International Atomic Energy Agency

Technology and Financing

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Technology and financing

Technology impacts

Cost and Schedule

Which impact financing

How does technology affect financing?

- **Plant initial capital cost**
  - operation and maintenance and fuel costs
- **Status of development**
  - design detail
- **Status of regulatory approval**
  - what does approval mean?
- **Provenness**
  - construction and operation risk

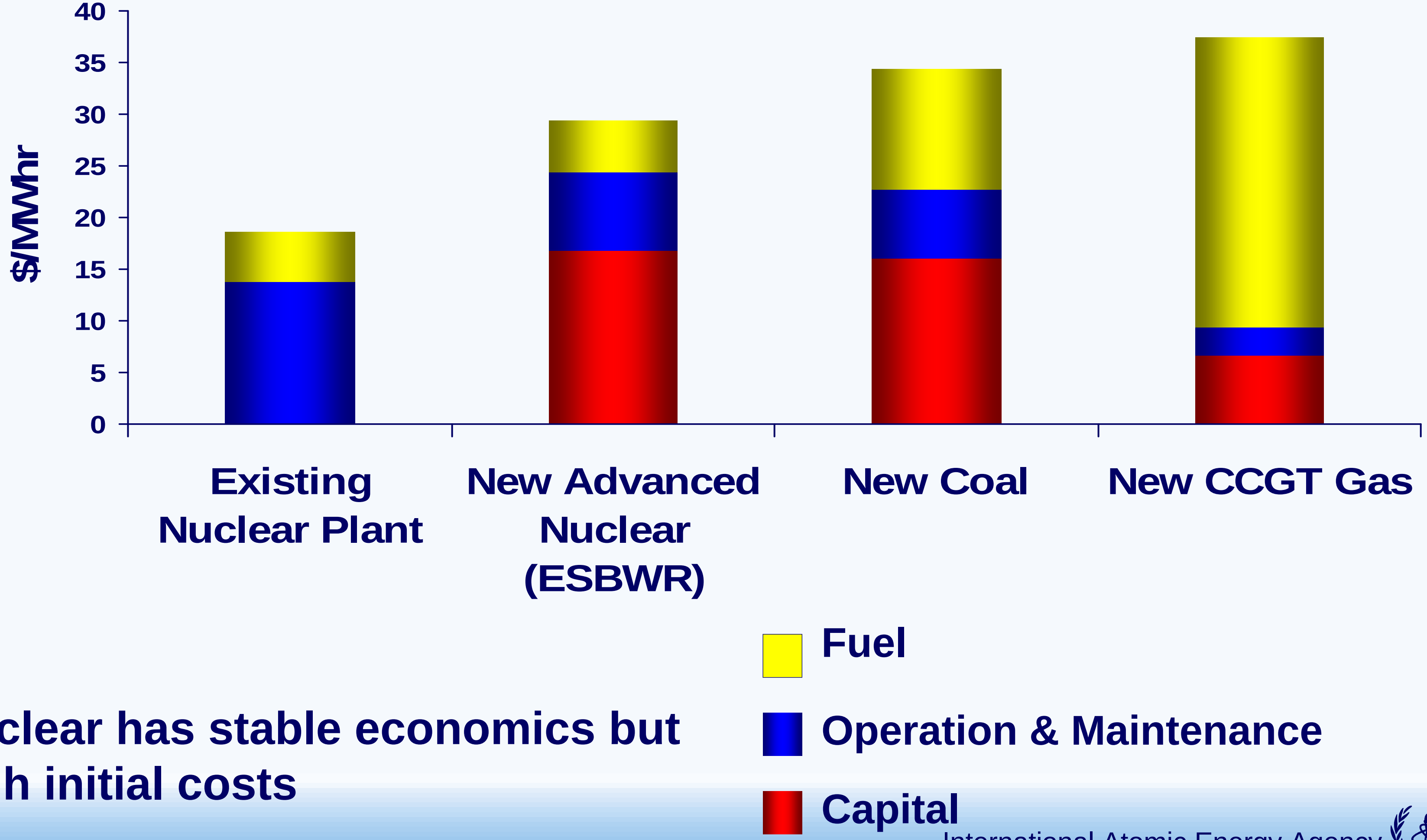
Nothing is as difficult as it may appear
– it has been done many times before

