Global Nuclear New Build and Technology Expansion

NEI / PGS Scoping Meeting

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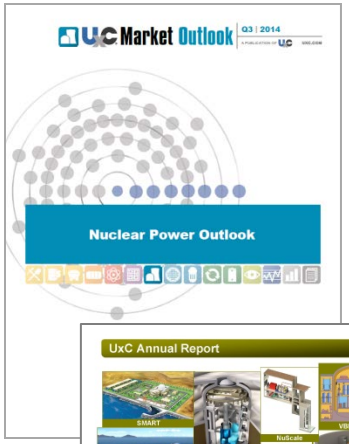
UxC Actively Tracks Reactor Developments and Market Demand

- **Nuclear Power Outlook (NPO)**
  - Quarterly reviews of country developments & bottom-up reactor forecasts to 2040
- **Nuclear Reactor Technology Assessments**
  - Analysis of all major LWR/PHWR designs
- **Small Modular Reactor Market Outlook**
  - Analysis of all available SMR designs
- **Supporting Utilities on New Reactors**
  - Creating cost models & analysis for new plants
  - Advising utilities on vendor negotiations, etc.
- **UxC Requirements Model (URM)**
  - Used for UxC fuel forecasts since Q1 2009

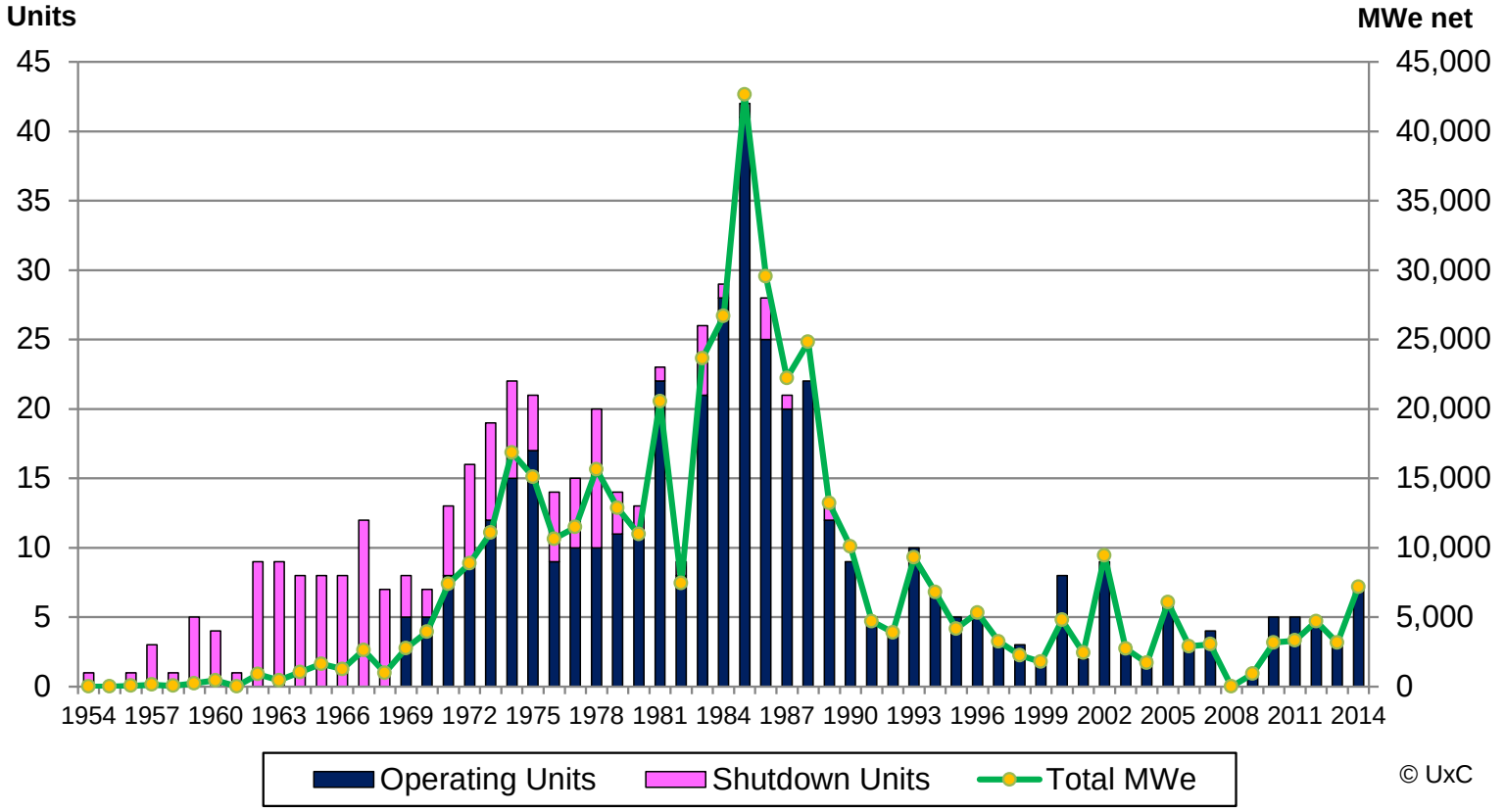


Where Have We Been?

