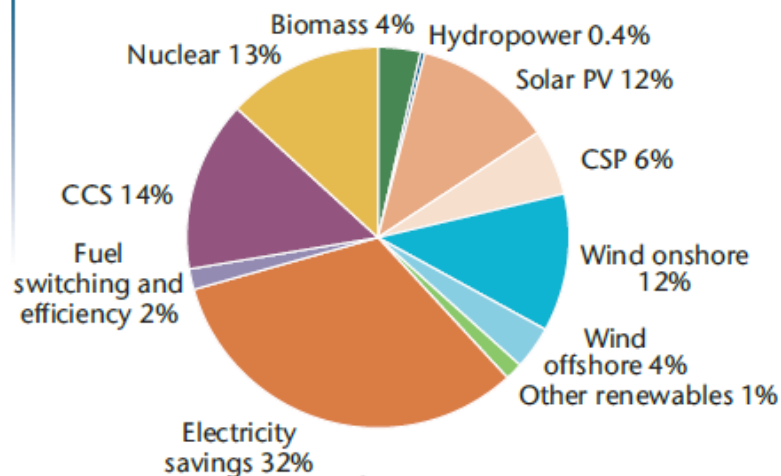
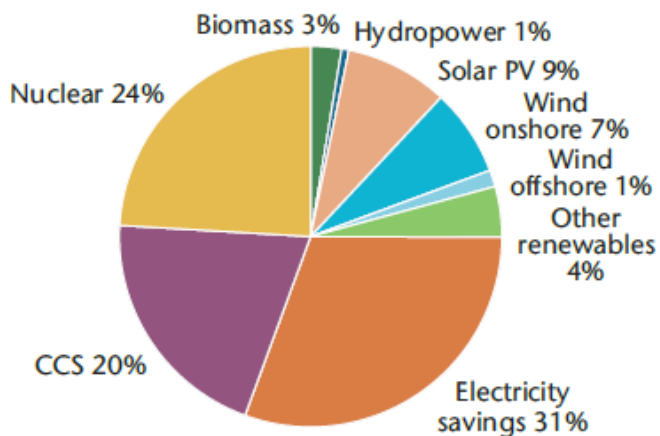
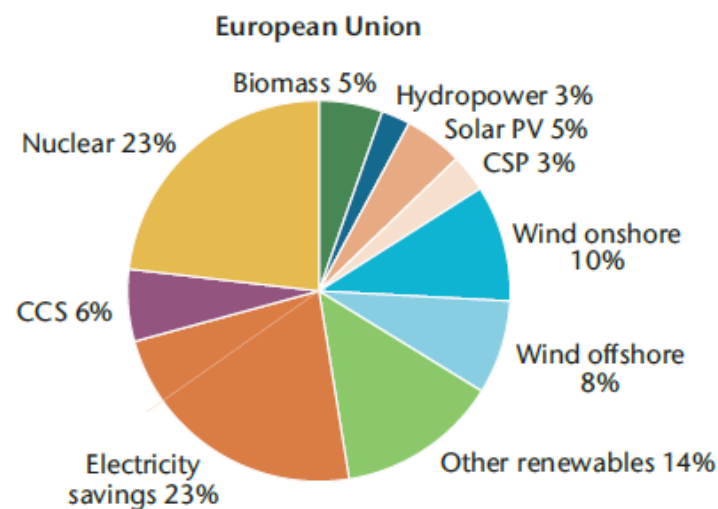
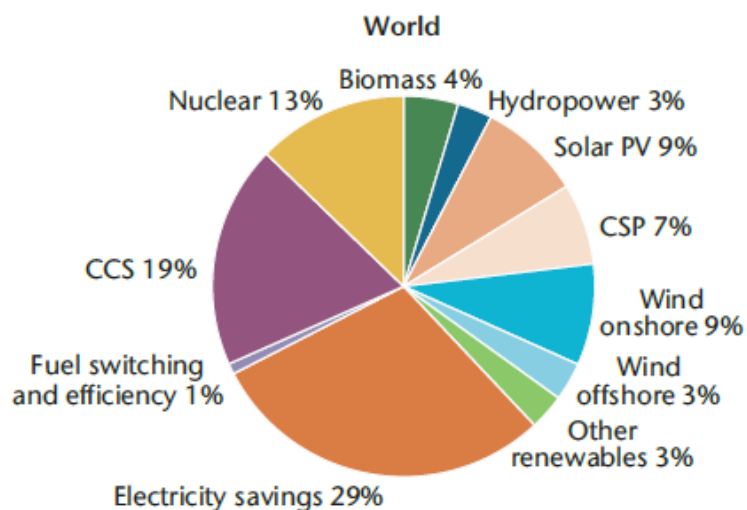
Nuclear capacity additions