Plant initial capital cost

- **Reliable numbers are very difficult to get**
  - different assumptions – e.g labor rates
  - depends on what is included – initial fuel?
  - where are major components made?
  - Exchange rates?
- **Comparisons of material quantities**
  - maybe more reliable measure of relative costs
- **Other factors**
  - location in the queue

THE CHALLENGE FOR ADVANCED WATER COOLED REACTORS IS TO ACHIEVE LOW CAPITAL COSTS

(example shows a result by a supplier involved in different markets)



Nuclear has stable economics but high initial costs

PROVEN MEANS FOR COST REDUCTION

- *standardization and series construction*
  Rep. of Korea's Standardized Plants ("OPRs"), Japan's ABWRs, India's HWRs
- *multiple unit construction at a site*
  France's 58 PWRs at 19 sites
- *improving construction methods to shorten construction schedule*
  Techniques used at Kashiwazaki-Kariwa 6 &7; Qinshan III 1&2; Lingau 1&2; Yonggwang 5&6; Tarapur 3&4
- in developing countries, *furthering self-reliance by increasing domestic portion of construction and component fabrication*
  Experience at Qinshan III 1&2; Lingau 1&2; Yonggwang 5&6; Cernavoda 1 & 2
- *economy of scale*
  N4 and Konvoi to EPR; KSNP to APR-1400; ABWR to ABWR-II; AP-600 to AP-1000; 1550 MWe ESBWR; 220 MWe HWR to 540 & 700 MWe HWR; WWER-1000 to WWER-1500
- …*others*

NEW APPROACHES FOR COST REDUCTION?

- *Computer based techniques*
- *PSA methods and data bases to support*
  - **establishment of risk-informed regulatory requirements**
- *Establishment of commonly acceptable safety requirements*
- *Development of systems with higher thermal efficiency*
- *Modularization, factory fabrication, and series production*
- *Highly reliable components and systems, including "smart" (instrumented and monitored) components -*
- *Improving the technology base for reducing over-design*
- *Development of passive safety systems*[1]

Some observations…for new plants

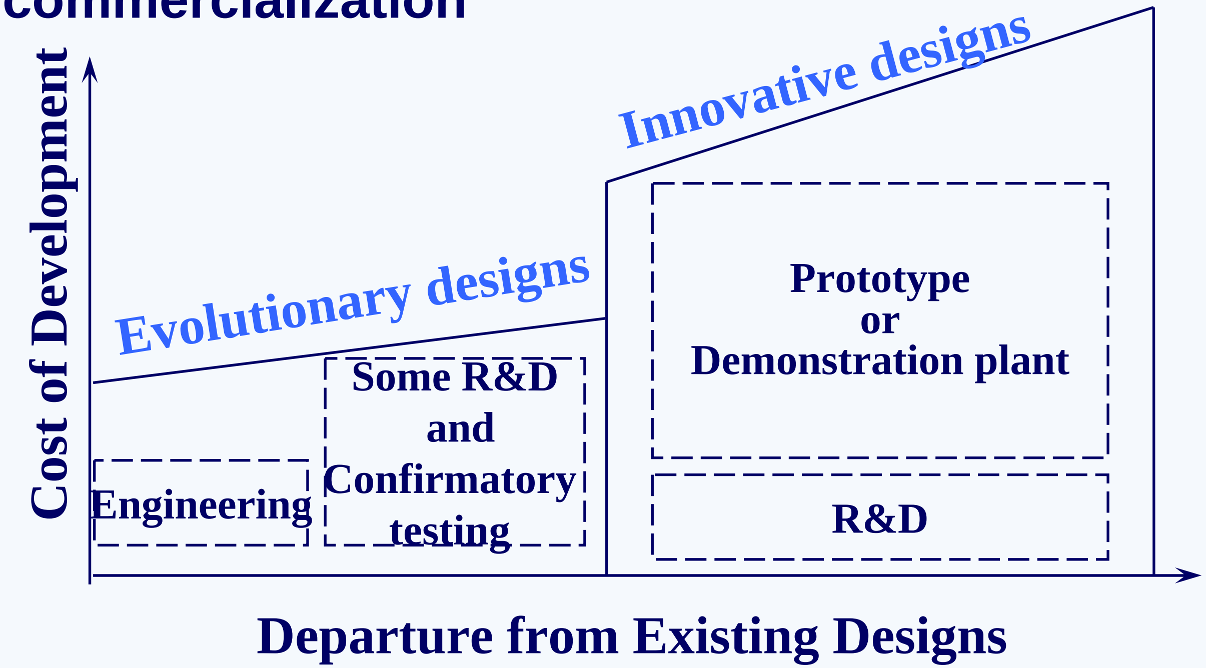
- Competitive targets change with time
- production costs (fuel + O&M) will not likely go below 1.1 – 1.2 US cent / kWh – the best of current experience