Total New Builds Since 1954:

588 Units

455 GWe



- **61-Year Annual Average: 10 Units / 7,500 MWe**
- **Average Since 2000: 4 Units / 3,500 MWe**
- **73% of All Operating Units Built Before 1990**

Where Are We Now?

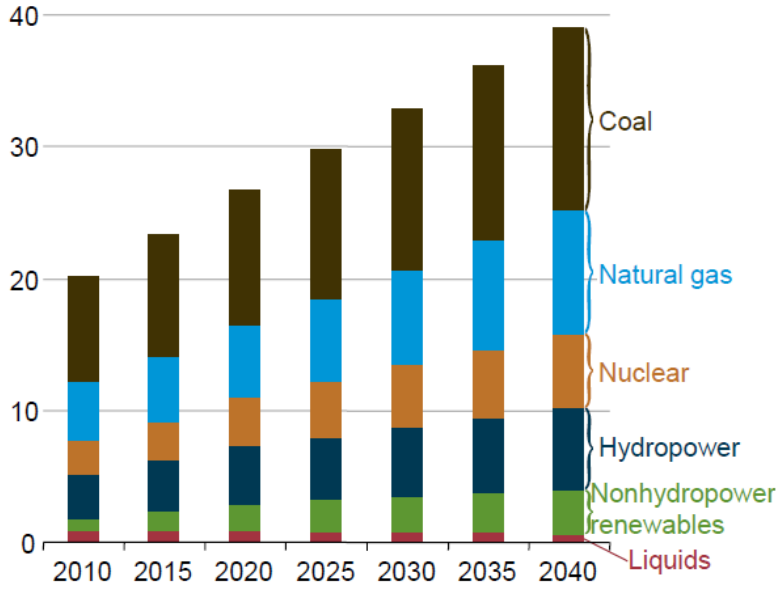
- **437 reactors / 376 GWe operating in 31 countries today**
  - Provide roughly 13% of total global electricity as baseload power
- **67 reactors under construction in 15 countries**
- **Traditional ~20 countries with nuclear power in steady state, but a few in slow decline (e.g., Germany, Japan, Belgium)**
- **10 faster growth/new build expansion countries**
- **Up to 20 "newcomer states" → no more than 10 possible by 2030**
- **Post-Fukushima, safety is paramount (trumps economics)**
- **Relative low costs of competing energy sources makes new nuclear a hard sell in many places (including the U.S.)**
- **Same logic for nuclear power applies as before:**
  - Increased world demand for electricity due to economic & population growth
  - Climate change and environmental issues impacting fossil fuels
  - Many countries desire enhanced energy security and diversification
- **However, fallout from Fukushima, shale gas boom, and renewables has created significant headwinds for global nuclear power…**

Current Major Questions

- What will be the pace of China's new reactor construction?
- Will any more U.S. reactors retire early? Who will build new ones?
- When will Japan's reactors restart? Will any new units be built?
- Are phase-outs in Germany, Belgium & Taiwan a done deal?
- What are the costs for post-Fukushima safety requirements?
- Which reactor suppliers will stay? Which might get out?
- Will Ukraine turmoil impact Russian exports?
- Are China's reactor export ambitions to be taken seriously?
- Can climate change policies be fashioned to help nuclear?
- Can potential new countries make progress & achieve goals?
- What is the future of SMRs?

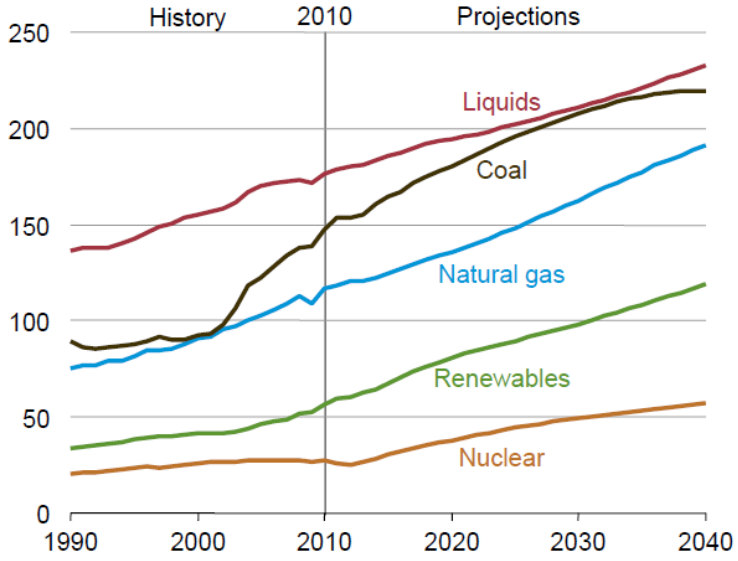
Where Are We Going?

