World Nuclear Fuel Market

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MPhil Nuclear Energy Lecture

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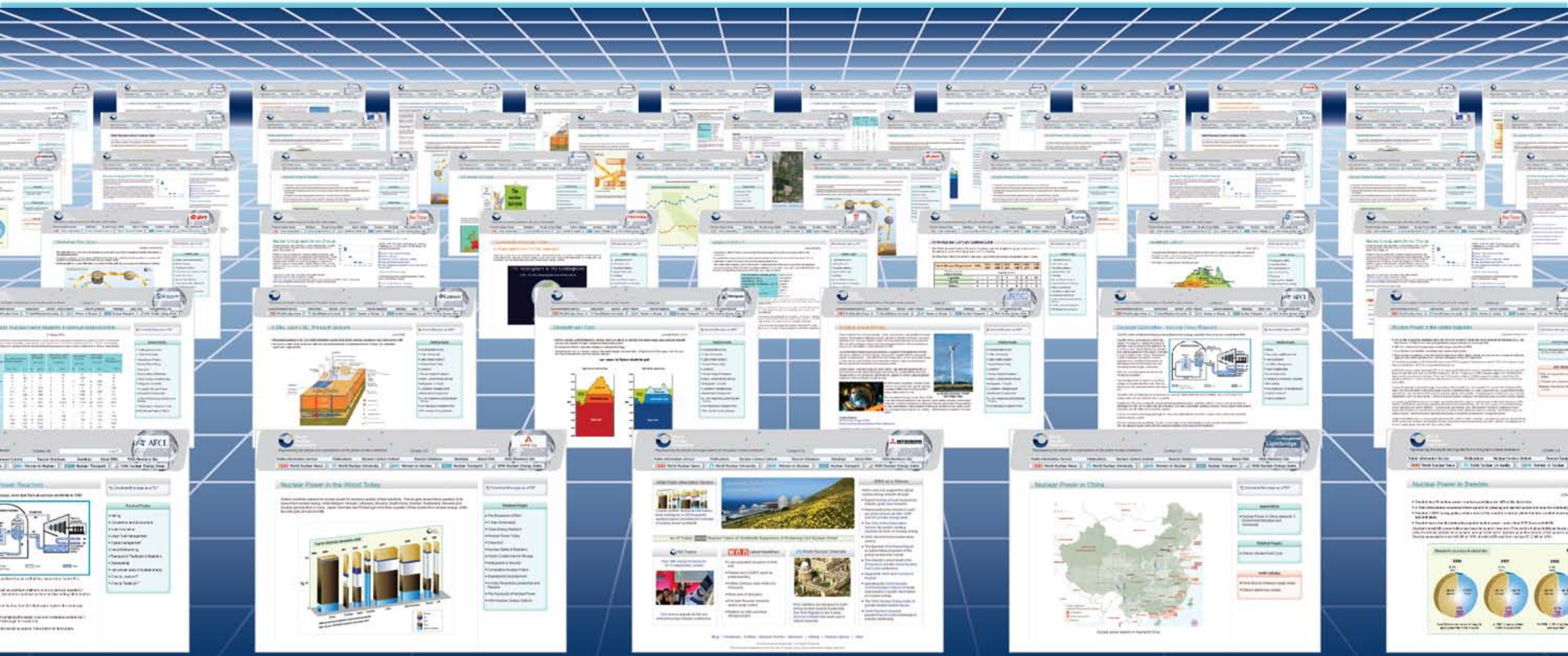
WNA Roles & Activities

4. Providing Public Information and News
3. Nuclear Fuel Market and Supply Chain
2. Enabling Industry Contacts and Cooperation
1. Representation in Key International Forums

Public Information & News



- 200 Information Papers updated regularly
- A 'hit' every 5 seconds round the clock
- Used by the public, policymakers & industry

Public Information & News

- **Free online news service**
- **Timely & concise daily reporting**
- **Daily distribution: 20,000 and growing**

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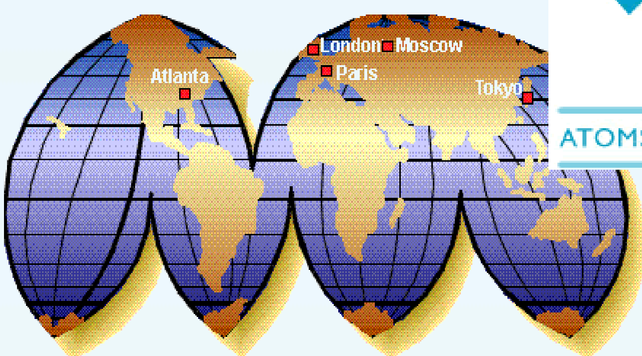
ATOMS FOR SUSTAINABLE DEVELOPMENT

OECD/NEA
Nuclear Energy Agency



W A N O

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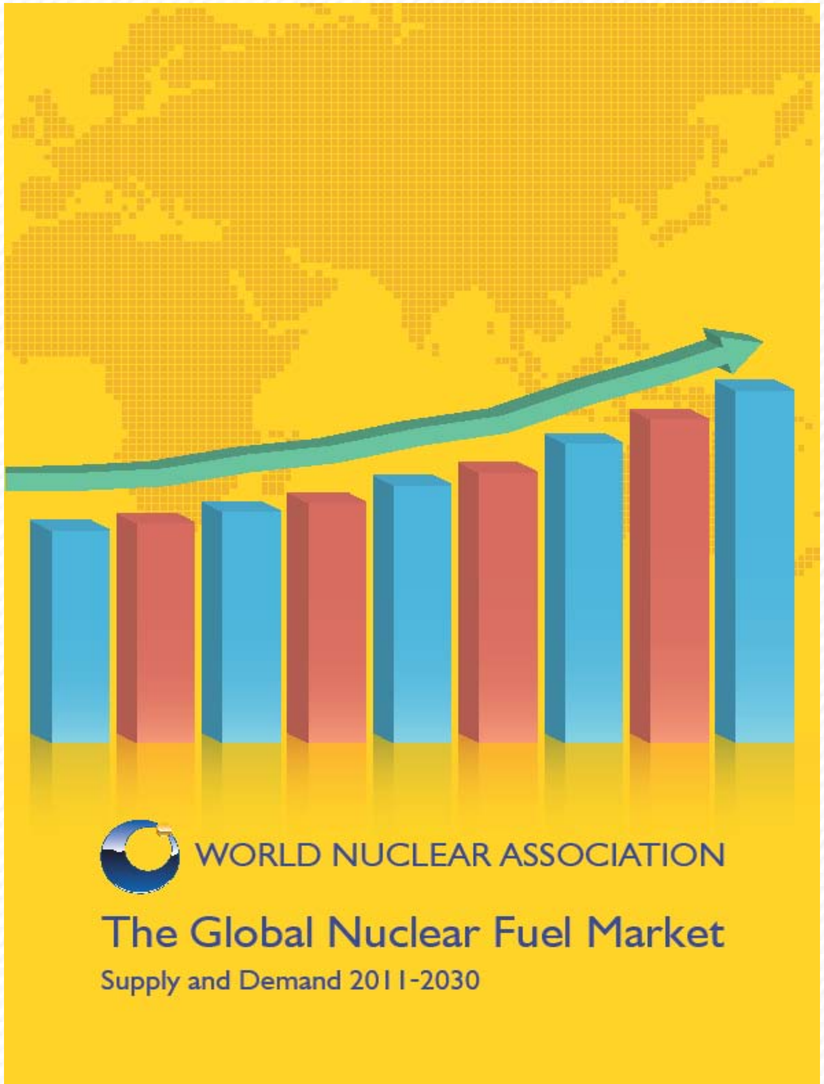
Daya Bay WNU class – July 2012

Outline

- Overview of the fuel cycle and importance of fuel
- What determines the demand for nuclear fuel?
- Uranium
- Conversion
- Enrichment
- Fuel fabrication
- Nuclear fuel market

n.b. This presentation covers the commercial side of nuclear fuel - the technical side is a huge but different area!

WNA Market Report 2011



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WNA Market Report

- **This new report is the fifteenth in the series to be published since the foundation of the WNA (formerly Uranium Institute) in 1975.**

- **The report concentrates on the “front end” of the fuel cycle, from uranium mining to electricity generation, describing the supply and demand of**
    - Natural uranium
    - Conversion
    - Enrichment
    - Fabrication

- **This report maintains the forecasting period up to 2030.**

- **WNA Market report is produced mainly for the members of the WNA but it is widely used by many other sectors as nuclear energy getting more attention**

- **The report is highly appreciated by all sectors as it is based on the knowledge and opinion of the whole industry**

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OVERVIEW OF THE FUEL CYCLE

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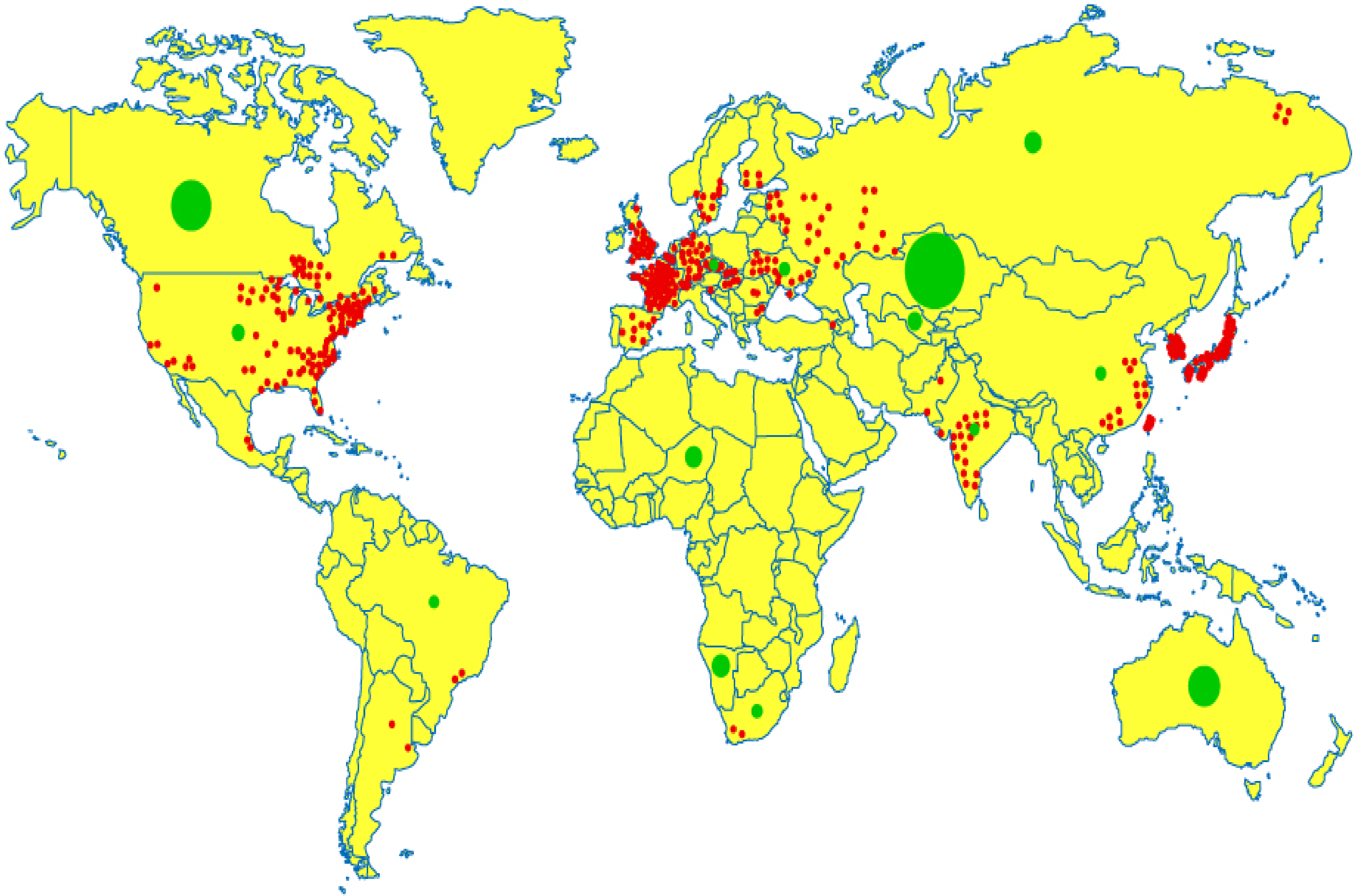
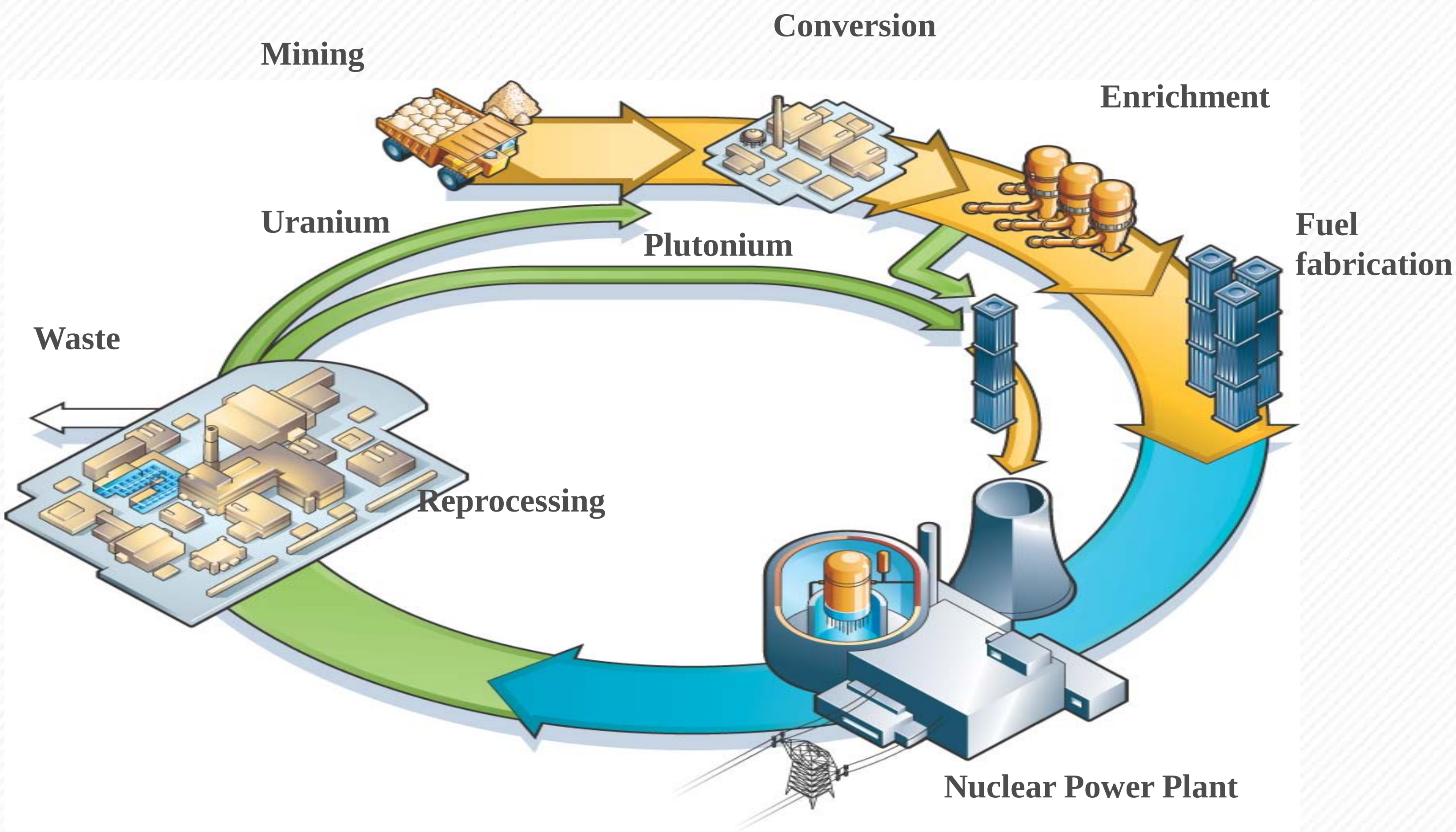
World Nuclear Power Reactors - with Uranium Sources