- Design organizations focus on competitive capital cost
  - Short construction times (~ 4 to 5 yr)
  - Sizes appropriate to grid capacity and owner investment capability
    - large sizes for major home markets
    - small & medium sizes for niche markets

- Generation cost targets are 3-5 US cent / kWh
- To achieve competitive costs, proven means are being applied and new approaches are being pursued

Status of development

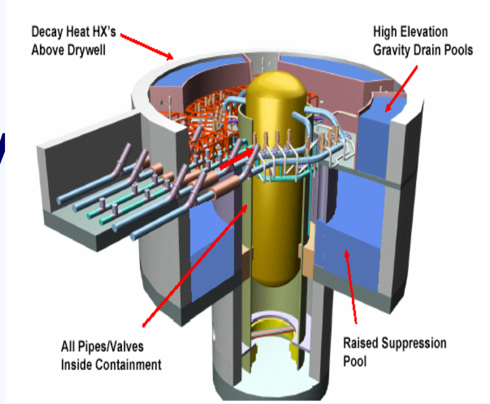
- **Evolutionary designs - achieve improvements over existing designs through small to moderate modifications**
- **Innovative designs - incorporate radical conceptual changes and may require a prototype or demonstration plant before commercialization**

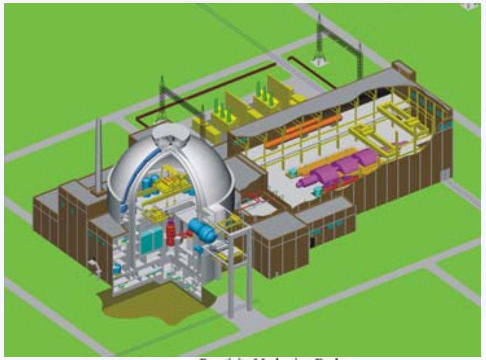


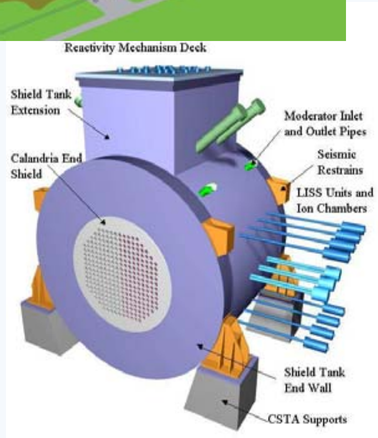
Conceptual designs are always cheaper than real designs!

Trends in advanced reactor design

- Increase plant availability
- Reduce components – simplify
- Design for easier construction
- Build safety into the design