World Electricity Generation by Source, 2010-2040 (trillion kWh)



Source: EIA

World Energy Consumption by Fuel, 1990-2040 (quadrillion Btu)



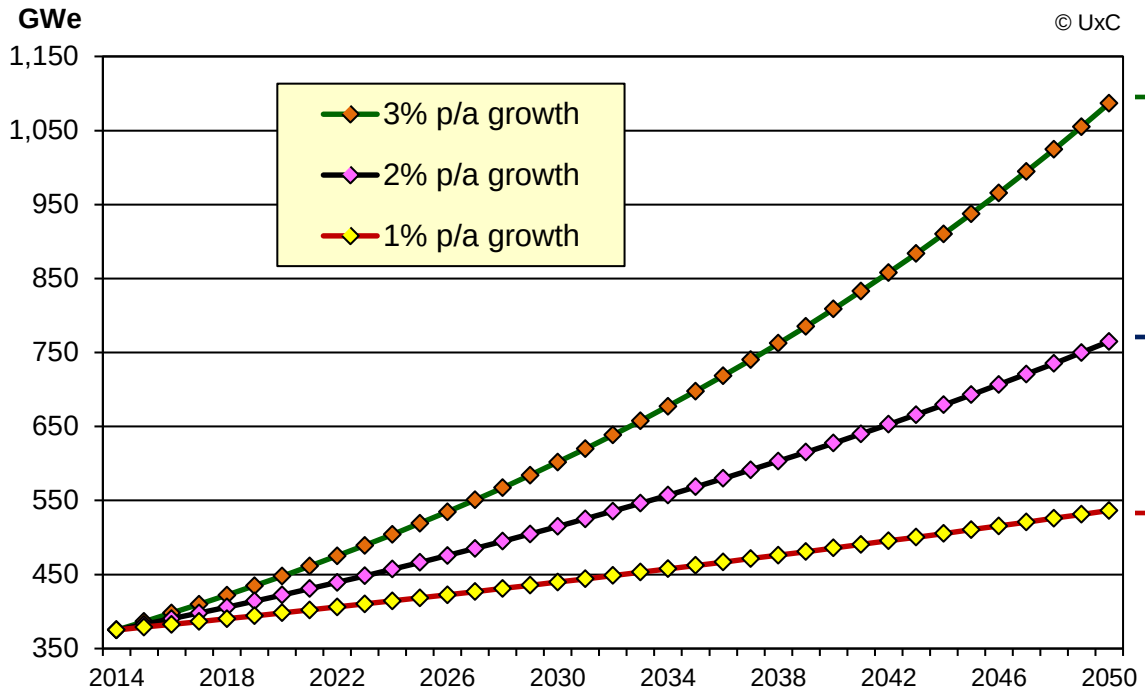
Source: EIA

Nuclear power remains a critical part of the global energy system, and all independent forecasts indicate continued expansion.

How Will We Get There?

- **Average Age of Operating Units: 28 Years Old**
- **Assuming Global Average 55-Year Lifespan:**
  - By 2030, Loss of 72 Units & 48 GWe
  - By 2040, Loss of 243 Units & 206 GWe
  - By 2050, Loss of 362 Units & 329 GWe

Future growth requires new build plus replacement capacity!