The Nuclear Fuel Cycle - Closed



Key aspects of fuel cycle

- Complexity!
- Specialisation of producers
- International aspects
- Trade rules & regulations
- Transport difficulties
- Recycling possibilities
- Historical production levels still relevant

Relative Cost Structure of Power Generation

General shares	Nuclear	Gas CCGT	Coal
Investment	50-60%	15-20%	40-50%
O&M	20-35%	5-10%	15-25%
Fuel	15-20%	70-80%	35-40%

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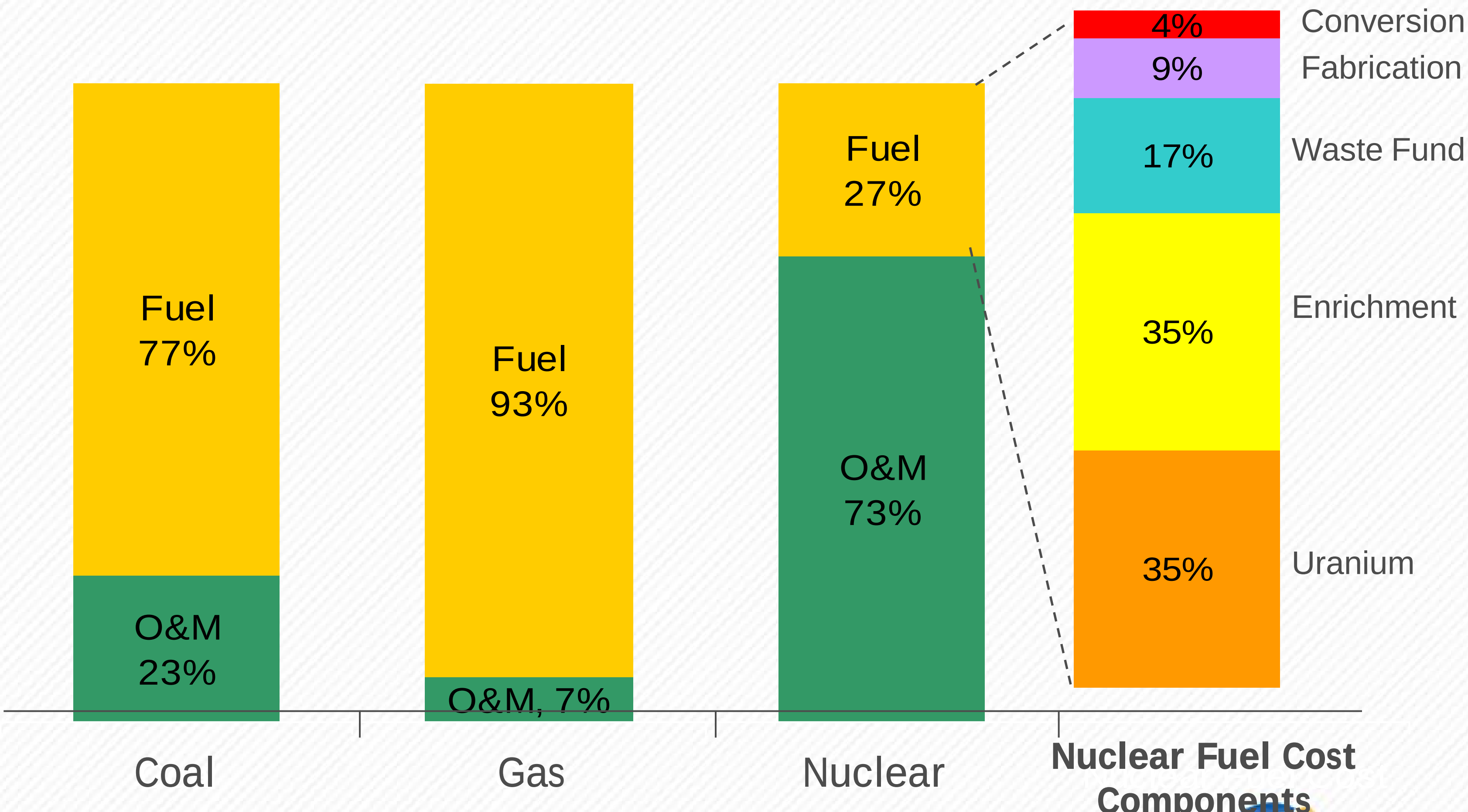
Fuel as a Percentage of Electric Power Production Costs



Source: Global Energy Decisions; Energy Resources International, Inc.
Updated: 5/08

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Monthly Fuel Cost to U.S. Electric Utilities

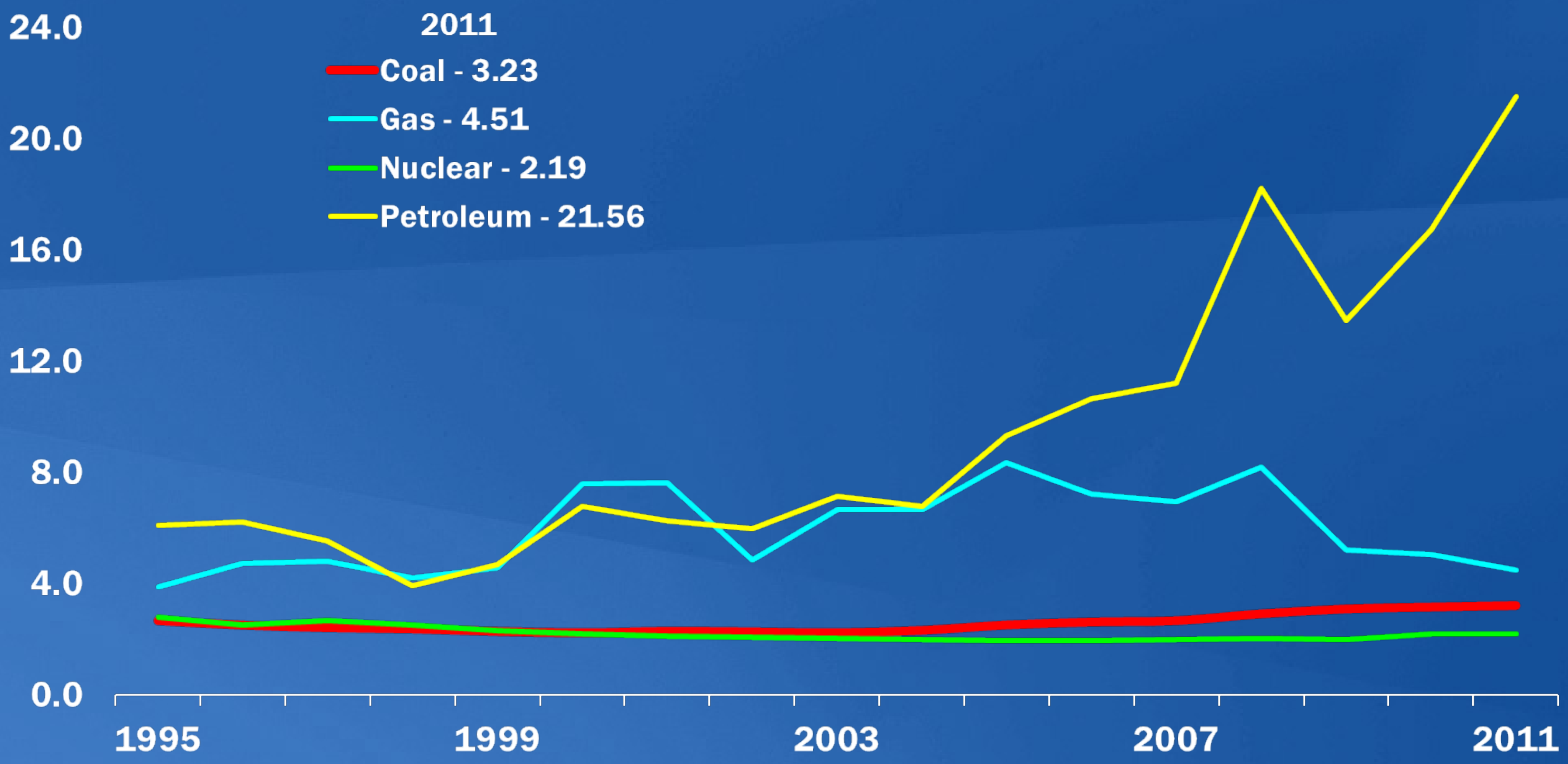
1995 – 2011, *In 2011 cents per kilowatt-hour*

Source: Ventyx Velocity Suite

Updated: 5/12

U.S. Electricity Production Costs

1995-2011, *In 2011 cents per kilowatt-hour*

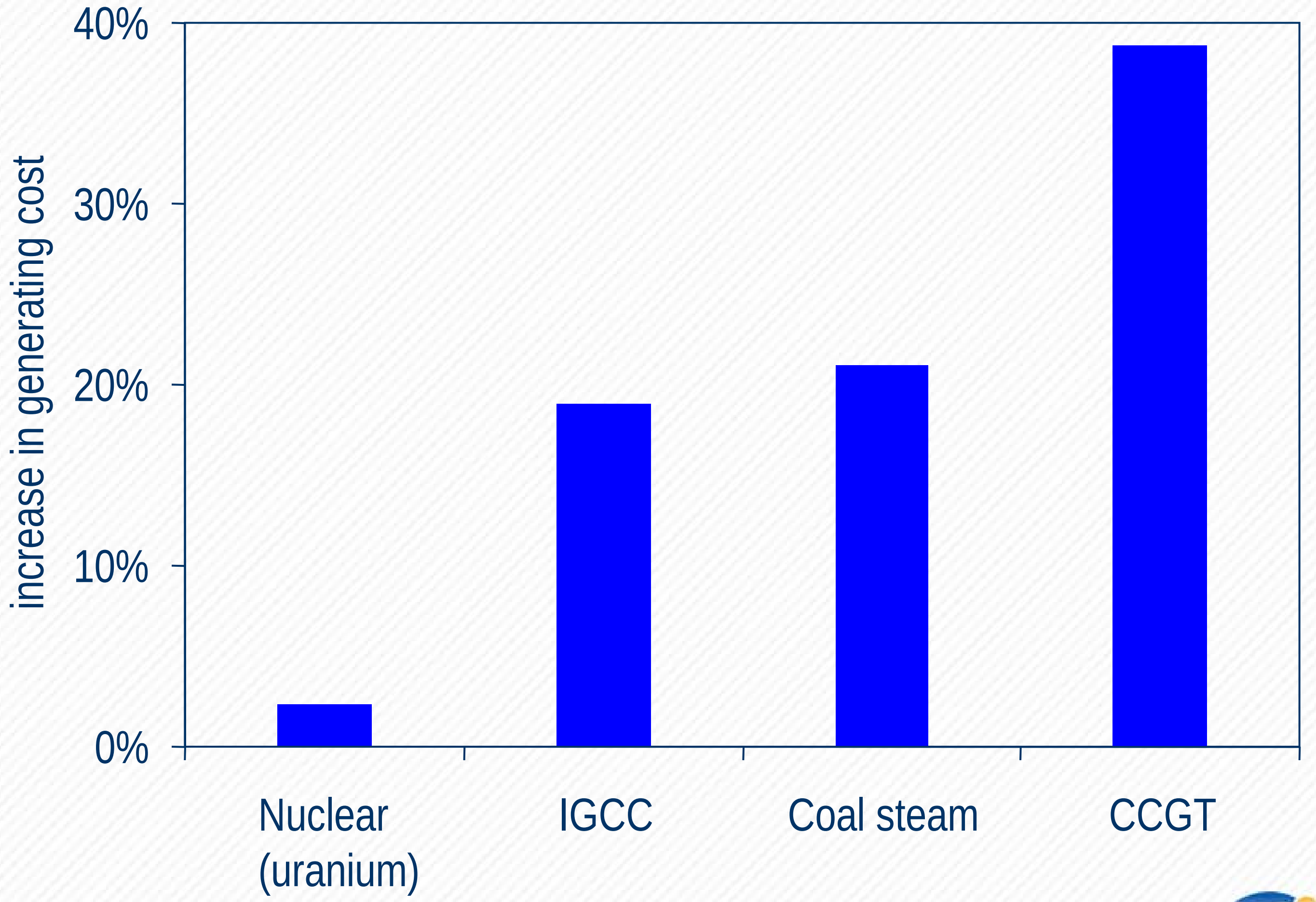


Production Costs = Operations and Maintenance Costs + Fuel Costs. Production costs do not include indirect costs and are based on FERC Form 1 filings submitted by regulated utilities. Production costs are modeled for utilities that are not regulated.

NEI

Source: Ventyx Velocity Suite
Updated: 5/12

Impact of 50% increase in fuel cost



Sources: IEA "World Energy Outlook 2006" - " Reference Scenario "

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Why is nuclear fuel important?