Relying on 50 years of experience

DEVELOPMENT OF ADVANCED DESIGNS

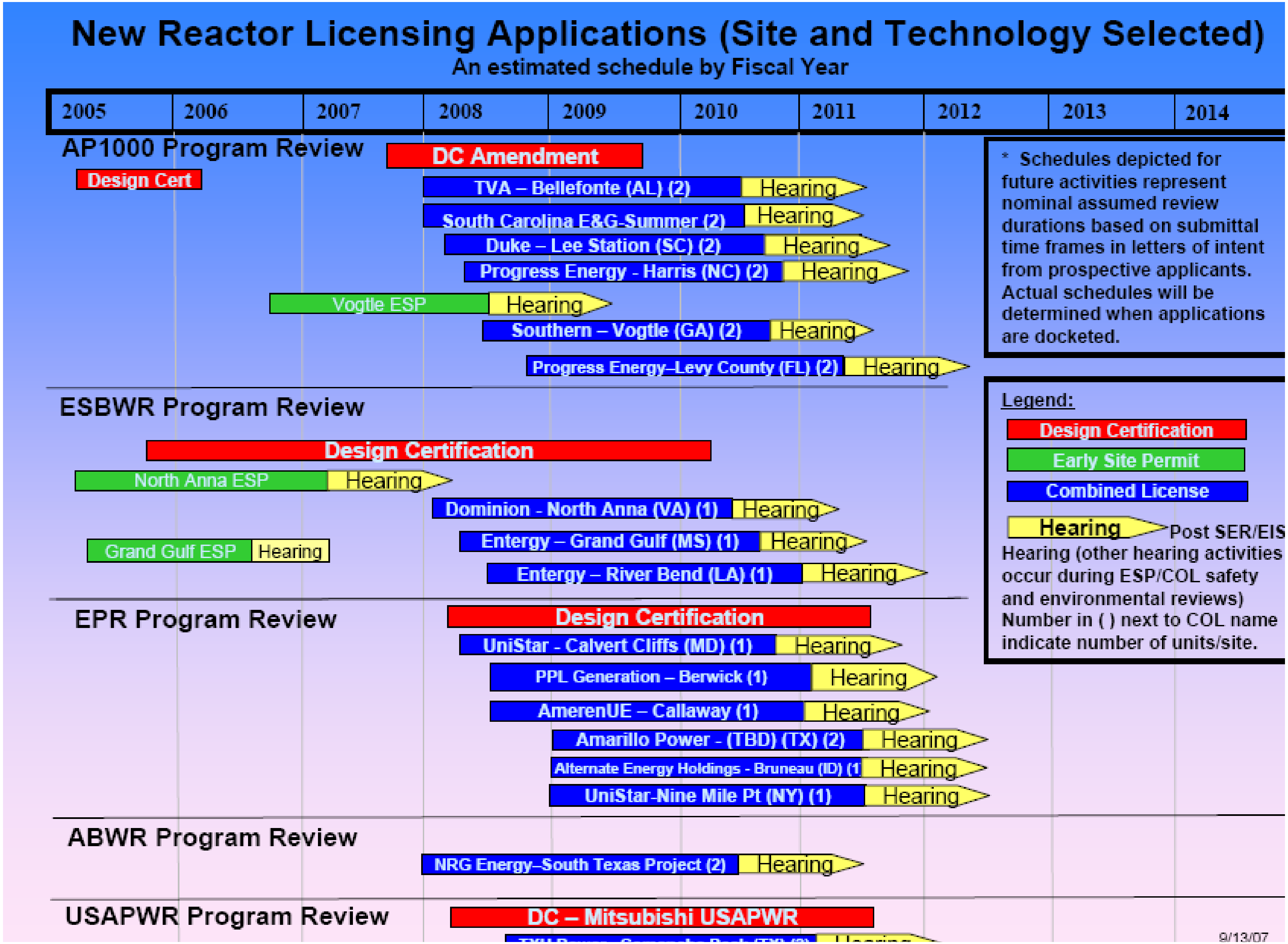
- **Light and Heavy Water Reactors are proceeding**
  - Fast & Gas Cooled Reactors in prototype stage
  - Other “Niche” designs in very early stages
- **Guided by “Users Requirements Documents”**
  - ***“Common User Criteria” in preparation***
- **Incorporate**
  - experience from current plants
  - Advancements and R&D results

Status of regulatory approval

- **Countries have different processes**
  - what do each of the approvals mean?
  - is one certificate better than another?
  - countries impose individual requirements
- **Variations exist within each country**
- **Impacts of regulatory approval**
  - Standardization
  - Impact on overall schedule
  - Changes in design during construction

SAFETY APPROACHES REFLECT STRINGENT SAFETY GOALS

- reduction of the operator burden by improved man-machine interface and digital instrumentation and control;
- incorporation of highly reliable active safety systems or passive safety systems;
- a reduction in core damage frequency relative to current plants; and
- ensuring very low releases in the event of a severe accident to provide a technical basis to simplify emergency planning