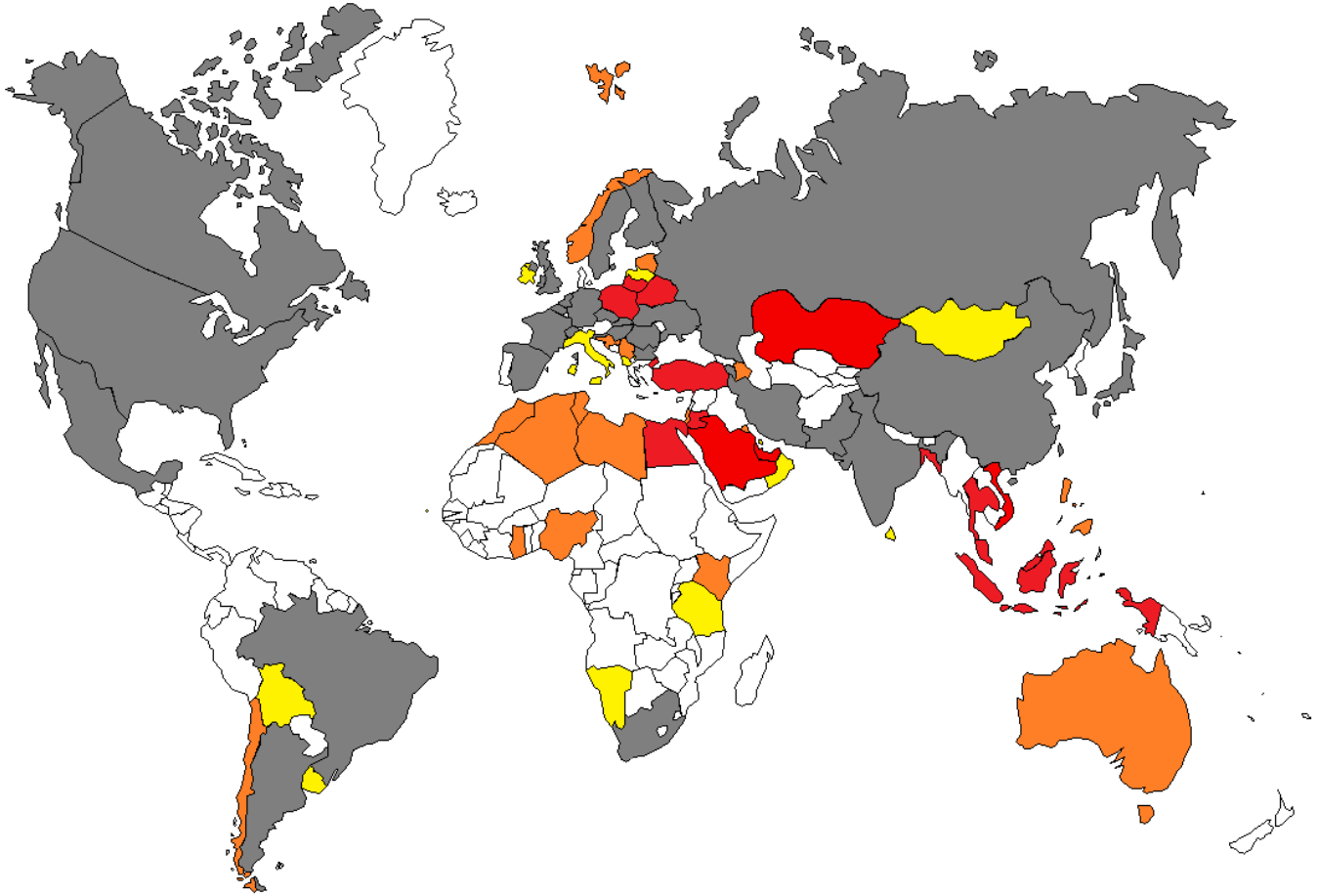


~1,040 GWe new build

~720 GWe new build

~490 GWe new build

Current & Potential Nuclear Countries



Ranking	Status	Color	Number
Existing	One or more operating nuclear power plants	Grey	31
High Potential	Active construction or significant preparatory activities	Red	14
Medium Potential	Some preparatory activities, but more long-term prospects	Orange	17
Low Potential	Interest, but no serious preparations or competencies	Yellow	13

Source: UxC *Nuclear Power Outlook*, Q1 2015

Critical Countries

- **Nuclear power's future depends greatly on 7 key countries:**
  - Additional Capacity in: China, Russia, India and South Korea (CRIS)
  - Maintaining Capacity in: U.S., France and Japan
- **China: 26 construction / 100+ in planning**
- **Russia: 9 construction / ~20 in planning**
- **India: 6 construction / 30+ in planning**
- **South Korea: 5 construction / ~10 in planning**
- **U.S.: 5 construction / new build vs. shutdowns?**
- **France: 1 construction / dropping to 50%?**
- **Japan: 2 construction / how many will restart?**