- In 2014, 3 construction starts, 5 GW connected! (<< 12 GW/year needed this decade)
- Nuclear is not on track to meet 2DS targets

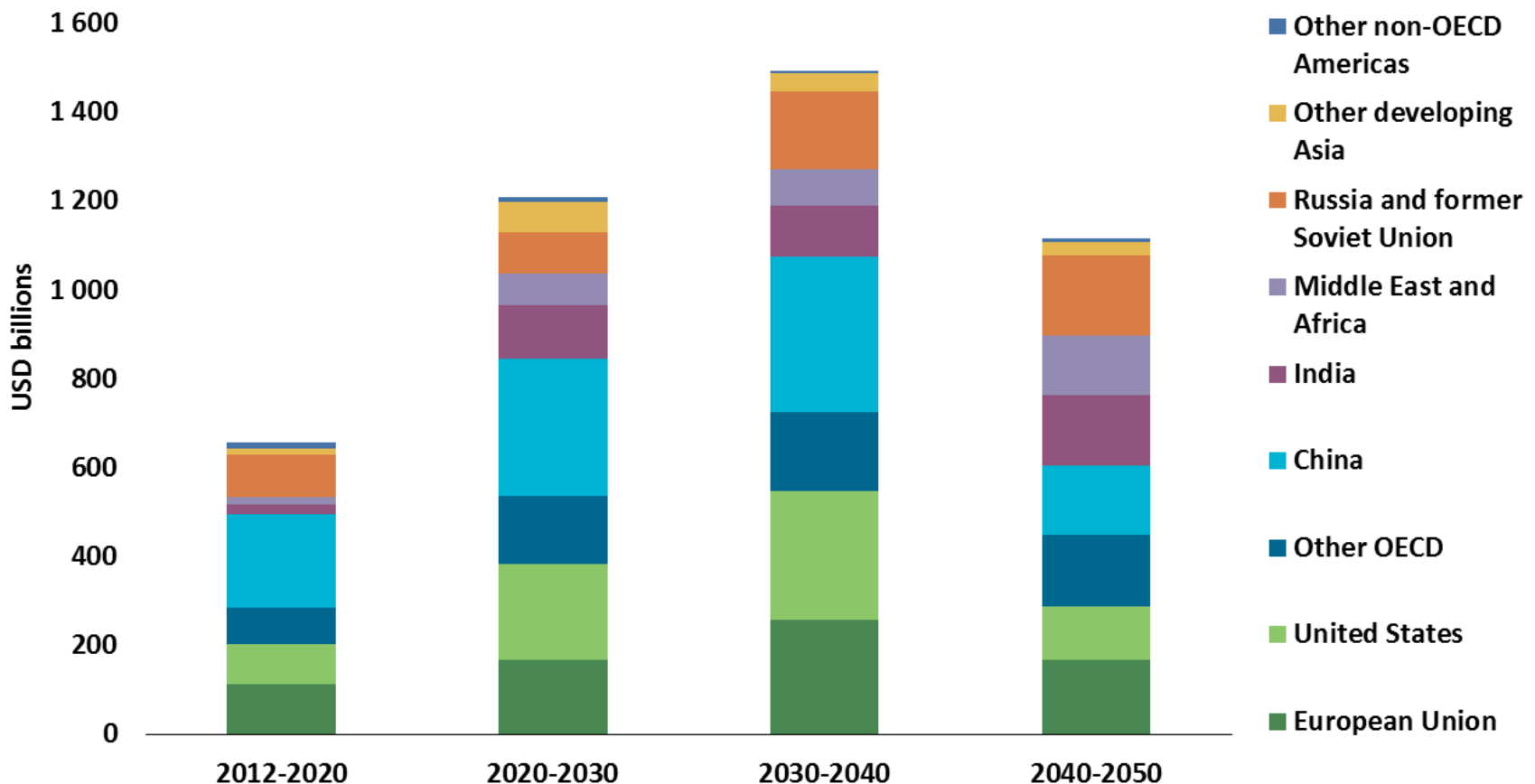


Emissions reduction in the power sector in 2050





Nuclear investment requirements in 2DS, 2012-2050



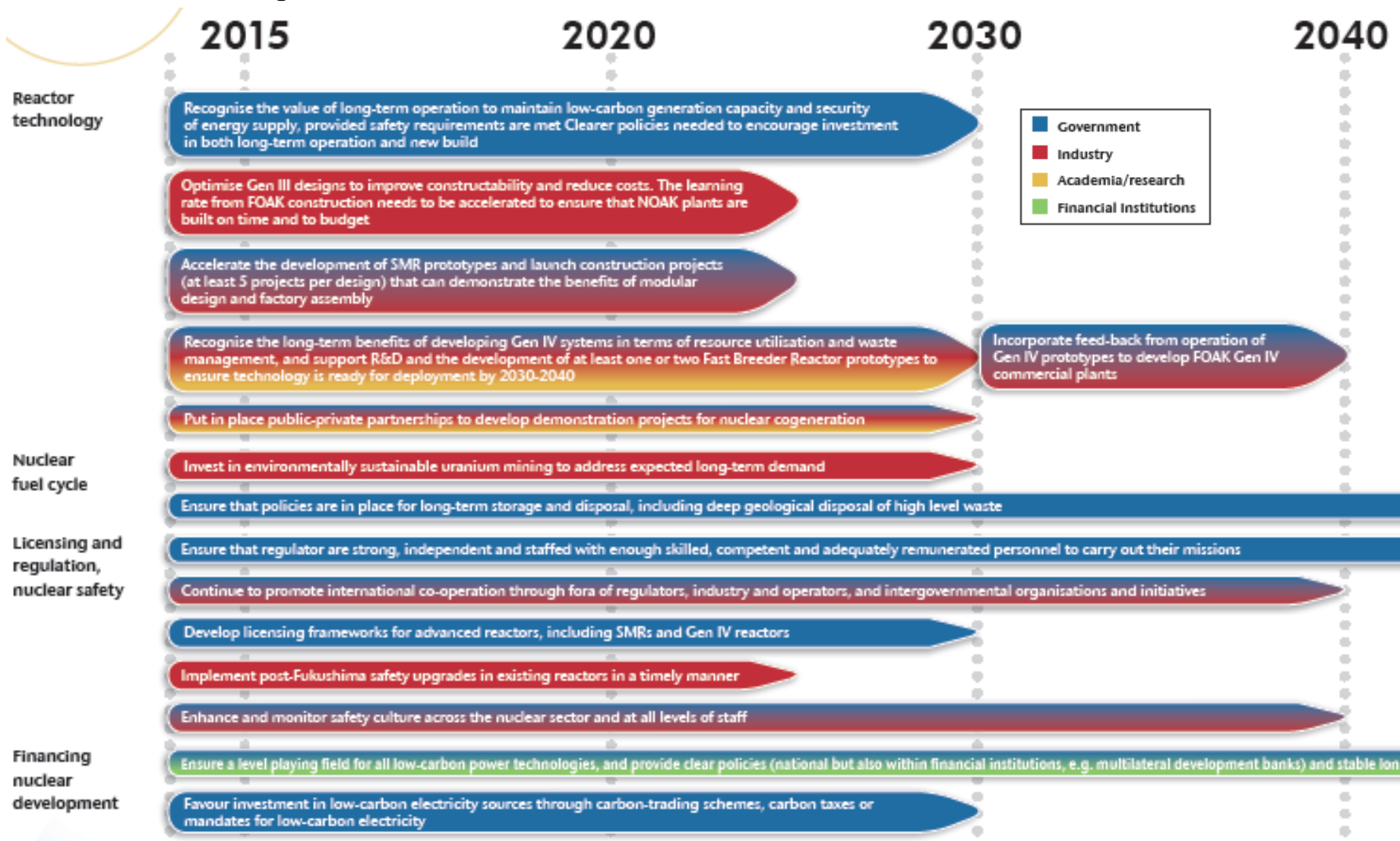


Financing

- **Government support key – long term strategy & policy stability (importance of technologically-neutral policies)**
- **Role of export credit agencies, part equity financing**
- **Refinancing strategies once construction completed**
- **Financing in liberalised markets challenging:**
 - **Cooperative model (Mankala principle), BOO model, ...?**
- **Importance of de-risking nuclear projects:**
 - **“Build on time & to budget” requirement**
 - **long term power purchase agreements, CfD in UK**
 - **Importance of international nuclear liability conventions, clarify costs of nuclear accidents**