New Reactor Licensing Applications (Site and Technology Selected)
An estimated schedule by Fiscal Year
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
AP1000 Program Review
DC Amendment
Design Cert
TVA – Bellefonte (AL) (2)
Hearing
South Carolina E&G-Summer (2)
Hearing
Duke – Lee Station (SC) (2)
Hearing
Progress Energy - Harris (NC) (2)
Hearing
Vogtle ESP
Hearing
Southern – Vogtle (GA) (2)
Hearing
Progress Energy–Levy County (FL) (2)
Hearing
* Schedules depicted for future activities represent nominal assumed review durations based on submittal time frames in letters of intent from prospective applicants. Actual schedules will be determined when applications are docketed.
ESBWR Program Review
Design Certification
North Anna ESP
Hearing
Dominion - North Anna (VA) (1)
Hearing
Grand Gulf ESP
Hearing
Entergy – Grand Gulf (MS) (1)
Hearing
Entergy – River Bend (LA) (1)
Hearing
Legend:
Design Certification
Early Site Permit
Combined License
Hearing
Post SER/EIS Hearing (other hearing activities occur during ESP/COL safety and environmental reviews)
Number in ( ) next to COL name indicate number of units/site.
EPR Program Review
Design Certification
UniStar - Calvert Cliffs (MD) (1)
Hearing
PPL Generation – Berwick (1)
Hearing
AmerenUE – Callaway (1)
Hearing
Amarillo Power - (TBD) (TX) (2)
Hearing
Alternate Energy Holdings - Bruneau (ID) (1
Hearing
UniStar-Nine Mile Pt (NY) (1)
Hearing
ABWR Program Review
NRG Energy–South Texas Project (2)
Hearing
USAPWR Program Review
DC – Mitsubishi USAPWR
9/13/07

Provenness

- **Past good (or bad) experience affects costs**
  - design detail
  - construction times
  - reliability and performance
- **Past experience results in certainty**
  - Suppliers will have reliable costs
  - Suppliers may not include uncertainty margins
  - Financiers may reduce risk premium

Status of Advanced LWR Designs- IAEA TECDOC - 2004

Large Size (above 700 MWe)

- ABWR and ABWR-II (GE,Hitachi and Toshiba)
- APWR and APWR+ (Mitsubishi and Westinghouse)
- BWR 90+ (Westinghouse Atom)
- EPR (Framatome ANP)
- SWR 1000 (Framatome ANP)
- ESBWR (GE)
- KSNP+ (KHNP)
- APR-1400 (KHNP)
- AP-1000 (Westinghouse)
- EP-1000 (Westinghouse/Genesi)
- WWER-1000 (Atomenergoproject /Gidropress, Russia); and WWER-1500
- CNP-1000 (CNNC)
- SCPR (Toshiba, et. al.)
- RMWR (JAERI)
- RBWR (Hitachi)

Medium size (300-700 MWe)

- AC-600 (CNNC)
- AP-600 (Westinghouse)
- HSBWR (Hitachi)
- HABWR (Hitachi)
- WWER-640 (Atomenergoproject /Gidropress)
- VK-300 (RDIPE)
- IRIS (Westinghouse)
- QS-600 co-generation plant (CNNC)
- PAES-600 with twin VBER-300 units (OKBM)
- NP-300 (Technicatome)