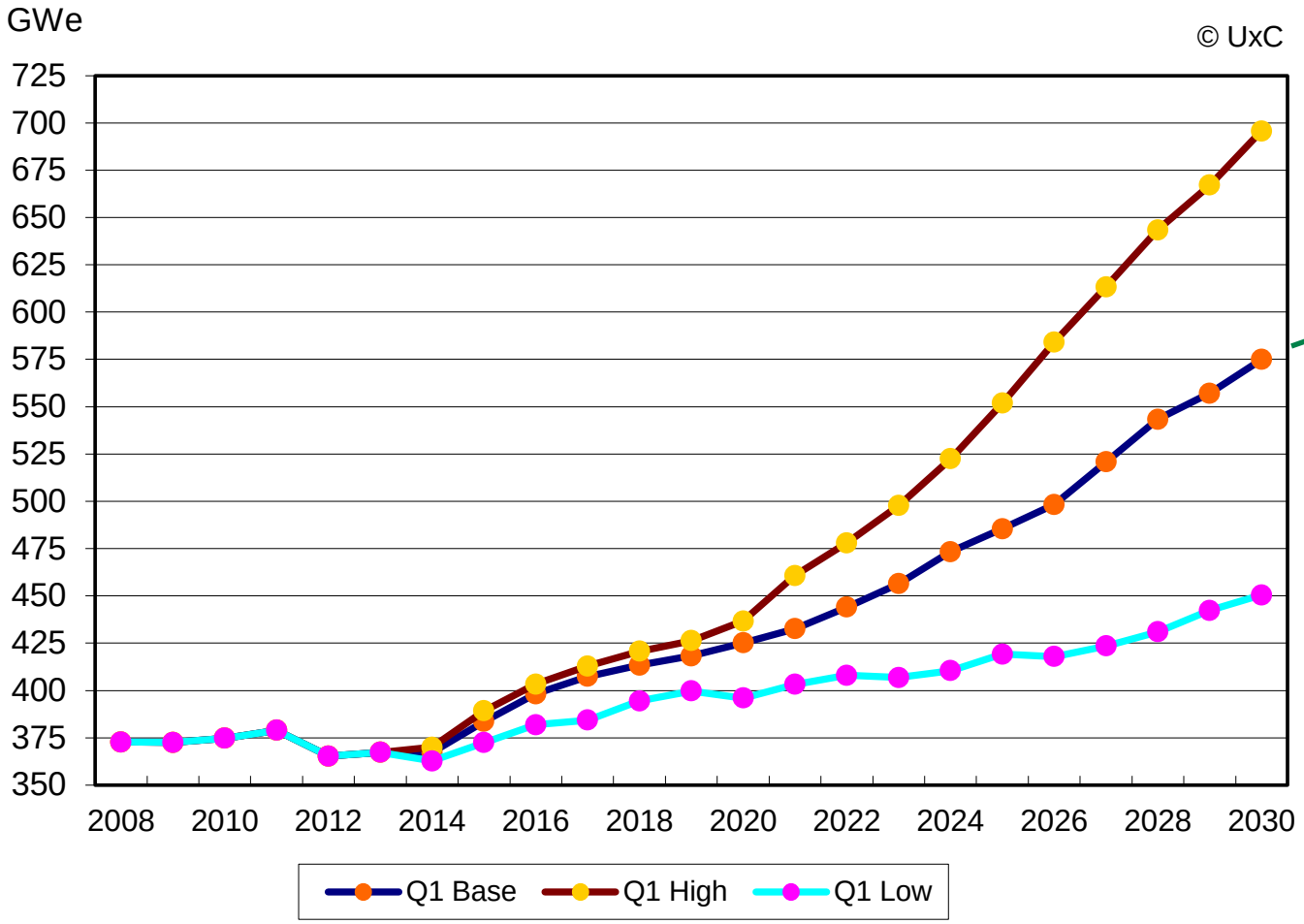
Totals:

54 under construction

170 additional possible by 2030

- **CRIS represent ~66% of all new build in UxC forecasts thru 2030**
- **Other important countries to watch:**
  - UAE, UK, Turkey, Poland, Finland, Saudi Arabia, South Africa, Brazil