- Without it the reactor will not operate!
- Yet if it is so insignificant in nuclear economics, why are we bothering devoting a lot of time to it?
- But without cheap fuel, nuclear is dead economically. Everything else connected with a nuclear plant costs more!
- A paradox – fuel is essentially nuclear's biggest advantage, but potentially also its biggest drawback!

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Cost of 1 kg of enriched uranium

Uranium	9 kg U308	$50 per lb	990
Conversion	7.6 kg U	$13 per kg	99
Enrichment	7 SWU	$150 per SWU	1050
Fabrication	1 kg	$300 per kg	300
Total			$2439

Need about 20 tonnes of enriched uranium for an average large reactor refuel, so cost will be about $50 million

Total front end world market is now worth about $25 billion annually

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DEMAND FOR NUCLEAR FUEL

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Demand for nuclear fuel

Depends on two factors

- **Number and size of reactors in operation**
- **How they are run – load factors, enrichment level, burn-up and tails assay**

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Nuclear generating capacity scenarios

- Country-level judgements
- Existing reactors – consideration of operating lives (technical, licensing and policy issues) – also power up-rates
- New reactors - a) under construction

  b) already within planning & licensing

  c) proposed without firm commitment

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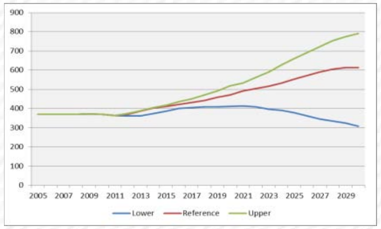
WNA scenario approach



- **Due to the uncertainties in forecasting future nuclear generation, three scenarios are developed to cover the full range of outcomes.**

- **Generic assumptions underlie each scenario – on nuclear economics, public acceptance, impact of climate change debate and electricity market structure**
  - **<u>Reference Scenario:</u>**
    - Improvements occur in the relative economics of nuclear power
    - Concerns about global warming continue
    - Gradual restructuring and liberalisation of electricity sector continue
    - The Fukushima accident has an impact in some countries, but most continue with their previous plans
    - Public acceptance problems for nuclear projects begin to diminish
  - **<u>Lower and Upper Scenarios:</u>**
    - More pessimistic and optimistic assumptions in these areas, compared with reference scenario

- **No attempt is made to attach probabilities to each scenario**

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Reflections on Fukushima - positive

- World energy situation is unchanged
- Lessons will be learned
- More attention will be paid to used fuel
- Beyond negative images, more attention and discussion of nuclear may benefit the industry
- More knowledge of radiation

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Reflections on Fukushima - negative

- More expense for operating plants
- Some will shut down earlier than expected
- New reactors maybe also become more expensive
- Harder to build plants in some countries where public opinion is difficult
- Story will "run and run" for months – especially the economic cost of evacuating people – more insurance?

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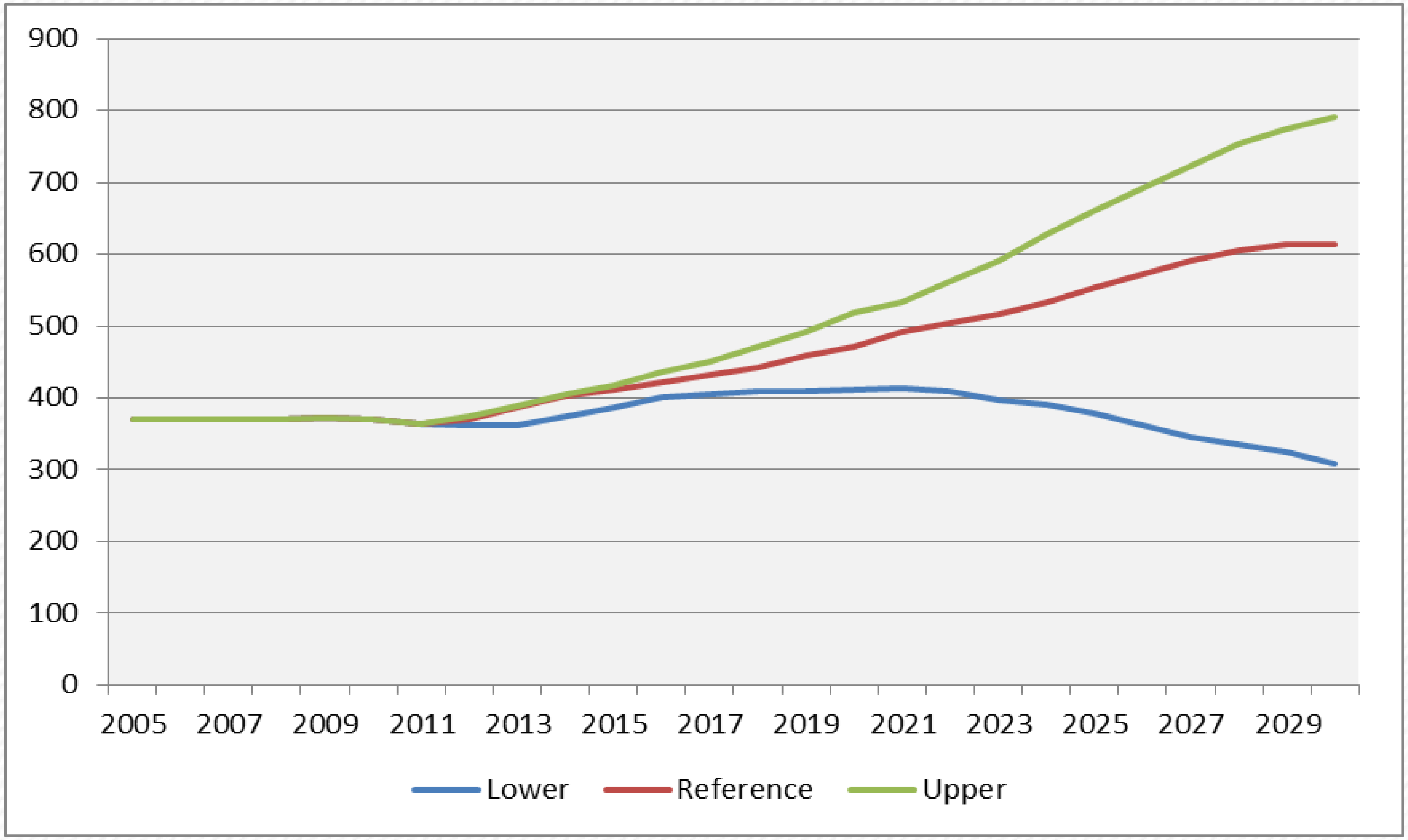
World Nuclear Generating Capacity, GWe



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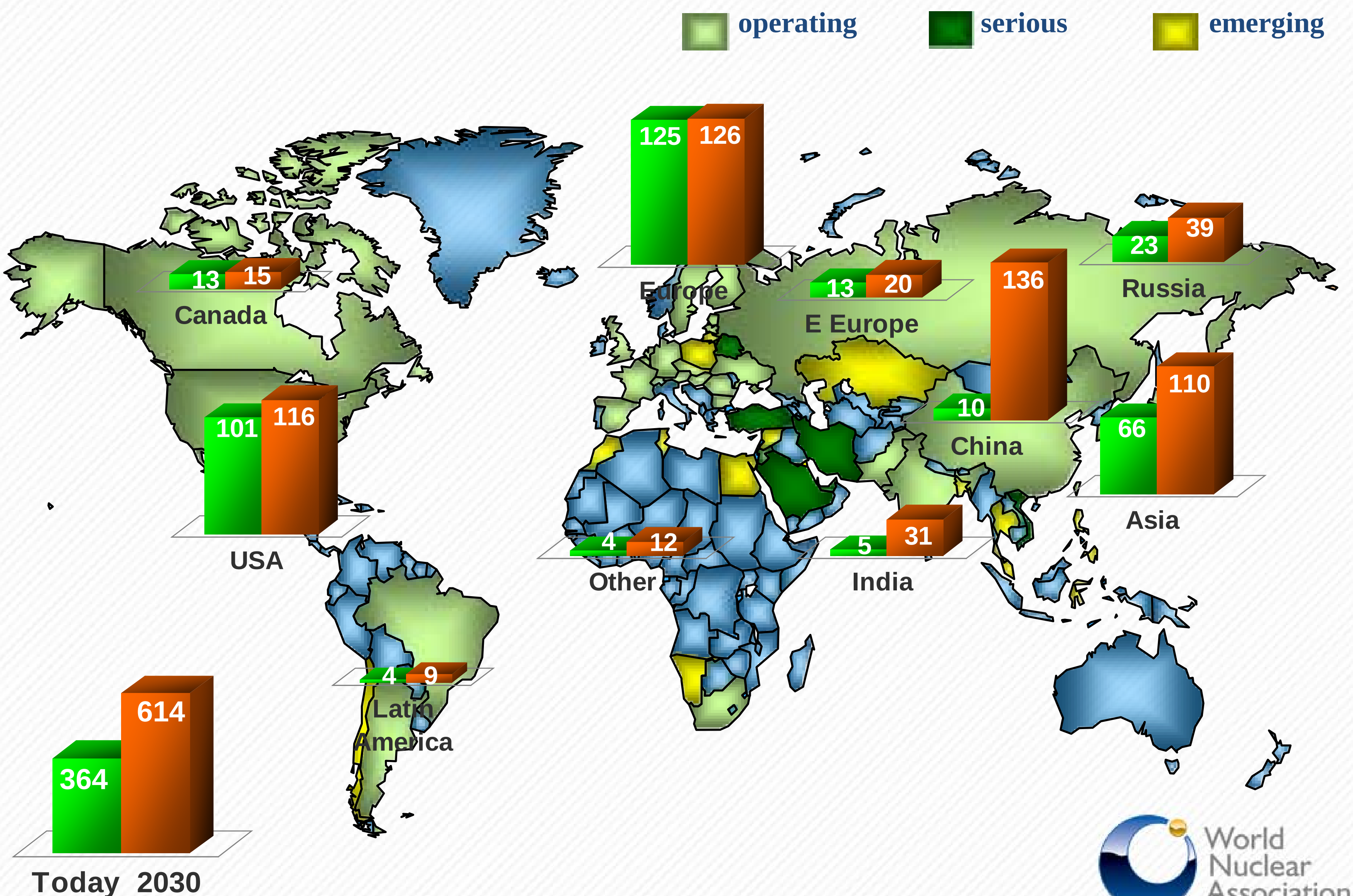
Reference case to 2030, GWe



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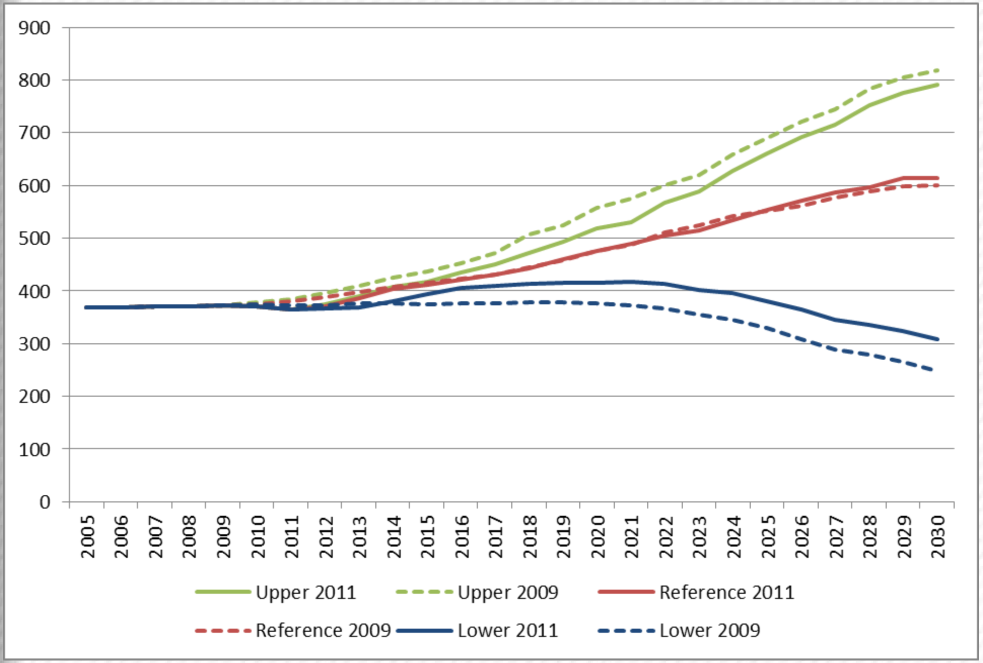
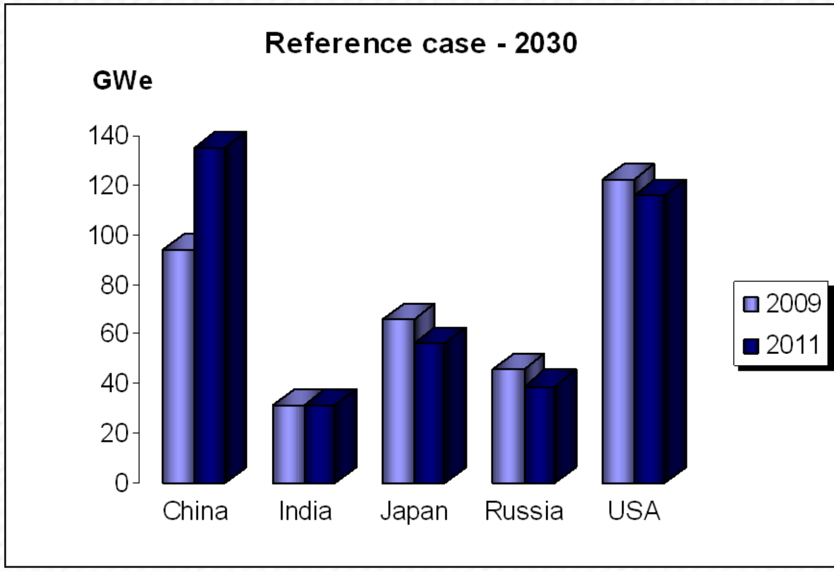
Reference Case Reactors

operating serious emerging

Regions	Operating 2009	New	Shut	Operating 2030	Change
Latin America	6	7	1	12	6
USA	104	30	32	102	-2
Europe	149	30	72	107	-42
Asia	79	41	16	104	25
Canada	18	4	3	19	1
Other	4	12	1	15	11
India	17	33	5	45	28
China	11	102	0	113	102
Russia	31	31	23	39	8
Eastern Europe	16	8	3	21	5
Total	**435**	**298**	**156**	**577**	**142**