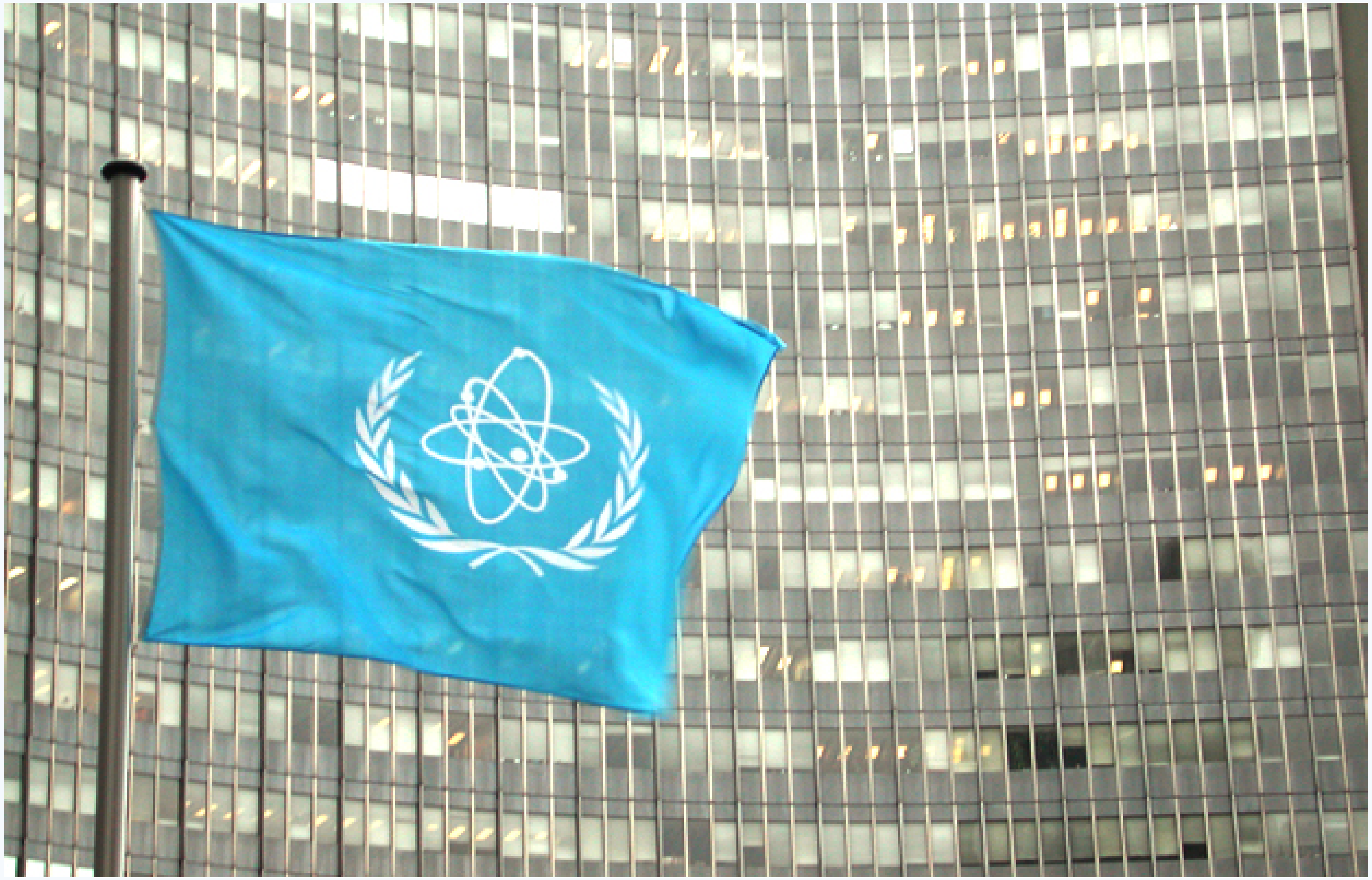
Small size (below 300 MWe)

- LSBWR (Toshiba)
- CAREM (CNEA/INVAP)
- SMART (KAERI)
- SSBWR (Hitachi)
- IMR (Mitsubishi)
- KLT-40 (OKBM)
- PSRD-100 (JAERI)

Summary and Conclusion

- **Technology choice has several impacts**
  - Plant initial cost
  - Overall project schedule incl. start time
  - Overall construction schedule
- **"Provenness" has many impacts**
  - Overall schedule
  - Ability to get & cost of financing

Backup slides



…atoms for peace

Status of Advanced LWR Designs: 2004

- Development goals and safety objectives
- Descriptions of 34 Advanced PWRs, BWRs and WWERs
  - Evolutionary and innovative
  - Electricity or co-generation
  - Descriptions – each design:
    - Systems
      - Nuclear
      - Power conversion
      - I&C
      - Electrical
      - Safety
    - summary level technical data
    - measures to enhance economy and reliability
- **Next Status Report will be web-based**