UxC Nuclear Power Forecasts

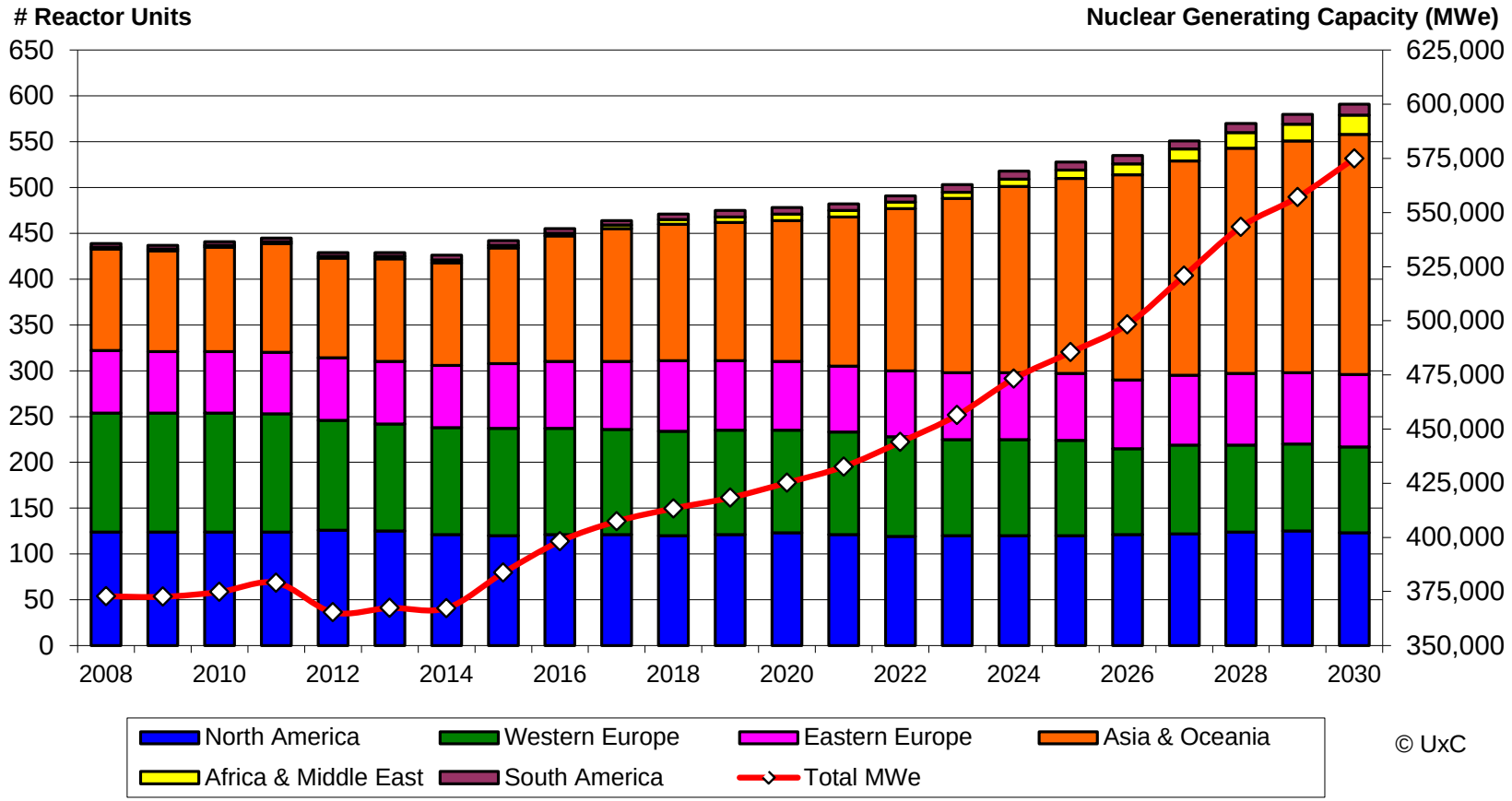


Base Case:

57% net growth by 2030

Source: UxC *Nuclear Power Outlook*, Q1 2015

UxC Base Case Forecast Details

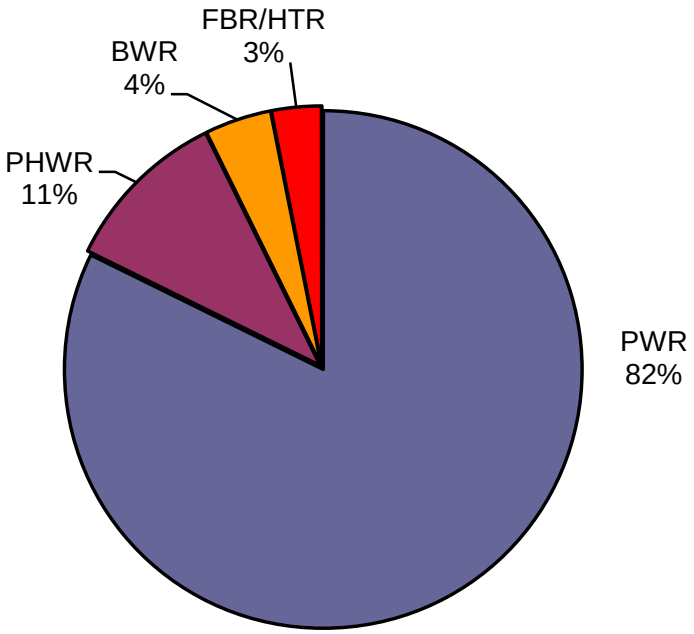


Asia = 44% of world in 2030 (vs. 23% in 2014)

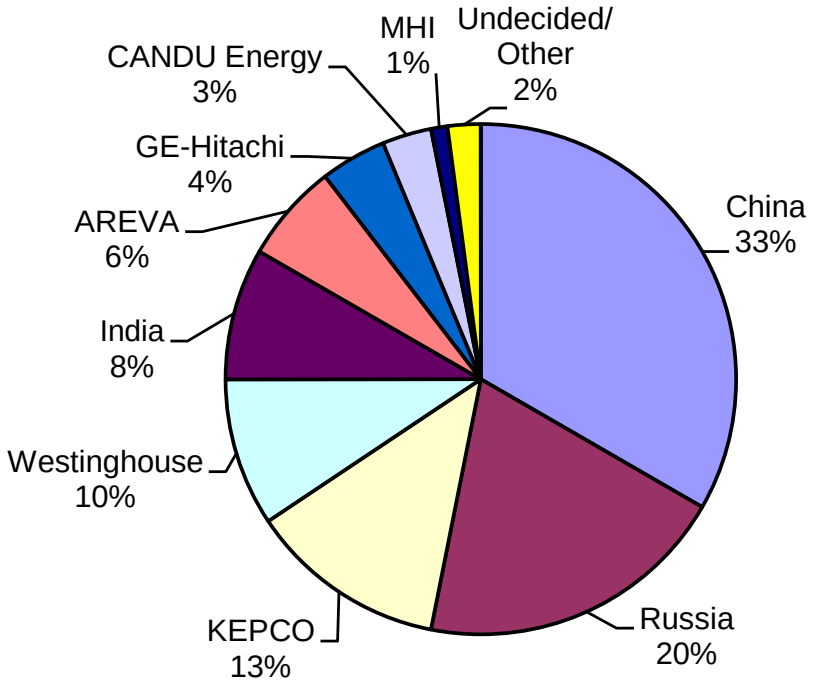
Source: UxC *Nuclear Power Outlook*, Q1 2015