World Nuclear Generating Capacity, 2011 vs 2009 Report





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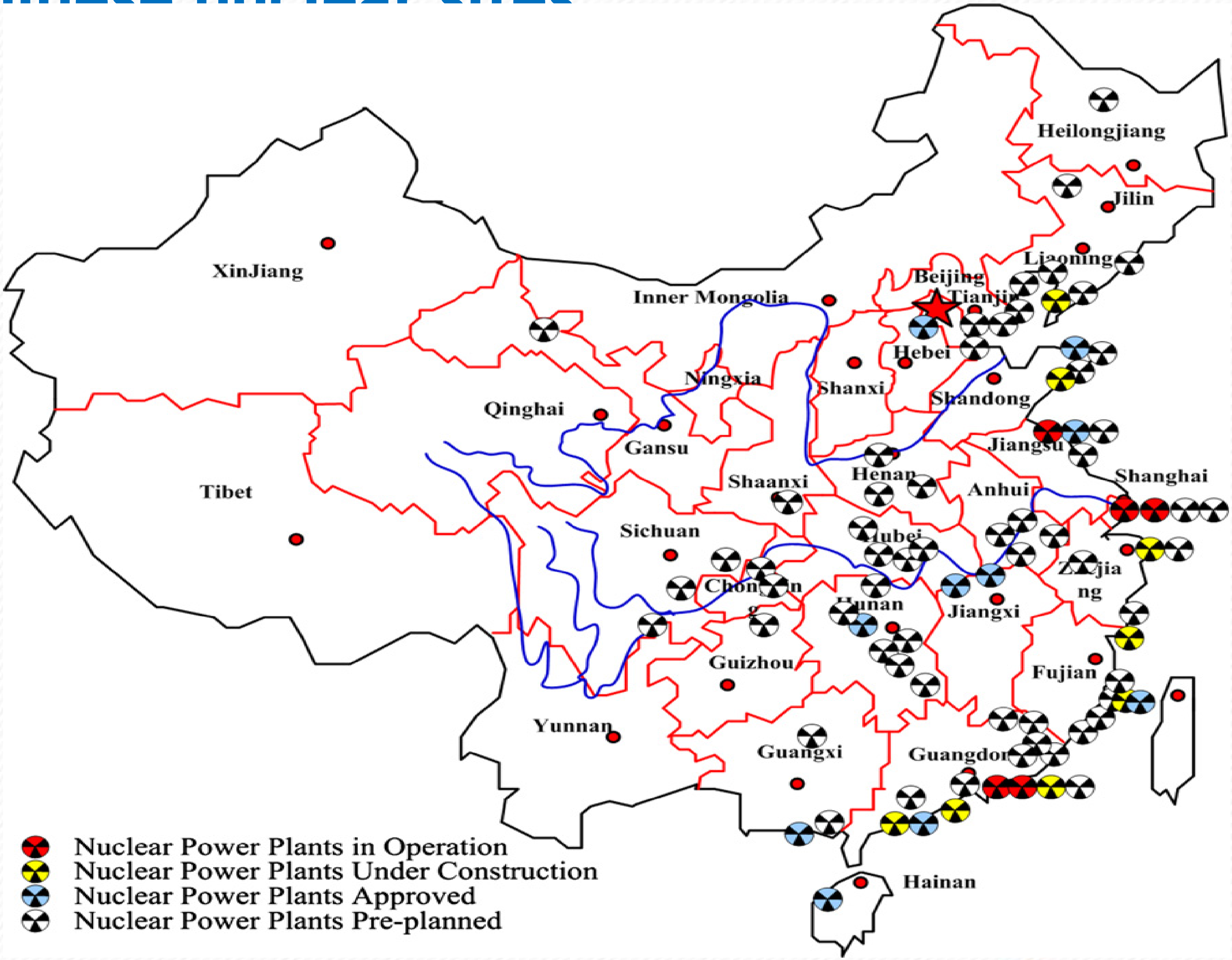
Chinese nuclear sites



Chinese reactors under construction

- 4 x AP1000 at Sanmen and Haiyang
- 2 x EPR at Taishan
- 19 x CPR-1000 at 6 sites
- 2 x CNP-600 at Changjiang
- 1 x VVER-1000 at Tianwan
- 1 x HTR-PM at Shidaowan

Total - 29 units, 30 GWe

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Forecasting reactor requirements

GWe - Nuclear generating capacity

MS Excel-based spreadsheet model

Fuel cycle and reactor operating factors

tU - Uranium, conversion and enrichment requirements

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Fuel cycle & reactor operating factors

Capacity factors	10% worldwide increase in 1990s - still rising
Enrichment level	rising slowly - up to 5% U-235
Fuel burn-up	now rising above 50 GWd/tU
Tails assay	Possible substitution between uranium and enrichment, depending on relative prces

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Importance of the tails assay

- Reactor operators require enriched uranium and can achieve this by many combinations of uranium and enrichment
- Relatively high enrichment input means lower tails assay (waste stream from the enrichment plant)
- Essentially an economic decision – relative price of U and SWU

- Optimal tails assay - 0.30%-0.35% until 2003-04, now below 0.25%
- 2009 Market Report - 0.15% for Russian-origin reactors, 0.25% for Western-origin
- 2011 Market Report - 0.22% for all reactors

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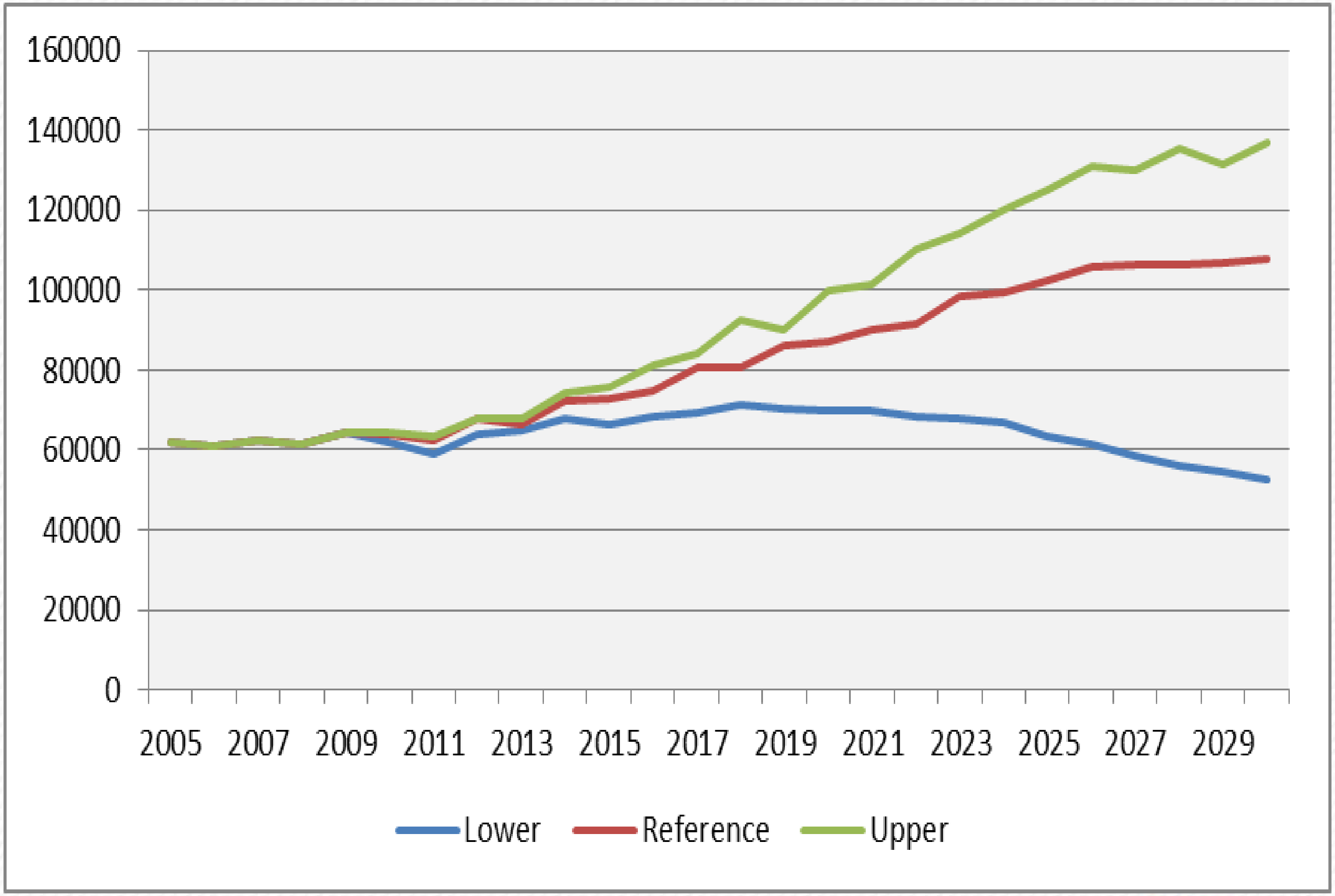
World Uranium Requirements, tU



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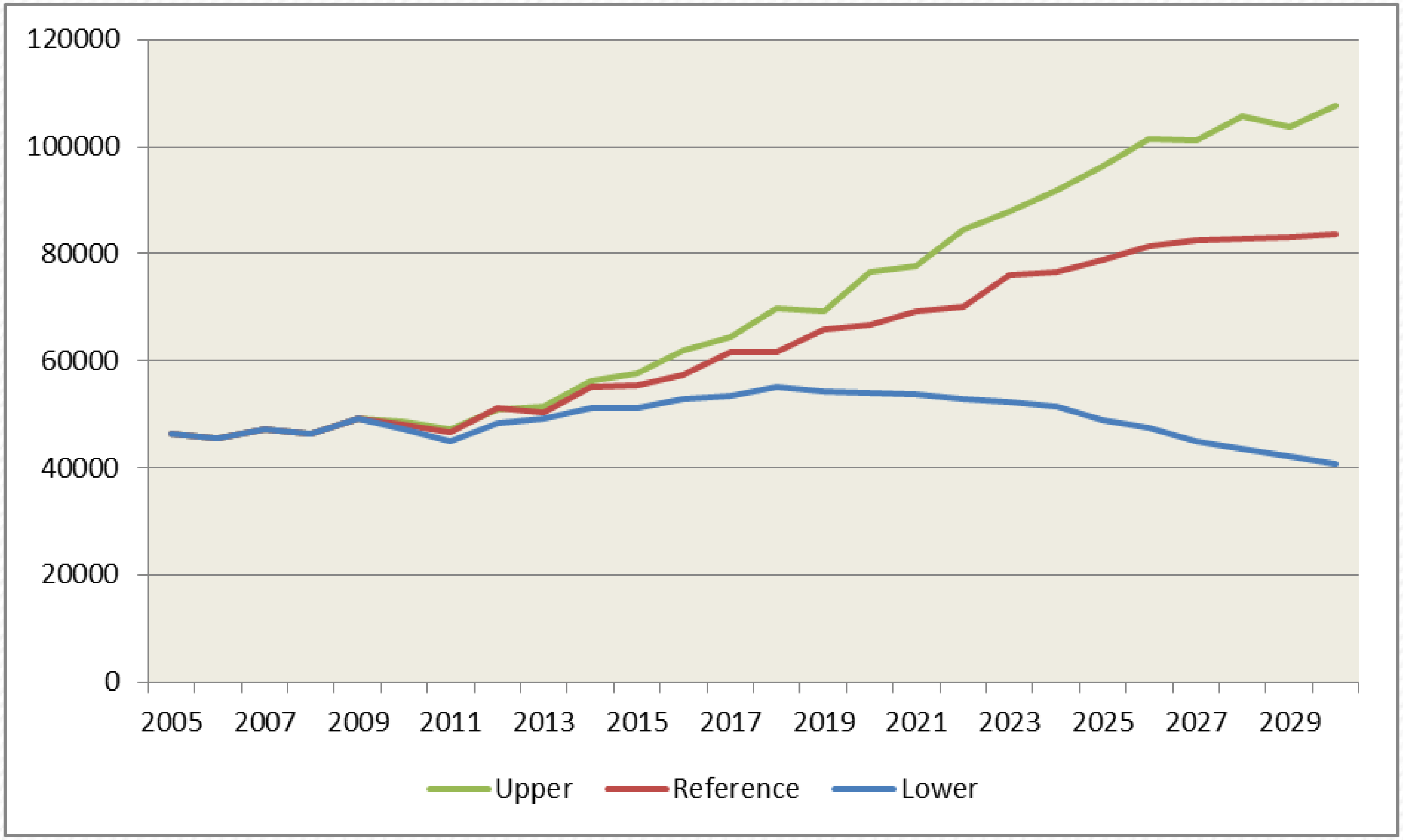
World Enrichment Requirements, 000's SWU



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URANIUM

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Uranium geology

- Found in several different types of deposits
- 0.1% grade enough for mining today
- Average concentration in Earth’s crust 2.8 ppm
- Phosphates
- Trace amounts in sea water
- Uranium is by no means scarce

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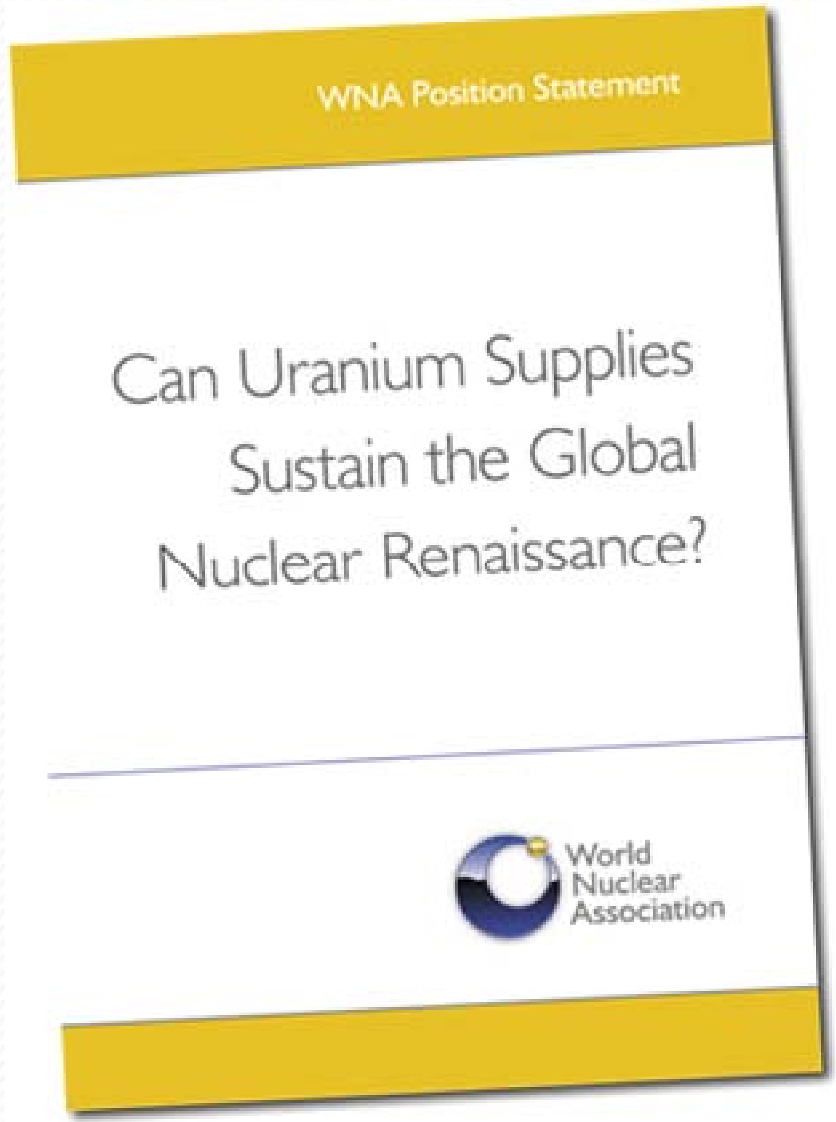
WNA Position Statement

Can Uranium Supplies Sustain the Global Nuclear Renaissance?