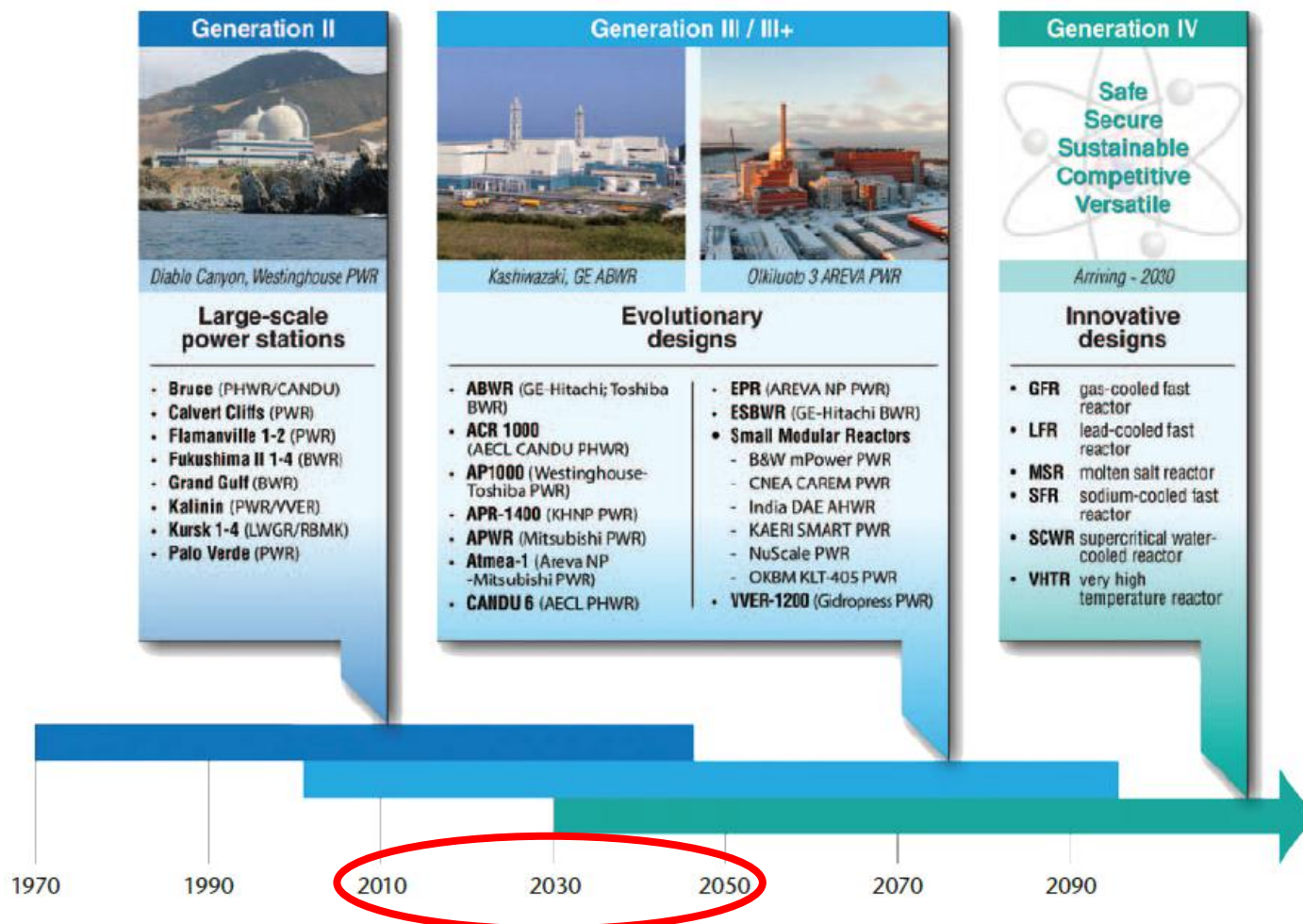


Roadmap actions and milestones





Reactor technology evolution

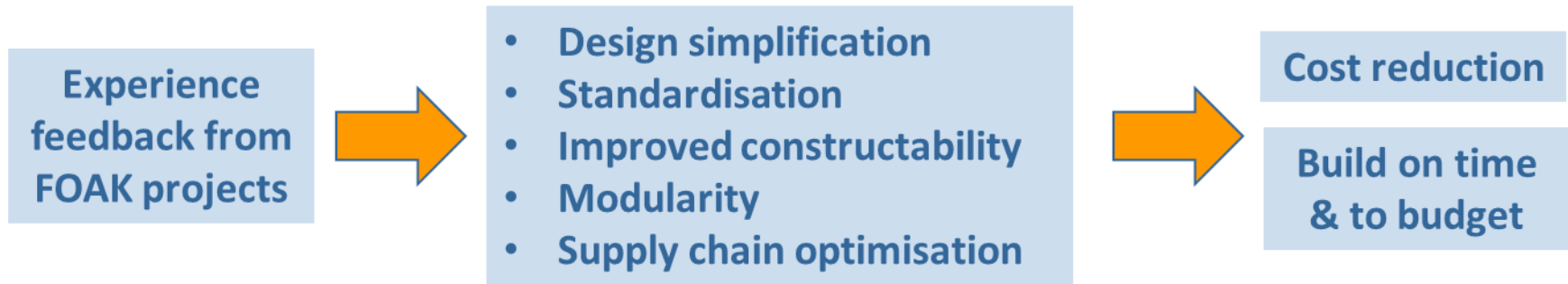


Source: Generation IV International Forum, www.gen-4.org.



Reactor technology evolution

- Safety upgrades & Long Term Operation of existing fleet
- Continuous evolution of Gen III/III+ designs:



- Small Modular Reactors
- Operational aspects
- Generation IV (Fast Neutron Reactors)
- Cogeneration / non-electric applications



Reactor technology

<i>This Roadmap recommends the following actions:</i>	<i>Proposed timeline</i>
Governments to recognise the value of long-term operation to maintain low-carbon generation capacity and security of energy supply, provided safety requirements are met. Clearer policies are needed to encourage operators to invest in both long-term operation and new build so as to replace retiring units.	2015-30
R&D in ageing of systems and materials is needed to support safe, long-term operation of existing nuclear power plants (NPPs) for 60 years operation or more.	Ongoing
Vendors to optimise Gen III designs to improve constructability and reduce costs. The learning rate from new build construction needs to be accelerated by rapidly integrating lessons learnt from FOAK projects (design optimisation, project management, supply chain, interactions with regulators) to ensure that NOAK plants are built on time and to budget.	Ongoing
To open up the market for small modular reactors (SMRs), governments and industry should work together to accelerate the development of SMR prototypes and the launch of construction projects (about 5 projects per design) needed to demonstrate the benefits of modular design and factory assembly.	2015-25
Governments to recognise the long-term benefits of developing Generation IV (Gen IV) systems in terms of resource utilisation and waste management, and support R&D and development of at least one or two Fast Breeder Reactor Gen IV prototypes.	2015-30
Public-private partnerships need to be put in place between governments and industry in order to develop demonstration projects for nuclear cogeneration in the area of desalination or hydrogen production.	2015-30
Incorporate feed-back from operation of Gen IV prototypes to develop FOAK Gen IV commercial plants.	2030-40