Reactor Technology Selections

New Reactor Types, 2009-2020



New Reactor Vendors, 2009-2020



96 total units

(70 units in 2015-2020)

Source: UxC *Nuclear Power Outlook*, Q1 2015

Reactor Technology Options

- **Large LWRs**
  - Vast majority of current and projected future reactors are large PWRs
  - Leading designs include Westinghouse AP1000, AREVA EPR, KEPCO APR1400, Rosatom VVER-1200, and China Hualong-1
- **PHWRs (CANDU)**
  - Only few countries interested: India, Canada, Argentina, Romania
- **SMRs**
  - LWR designs have the market edge (SMART, NuScale, mPower, Holtec, W-SMR, CAREM)
  - Other designs are farther out (Gen4Energy, EM^2, 4S)
  - SMRs need economies of scale to be achievable (chicken & egg)
- **Advanced Reactors**
  - Few FBRs in world: Russia, India, China
  - Liquid metal designs show promise: Transatomic, Terrestrial, PRISM
  - Bill Gates' support of TerraPower makes people pay attention

NSSS Market Developments

- **Post-Fukushima, reactor designs that can best handle extended Station Blackout events will likely have an advantage.**
- **Due to a smaller "nuclear market pie," expect fierce competition and consolidation as well as certain vendors exiting the market.**
- **Russia (Rosatom), France (AREVA), South Korea (KEPCO), and Japanese vendors (Toshiba, Hitachi, MHI) have advantage in bidding reactor projects given strong government support.**
- **China's "going out strategy" means companies are looking to exports as well as investments in international nuclear projects.**
- **Technology transfer and localizing content remains important for many newcomers.**
- **SMRs are getting much more attention due to perceived pluses in terms of cost and safety factors.**

Nuclear Project Business Models

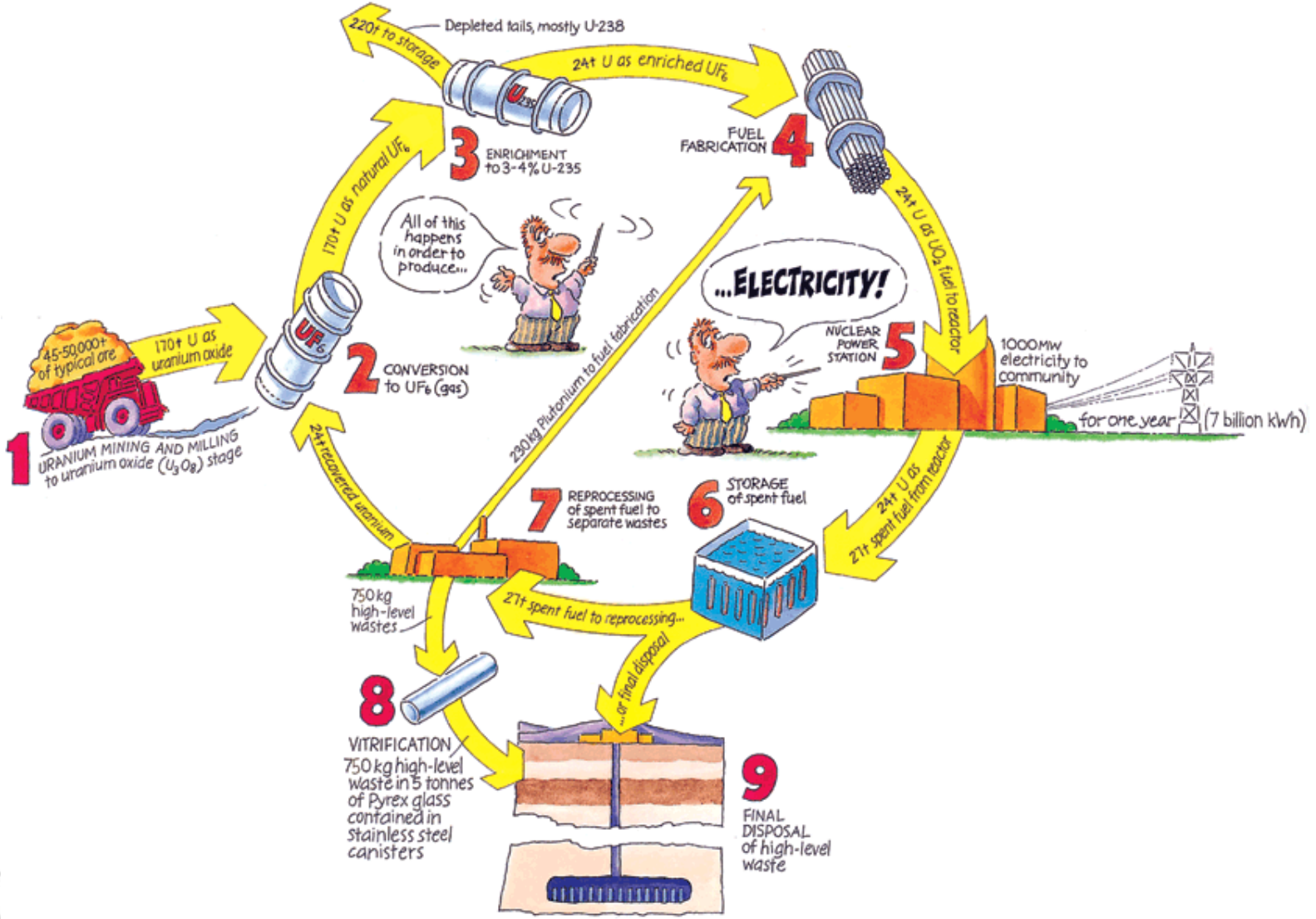
- **Traditional: NPP built & operated by electricity utility**
  - Turn-Key Project
  - EPC Contract Only
  - Complete Utility Control
- **Multiple Owners (Group Financing)**
- **NSSS Provides Financing**
- **Build-Own-Operate (BOO)**
- **Build-Own-Operate-Transfer (BOOT)**
- **Government Financing or Support (e.g., gov't sites)**
- **Finding ways to overcome the high capital burden is critical to opening new markets**