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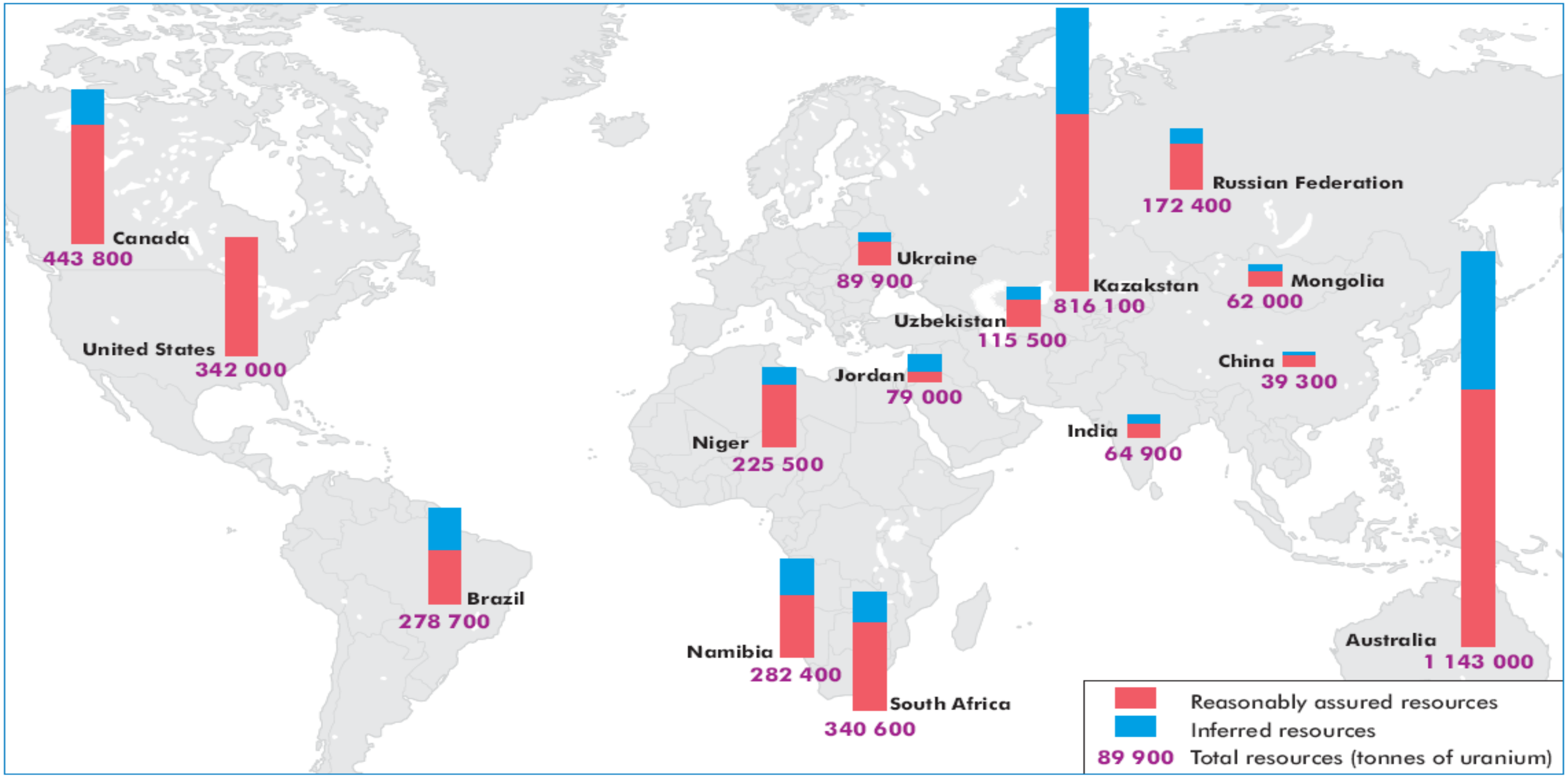
Global distribution of uranium resources



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Low cost (<$80/kg) uranium reserves, 000 tonnes U

Australia	714
Kazakhstan	344
Canada	329
South Africa	206
Russia	172
Brazil	157
Namibia	145
Ukraine	127
USA	99
Others	155
Total	2438

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World uranium production 2011, tU

Kazakhstan	19451
Canada	9145
Australia	5983
Niger	4351
Namibia	3258
Russia	2993
Uzbekistan	2500
USA	1537
Others	4276
Total	53494

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Top 10 companies producing uranium, 2011, tU

KazAtomProm	8884
Areva	8790
Cameco	8630
ARMZ-Uranium One	7088
Rio Tinto	4061
BHP Billiton	3353
Navoi	2500
Paladin	2282
Others	7906
Total	53494

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Top 10 uranium mines 2011 tonnes U

McArthur River	7686
Olympic Dam	3353
Arlit	2726
Tortkuduk	2608
Ranger	2240
Krasnokamensk	2191
Karatau	2175
Rossing	1822
Inkai	1602
South Inkai	1548

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Uranium production by mining method, 2011

Conventional underground	30%
Conventional open pit	17%
In situ leaching (ISL)	45%
By-product	7%
Total	100%

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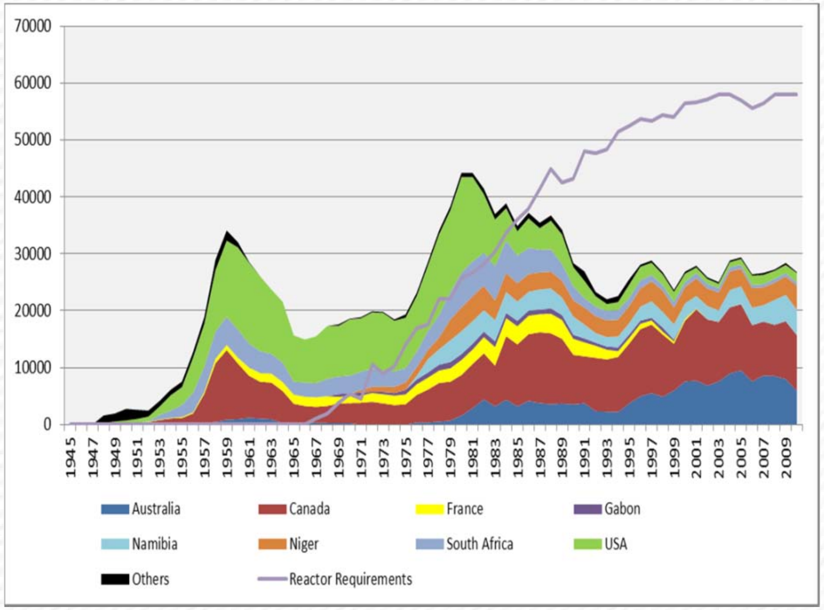
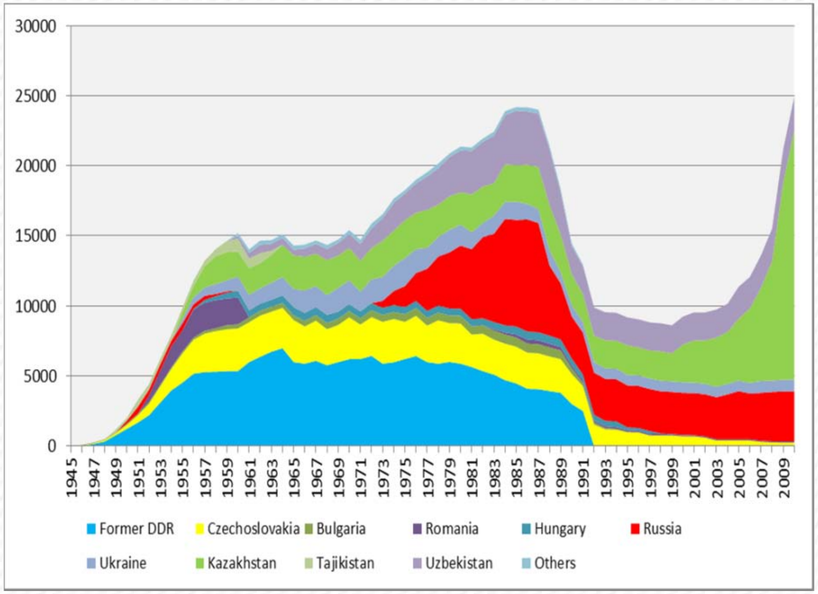
Historical uranium production



Western world total 1,520 ths.tU



USSR and Eastern Europe- 928 ths.t U

Since 1945	Ths. tU
Produced	2 449
Consumed	1 933
Stockpiled	516

Production was substantially ahead of reactor requirements until 1985, but has since fallen below. Since 1985, requirements have exceeded production by approximately 450,000 tU. The difference was covered by inventories and other secondary sources

Future uranium production

- Must now increase sharply to (a) cover rising demand and (b) diminishing secondary supplies
- Recent trend has been for increased dominance by a small number of major producing companies and countries
- Kazakhstan and Africa to lead expansion
- More exploration now taking place – stimulated by higher prices
- Over 200 “junior” uranium companies have suddenly appeared
- Some will eventually produce but how many?

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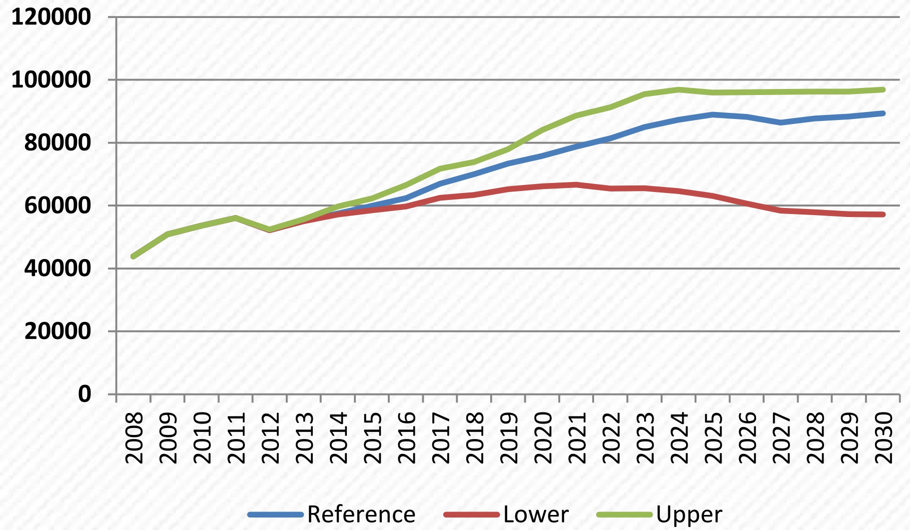
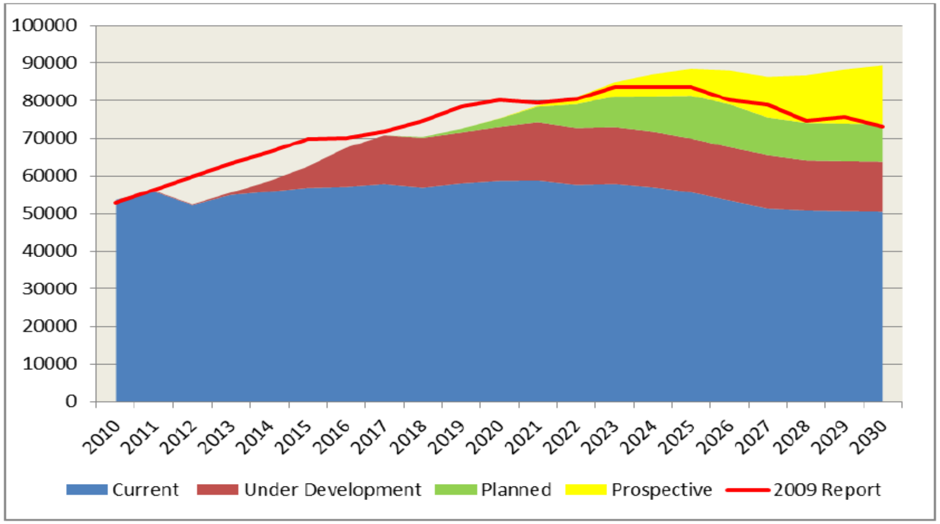
Anticipated uranium production through 2030

Scenarios for prospective uranium production, tU



Reference scenario prospective production, tU



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Secondary supplies

- Can be regarded as previous uranium production, held off the market for an extended period
- An important element in nuclear fuel supply
- Ex-military materials
- Commercial inventories
- MOX and RepU fuel

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Mixed oxide fuel (MOX) and reprocessed uranium (RepU)

- Reprocessing plants separate uranium and plutonium from used fuel
- RepU is re-enriched by centrifuges or blending to produce fresh fuel
- Extracted plutonium is introduced as the primary fissile element in MOX fuel
- Major reprocessing plants in France and UK with one nearing completion in Japan
- Russian system has always relied more on a closed fuel cycle

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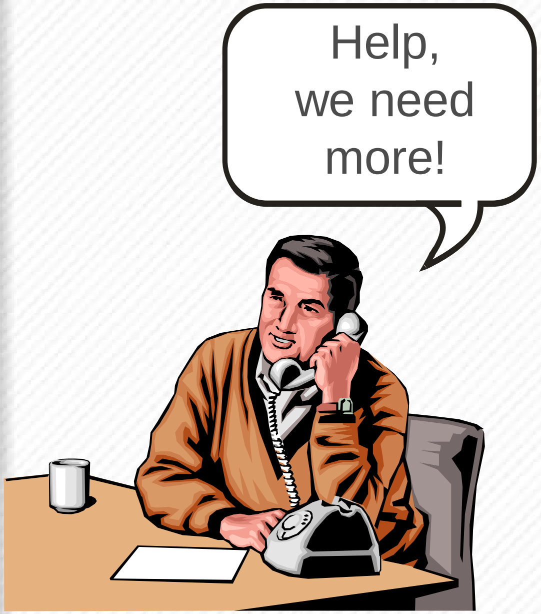
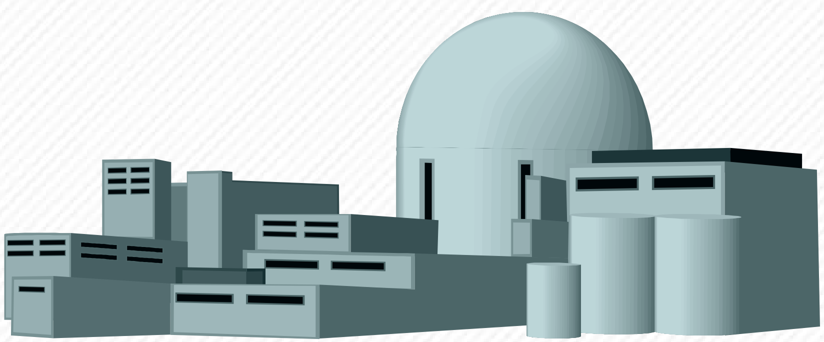
Will the future look like this?