Nuclear fuel cycle

- **Uranium supply – more than adequate to meet high demand up to 2035 (Red Book)**
- **Potential for laser enrichment to reduce costs**
- **Accident Tolerant Fuel still decades away**
- **Deep Geological Disposal – recommended strategy for managing HLW, what ever the route (once-through or recycling). “Wait and See” not an option**
- **Extended storage needed, but NOT alternative to DGD**
- **Optimising waste management**
- **Importance of “fuel services” to support development**



Nuclear fuel cycle

<i>This roadmap recommends the following actions:</i>	<i>Proposed timeline</i>
Investments in environmentally sustainable uranium mining should be developed to address expected long-term demand.	2015-35
Governments to continue to co-operate to discuss international fuel services as a means to secure the development of nuclear power.	Ongoing
Governments should ensure that policies are in place for long-term storage and disposal, including deep geological disposal (DGD) of high-level waste, and should not defer nuclear waste planning – “wait and see” is not an option.	2015-50
Studies should be carried out to ensure that extended (dry) storage of spent nuclear fuel (SNF) satisfies the highest safety and security requirements.	Ongoing
Governments to continue to support R&D in advanced recycling technologies to reduce volume and toxicity of high-level waste.	Ongoing



Decommissioning

- Perceived as an unresolved issue (~ waste)
- Issue of costs – and adequate funding
- Importance with respect to public acceptance
- Technology exists, and can be further developed to reduce decommissioning costs
- Also, newer designs take decommissioning into account

This roadmap recommends the following actions:

Proposed timeline

Governments need to ensure that dedicated funds are set aside for decommissioning activities and that operators accumulate sufficient funding during the operation of NPPs to cover the future costs of decommissioning these facilities. Operators should regularly review the adequacy of the accrued funds.

Ongoing

Nuclear operators to ensure that shutdown nuclear facilities are decommissioned in a timely, safe and cost-effective manner.

Ongoing



Safety and regulation

- **R&D: Severe accidents, assessment methodologies (PSA)**
 - Improved understanding, reduced conservatisms
- **Enhanced safety requirements (impact LTO prospects?)**
- **Regulation:**
 - Importance of strong & independent regulation stressed
 - Concern of 'over regulation' of nuclear industry (multiplication of regulatory requirements) → more coordination/harmonisation of requirements for more efficient regulation
- **Safety culture needs to be enforced across the whole of the nuclear sector and at all level of staff**
- **Importance of peer-reviews (regulators, operators)**



Training-capacity building

- Perceived as one of the key barriers:
 - In nuclear countries: retirement of a significant share of current workforce in coming decades & in newcomer countries
- Many initiatives to identify needed skills, HR requirements – and set up E&T schemes
- Role of R&D to attract and train researchers/engineers

Public acceptance

- Remains a key issue
- Particularly sensitive in non-OECD / newcomer countries
- Need to provide adequate communication / targeted factual information on risks & benefits



Key actions for the next 10 years

- Offer same level playing field to all low C technologies (electricity markets)
- Industry to build on time and to budget, FOAK → NOAK
- Enhance standardisation, harmonise C&S and regulatory requirements
- Continue to share information & experience (among regulators and among operators) to improve safety
- Public acceptance must be strengthened (post F safety upgrades, fact-based information)
- Develop long-term strategy for radwaste management



DOWNLOAD THE ROADMAP AND ANNEX AT:

<http://www.iea.org/publications/freepublications/publication/technology-roadmap-nuclear-energy.html>

<http://www.oecd-neo.org/pub/techroadmap/>

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Questions?