Global Successes & Challenges

- **Successes:**
  - China has mastered large-scale construction and reactor supply chain
  - Vendors are working better at collaborating and teaming arrangements
  - Russia has proven that providing financing with NPPs works
  - Public can be convinced of nuclear power advantages (e.g., UK)
  - Passive safety features can be added to designs without huge cost impacts

- **Challenges:**
  - Continuing political uncertainty in various countries
  - Regulatory reviews take too much time and cost too much money
  - Plethora of reactor designs makes it hard for customers to choose
  - Over-reliance on government support; lack of financing options
  - Newcomers often underestimate the time horizon to get to new nuclear

Nuclear Fuel Cycle



Front-End Nuclear Fuel Markets

- **Major Trends**
  - Post-Fukushima all sectors are oversupplied
  - Utilities are holding large inventories and future demand growth is lower
  - Producers have reduced output, but overcapacity remains
    - Uranium: Mined supply plus secondary supplies are well above annual req'ts
    - Conversion: Capacity is sufficient through 2025, but new plants will be needed
    - Enrichment: Large overcapacity all in centrifuges / Future projects on hold
    - Fabrication: Capacities suffice, but technical limits given design variations

- **Impact of Global Nuclear Expansion**
  - Most new reactor sales include fuel supplies
  - Expanding nuclear countries are increasing fuel cycle activities
    - Examples: China, India, Russia, South Korea
  - Some newcomer countries are considering domestic fuel cycle development
    - Examples: Saudi Arabia, Jordan, Vietnam
  - **Traditional markets losing importance as emphasis shifts to Asia**

Back-End Fuel Cycle Issues

- **Major Trends**
  - Only Finland and Sweden are well-advanced in repository development
  - Reprocessing limited to handful of countries (France, Russia, Japan, etc.)
  - Default preferred option is long-term storage in pools & dry casks
  - Large decommissioning programs mean huge increase in RadWaste

- **Impact of Global Nuclear Expansion**
  - Despite talk, no new vendors are offering spent fuel take-back
  - Some growing countries pursuing reprocessing (China, South Korea, India)
  - Newcomer countries are focused on reactor construction and fuel supply
  - Low level waste disposal capacity remains insufficient
  - **As typical, back-end issues are being pushed to the back-burner**

Conclusions

- **Reactor growth is global, but heaviest in Asia. Near term story is less optimistic, but long-term fundamentals remain strong**
- **Key factors impacting future new build rate include: natural gas prices, carbon policies and political will**
- **In order to maintain steady growth, additional plus replacement capacity will be needed on a large scale**
- **Post-Fukushima market shake-out will likely continue for several more years**
- **SMRs showing promise, but won't see success until post-2025**
- **Fuel cycle markets will follow the reactor demand developments**
- **Challenges/Risks for global nuclear power remain:**
  - Another major accident
  - Continued high capital costs for new reactors
  - Negative public opinion and policymaker sentiment
  - Shifts in economic growth or relative economics of other energy options

Questions?

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