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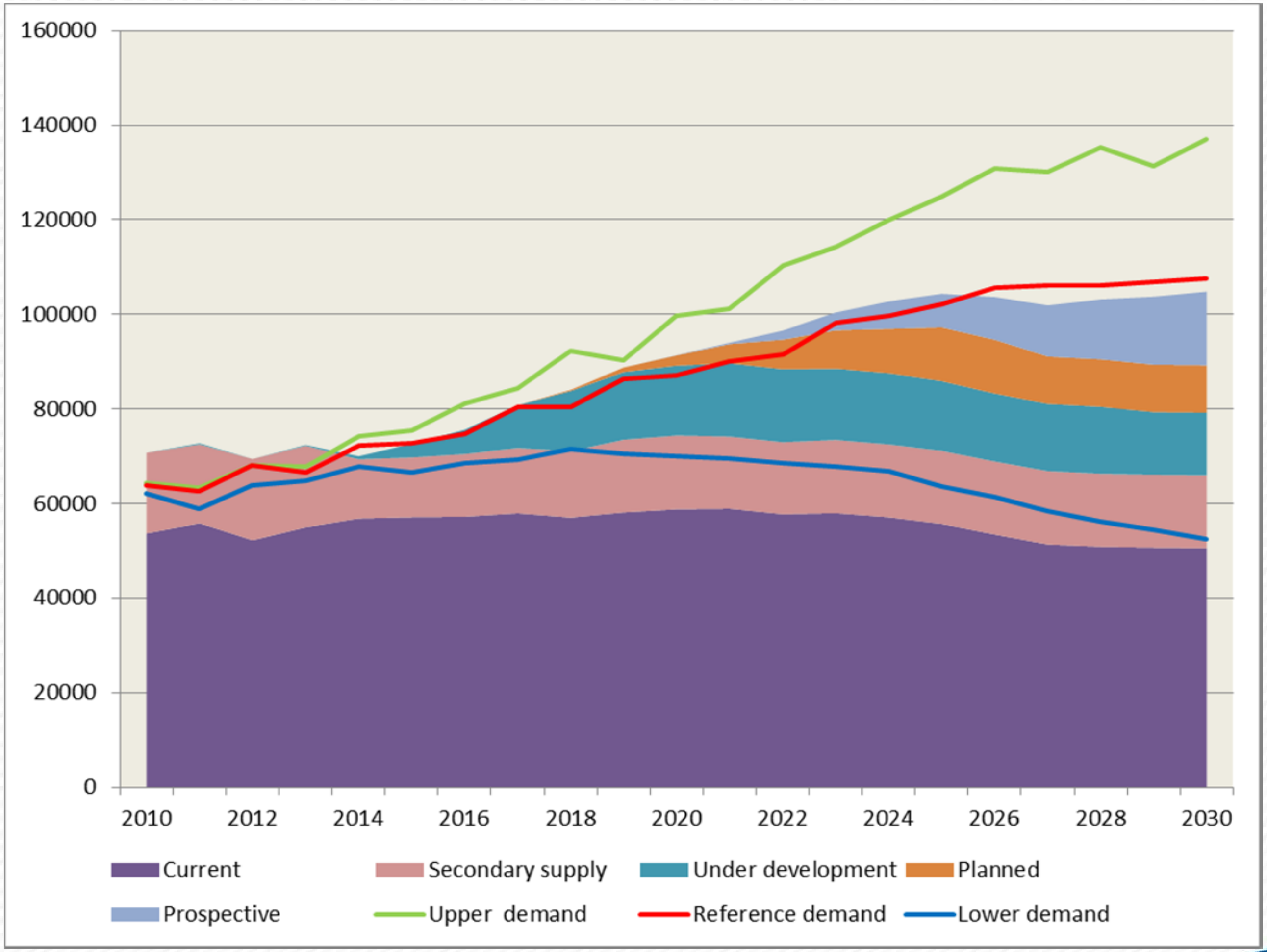
Reference case U supply demand balance, tU



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Conclusions

- Uranium market has sound supply to 2020 but meeting demand becomes more challenging thereafter, unless the lower scenario is accurate
- Primary uranium supply needs to rise sharply to meet rising market demand
- Secondary supplies will remain important

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CONVERSION

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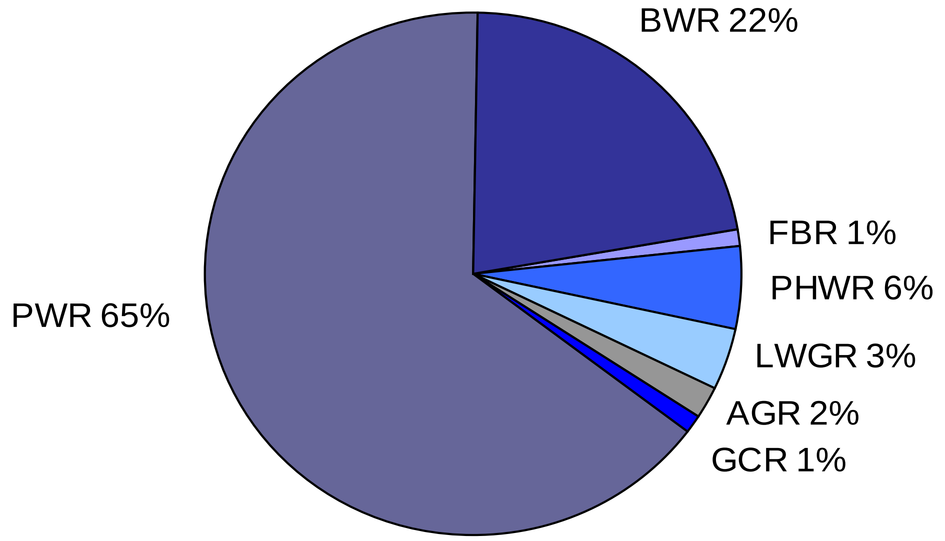
Reactors by type



Conversion - basics

- Enrichment for light water reactors requires conversion of uranium to UF_6
- CANDU reactors require direct conversion to UO_2
- 4 major UF_6 conversion suppliers – Cameco, Comurhex (Areva), ConverDyn and Rosatom
- UO_2 conversion by Cameco and domestic suppliers in Argentina, China, India and Romania

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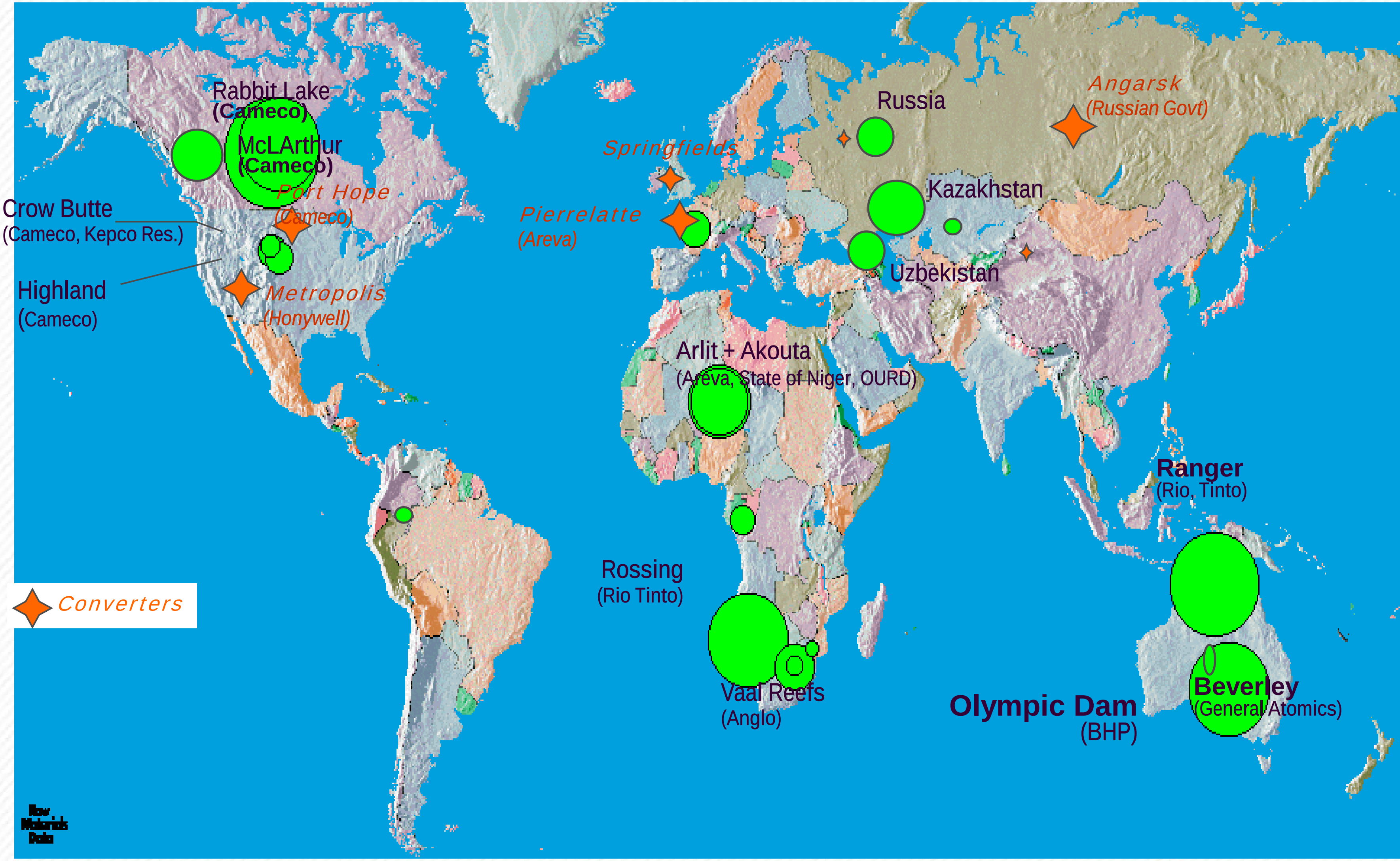
Uranium operations & conversion facilities



UF_6 conversion capacity, tU

Cameco	Canada	12,500
COMURHEX	France	14,500
CNNC	China	3,000
ConverDyn	USA	15,000
Rosatom	Russia	25,000
Westinghouse	UK	6,000
IPEN	Brazil	90
Total - nameplate capacity		76,090

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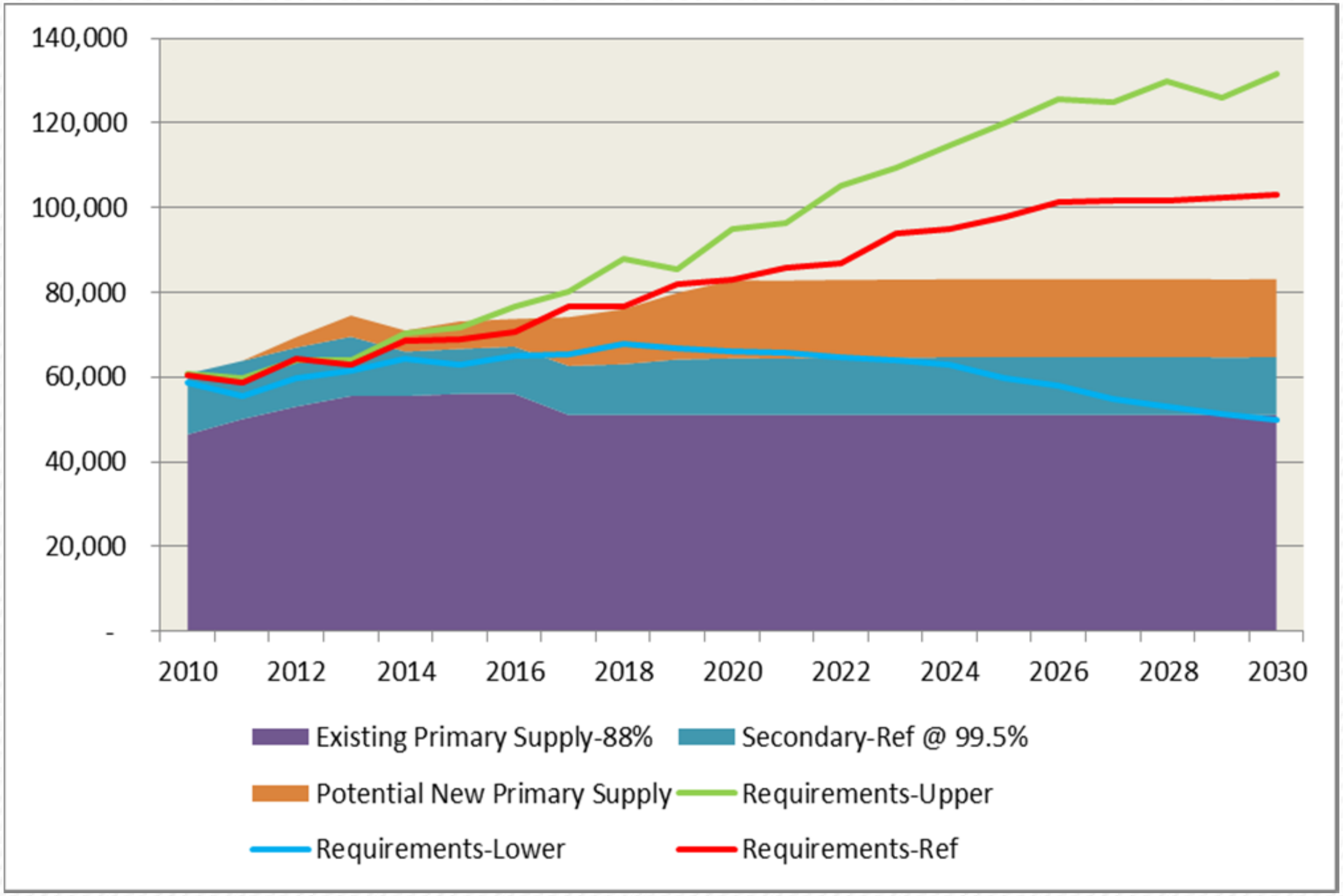
Reference case world conversion supply and demand



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ENRICHMENT

Enrichment - basics

- 90% of current power reactors need fuel where the U-235 isotope is above the natural 0.71% (typically 3-5%)
- Two main technologies – gaseous diffusion and centrifuges
- Investment in laser enrichment so far unrewarded by commercial application
- Large front-end expense for utilities
- Effort expended is measured in separative work units (SWUs)
- Significant part of capacity was historically developed for military requirements

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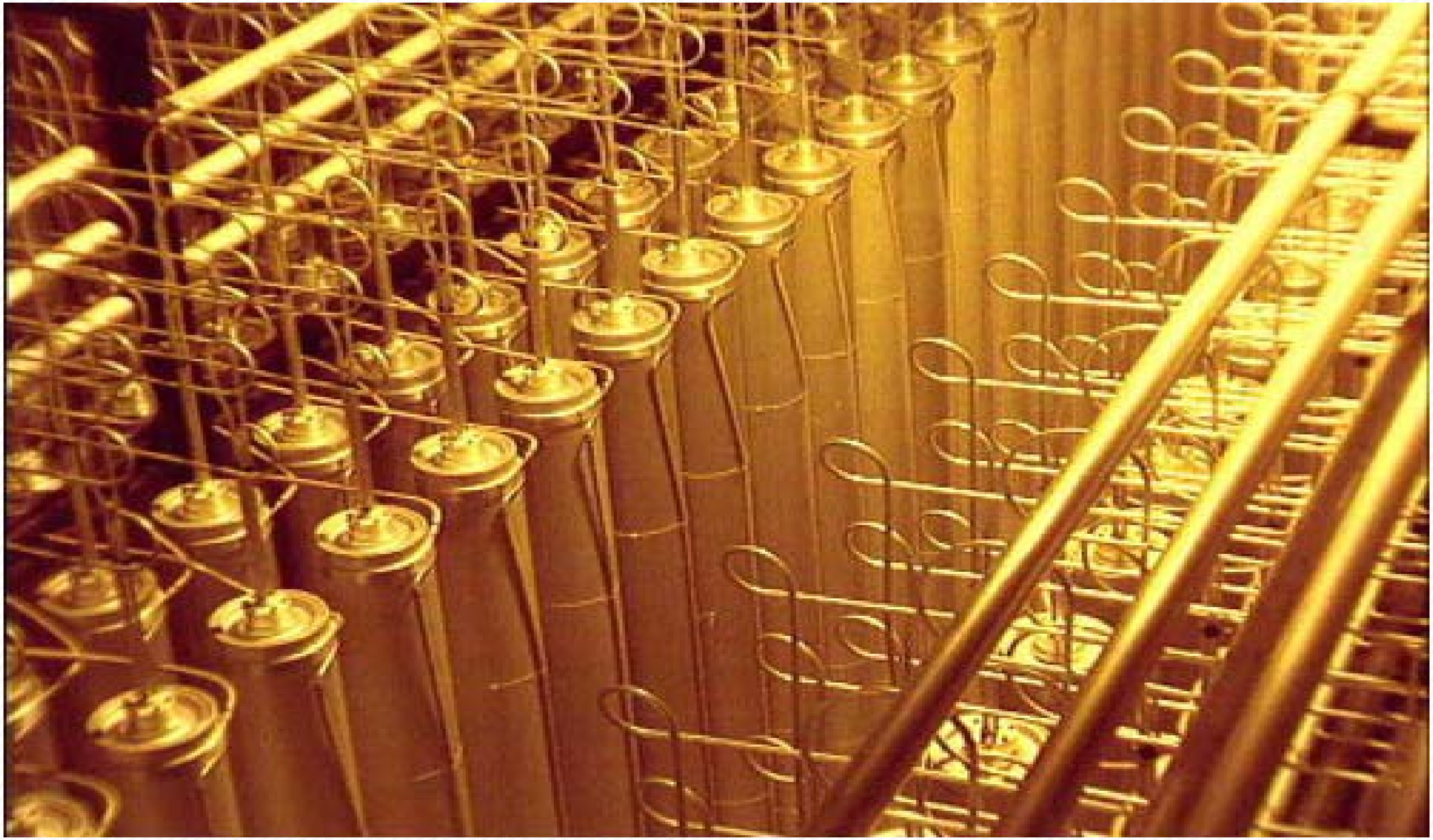
Centrifuges



What is a SWU?

- A unit unique to the nuclear industry
- A measure of the quantity of work or effort necessary to create a quantity of enriched uranium from natural uranium
- A complex unit – detailed mathematical formulae
- Given the huge electricity input in gas diffusion enrichment plants, the SWU could effectively be taken as the electricity required to separate the two isotopes

Enrichment – supply

- Four large suppliers of primary enrichment services – USEC, Eurodif (Areva), Urenco and Rosatom
- USEC and Eurodif have used gas diffusion
- Urenco and Rosatom already use centrifuges
- JNFL and CNNC also primary suppliers
- Heavy current investment in new centrifuge plants by USEC and Urenco in US and by Eurodif in France (and eventually US too)
- Will SILEX as a laser technology prove commercially viable?

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Enrichment capacities, 000 SWUs

CNNC	China	1,300
Eurodif	France	3,000
JNFL	Japan	150
Rosatom	Russia	25,000
Urenco	Europe	13,000
	USA	1,500
USEC	USA	7,000
Others		100
Total – nameplate capacity		51,050

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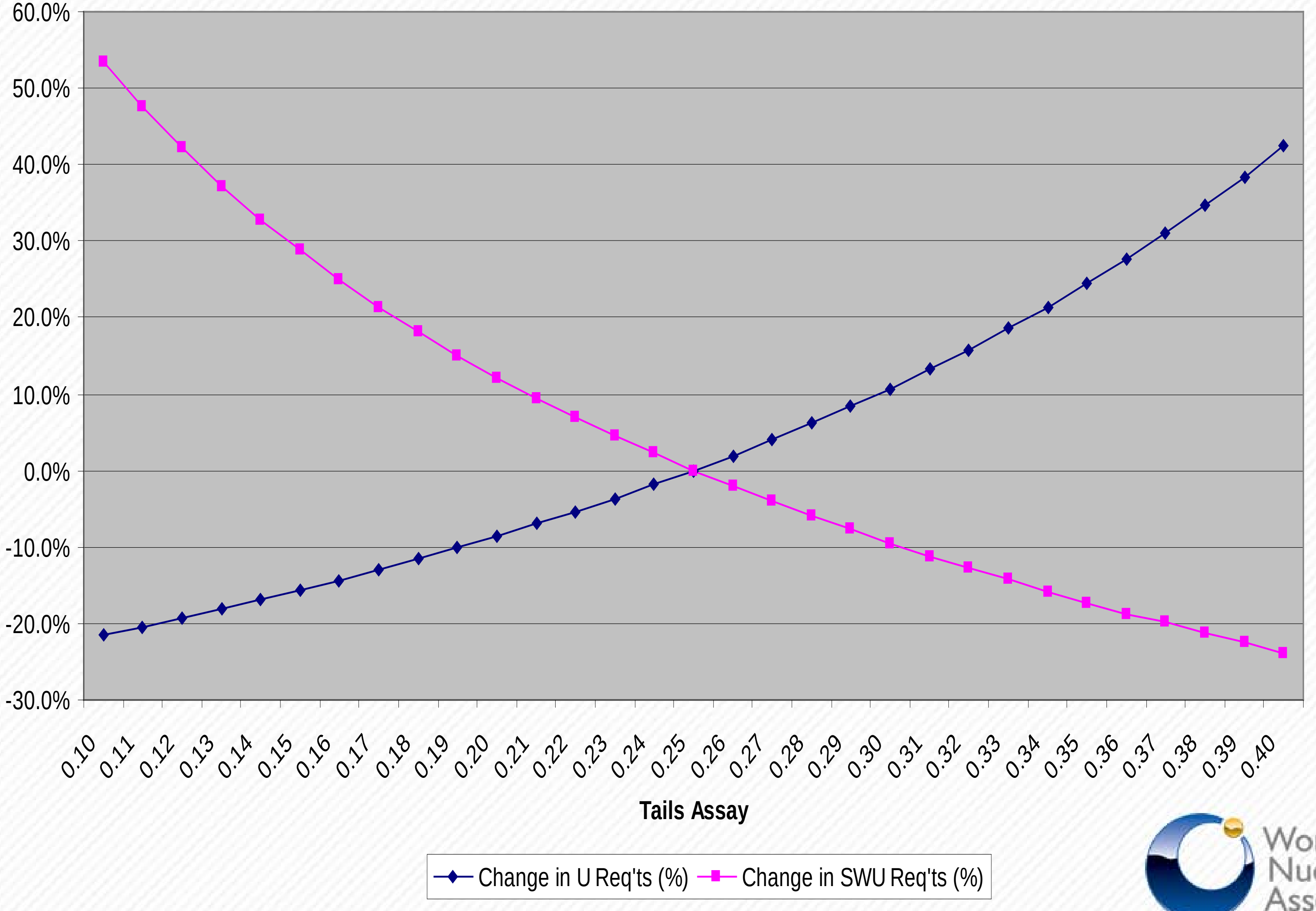
Percentage variation in U & SWU requirements with tails assay



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Depleted uranium

- Over 1.6 million tonnes in storage throughout the world
- Volume increasing by 50,000 tonnes per annum
- Use in diluting HEU
- Possibility of re-enrichment to form new reactor fuel
- Very minor non-nuclear uses owing to density

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Enrichment – current issues

- Acute proliferation issues surround this area of the fuel cycle – similar to reprocessing of used fuel
- Proposals for “regional fuel cycle centres”
- Significant dependence on down-blended Russian HEU – half of SWUs supplied in US in recent years
- Difficulties of access to large Russia capacity for Western reactor operators
- Some capacity is today devoted to re-enrichment of depleted uranium (“tails”)

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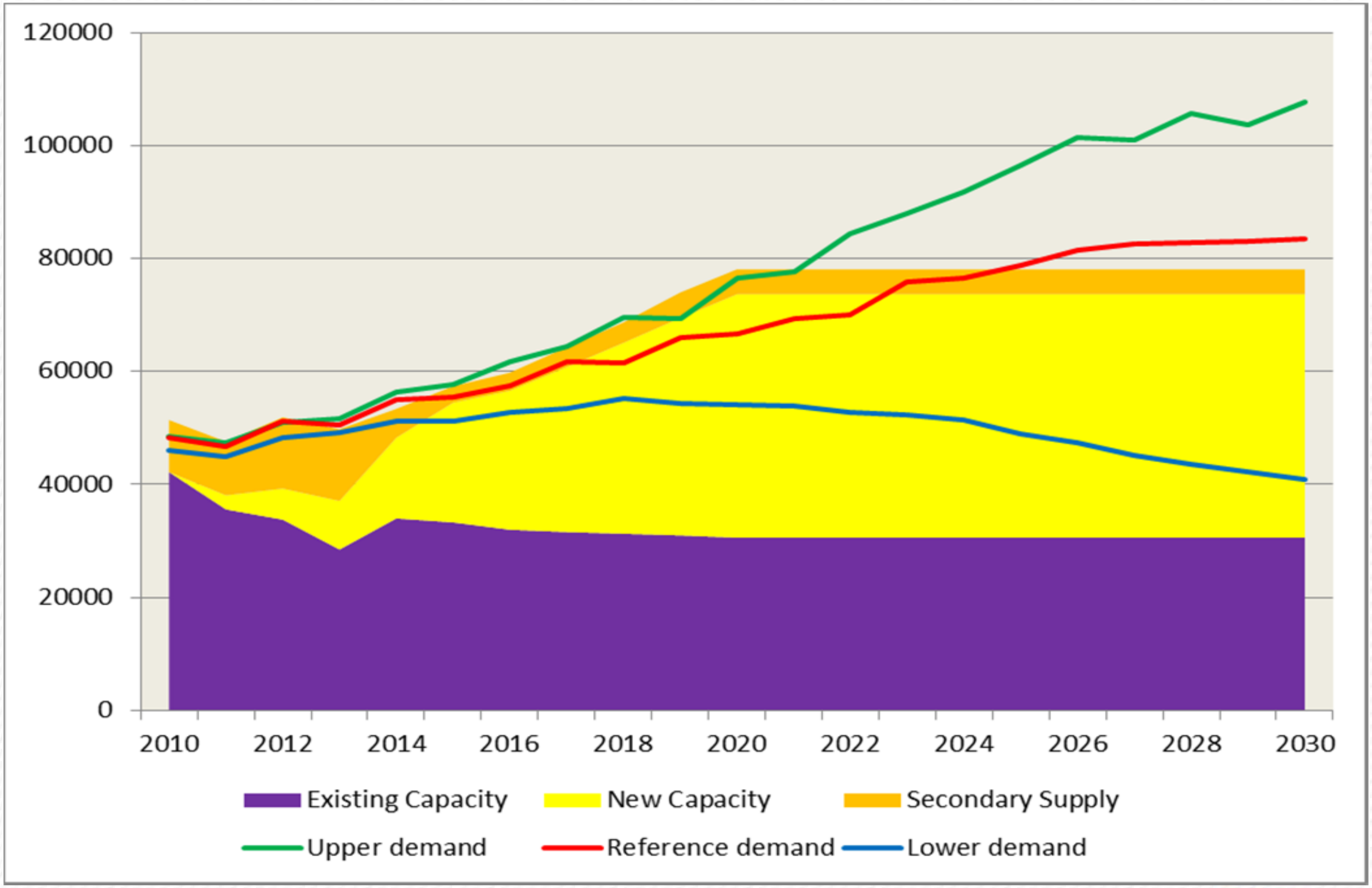
World reference enrichment capacities supply and demand



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FUEL FABRICATION

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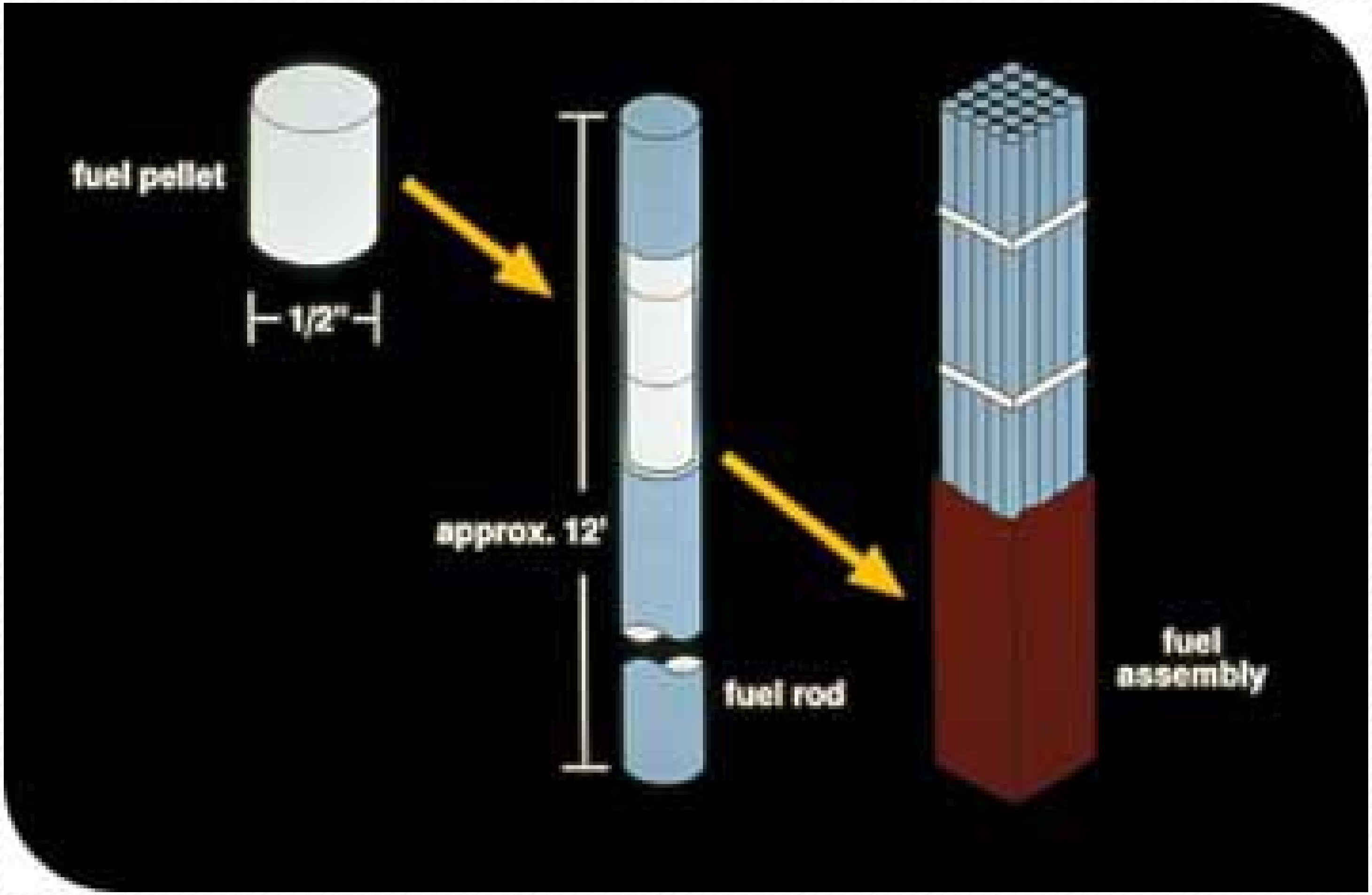
Fuel fabrication - process



UO_2 powder, pellet and fuel assembly

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Fuel fabrication

- Fundamentally different to uranium, conversion and enrichment – not a bulk commodity item and "fungible" - but a "high tech" product/service
- Annual requirements for LWR fuel fabrication is about 7,000 tonnes of heavy metal (enriched U)
- Annual requirements for CANDUS and other reactor types are 2,000-3,000 tU per annum
- Production much more "localised" than other areas of fuel cycle
- "Big boys are Areva NP, Toshiba-Westinghouse, GE-Hitachi and TVEL
- Important smaller suppliers – CNNC, JNFL, KNFC, ENUSA

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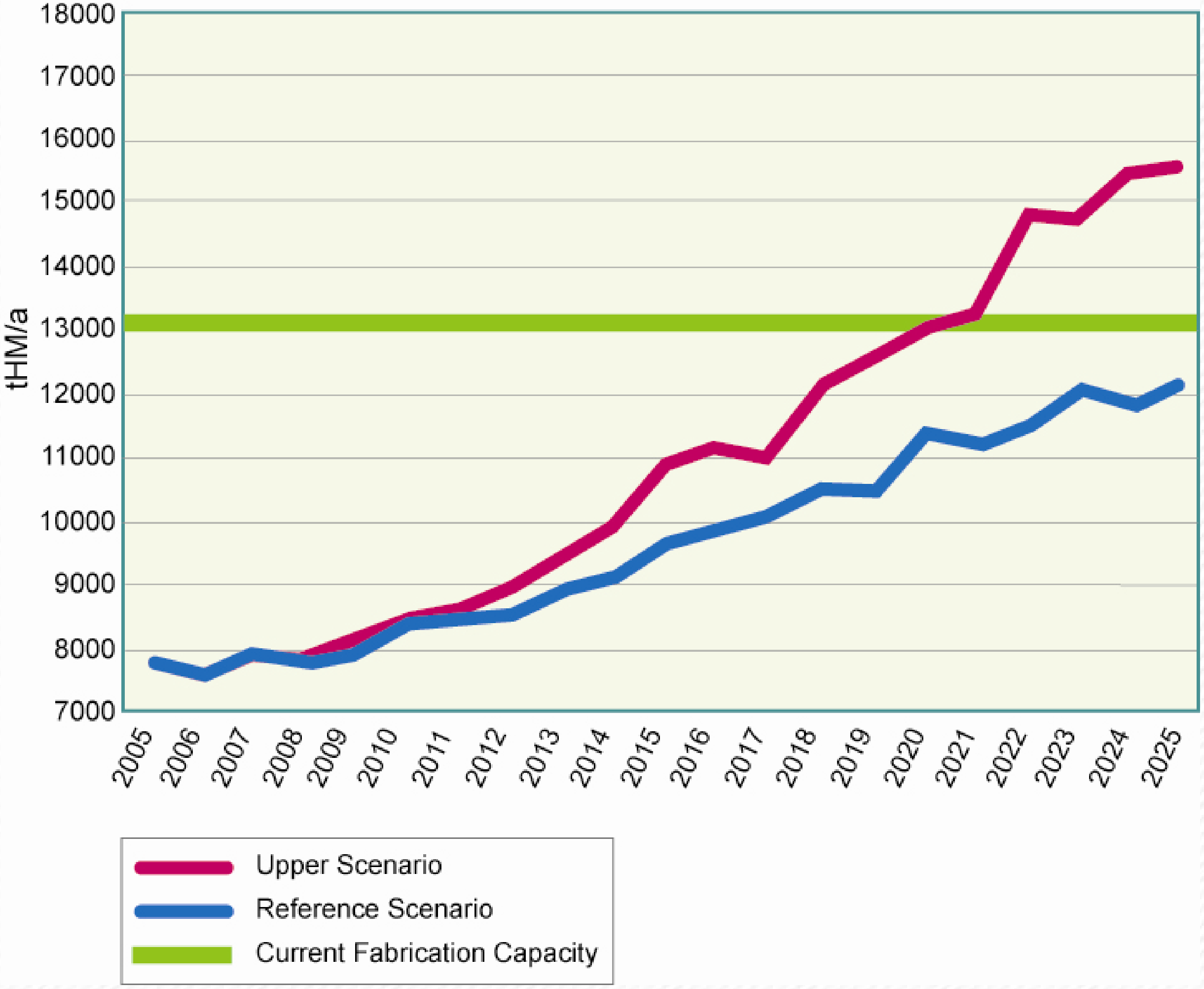
Fabrication supply/demand



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Outlook

- Supply of nuclear fuels will be sufficient to meet demand, even if requirements rise sharply
- But heavy investment will be needed to improve fuel cycle infrastructure
- Over the long-term, new reactor designs, much more efficient in their use of fuel, may fundamentally change the nature of the fuel market

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NUCLEAR FUEL MARKET

Features of nuclear fuel market

- Fuel is not generally bought in its fabricated form – rather the reactor operator buys uranium and conversion, enrichment and fuel fabrication services separately
- Many contracts are very long term
- Reactors are only refuelled once per year – buyers don't need to be in the market all the time
- Fuel can be easily stored – inventories can play an important part in the market
- Spot market is largely an outlet for smoothing out unforeseen blips in supply and demand
- Spot market prices relevant to many longer term contracts

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Market structure

- Few participants
- Small number of transactions – illiquid
- Not transparent – most deals highly confidential
- Data on prices limited – spot market quotations, estimates of contract prices and historic series

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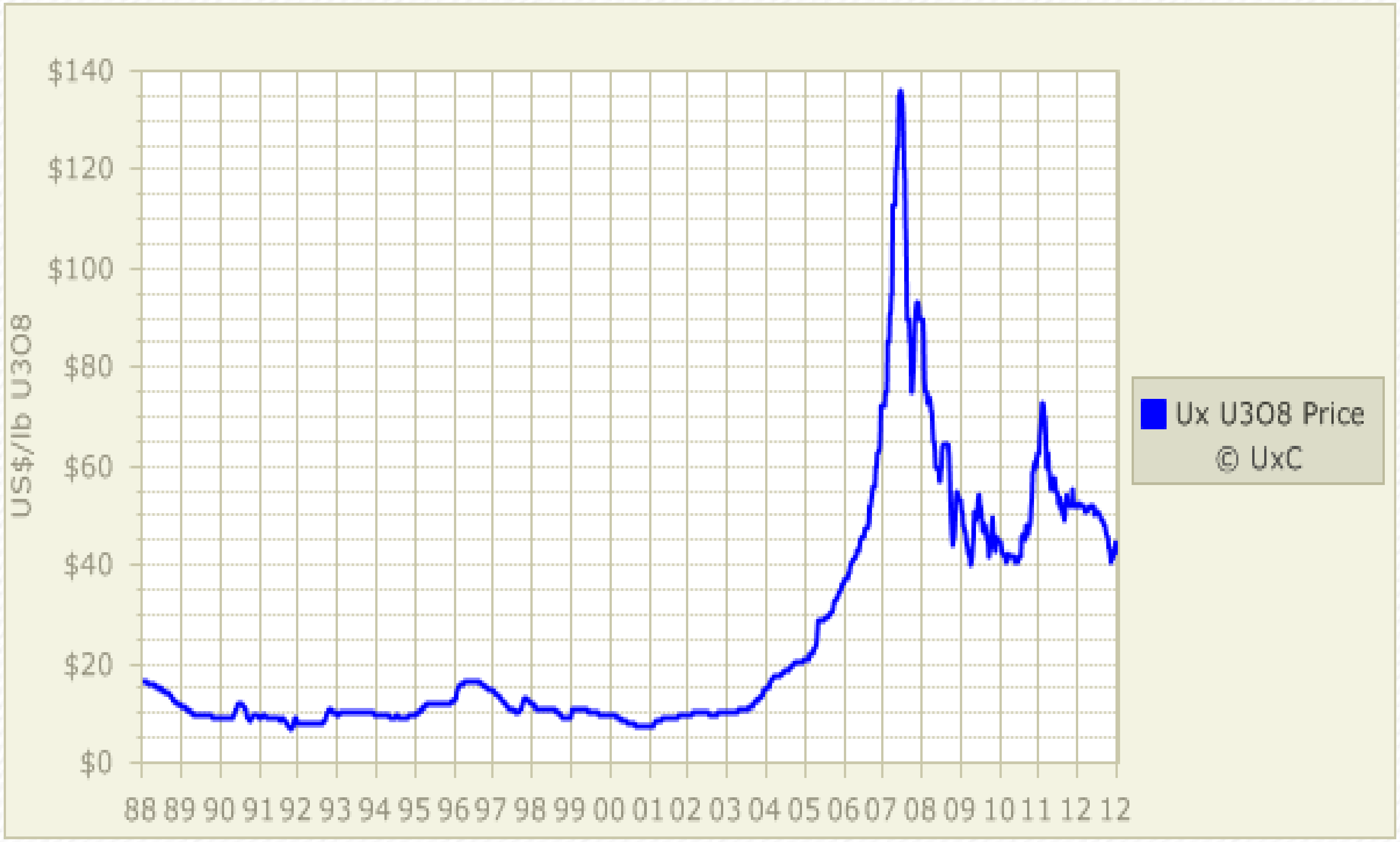
Spot uranium prices – current



A new era for the uranium market?

- It has not functioned well in the recent past
- Dramatic price increase since 2003 – supply very tight
- Gradual move back towards long-term contracts rather than “spot” transactions
- Both reactor operators and mining companies have similar time perspectives – both long-term
- Market transparency issue
- Will quotations on NYMEX and similar help?
- Participants are conservative in their practices

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Concluding issues for uranium market

- How to secure more liquidity and transparency?
- Reforming what we have…..or a revolution?
- Buyers will do all they can to economise on uranium
- Prices must become connected with costs at some point
- Risk of price collapse cutting off necessary investments in new capacity

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