IAEA-TECDOC-1391

Status of advanced light water reactor designs 2004

IAEA
International Atomic Energy Agency

May 2004

THERE ARE SEVERAL EVOLUTIONARY WATER COOLED REACTOR DESIGNS

- Evolutionary LWRs
  - Japan: 1360 MWe ABWR (GE-Toshiba- Hitachi);
    1700 MWe ABWR-II (Japanese utilities, GE-Hitachi-Toshiba);
    1540 MWe APWR (Japanese utilities, Mitsubishi and Westinghouse);
    1750 MWe APWR+ (Japanese utilities and Mitsubishi)
  - USA: 600 MWe AP-600; 1100 MWe AP-1000; and 335 MWe IRIS (Westinghouse);
    1350 MWe ABWR and 1550 MWe ESBWR (General Electric);
  - France/Germany: 1545 MWe EPR and 1250 MWe SWR-1000 (Framatome ANP)
  - Rep. of Korea: 1000 MWe OPR-1000 and 1400 MWe APR-1400 (KHNP and Korean Industry)
  - China: 1000 MWe CNP-1000 (CNNC) and 600 MWe AC-600 (NPIC)
  - Russia: WWER-1000 (V-392); WWER-1500; and WWER-640 (V-407) (Gidropress and Atomenergoprojekt)

SEVERAL INNOVATIVE DESIGNS ARE BEING DEVELOPED

- **Innovative designs may require a prototype as part of development programme**
- **many are small and medium size reactors (SMRs)**
  - **APPROPRIATE FOR MODEST DEMAND GROWTH AND SMALLER ELECTRICITY GRIDS**
  - **SMALLER AMOUNT OF MONEY TO FINANCE**
  - **SIMPLER DESIGN**
  - **PASSIVE SAFETY SYSTEMS; HIGH SAFETY LEVEL**
  - **GOOD FIT FOR NON-ELECTRIC APPLICATIONS**
  - **MAY OFFER PROLIFERATION RESISTANCE (e.g. SMRs without on-site refueling)**
  - **SMALL REACTOR DOES NOT MEAN SMALL NPP --- the NPP can have several units as “modules” giving high total MWe capacity**

STATUS OF INNOVATIVE SMRs

- **TECDOCs-1485 &-1536 address all reactor lines (LWRs, HWRs, GCRs, LMRs)**
- **Describe**
  - **Features pursued to improve economics**
  - **Provisions for efficient resource utilization**
  - **Safety features**
  - **Proliferation resistant and physical protection features**
  - **Enabling technologies requiring further R&D**

EXAMPLES OF INNOVATIVE WATER-COOLED REACTORS

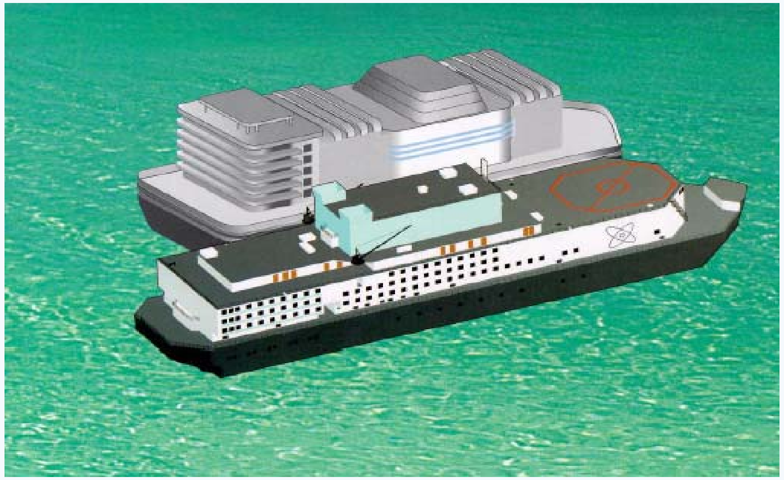
- **Some integral primary system PWRs**
  - **Core and SG in same vessel – eliminates piping**
    - **CAREM (CNEA) Argentina [small prototype planned by 2011; site preparation has begun]**
    - **SMART (KAERI) Rep. of Korea [FOAK –demo - planned]**
    - **SCOR (CEA, France)**
  - **Generally “small” - below 300 MWe**
  - **Often for electricity and seawater desalination**
- **Thermo-dynamically supercritical reactors**
  - **Operate above critical point (22.1 MPa; 374 ºC) – thermal efficiency of 44-45 % vs. 33-35% for current LWR**
  - **Selected for development by GIF**

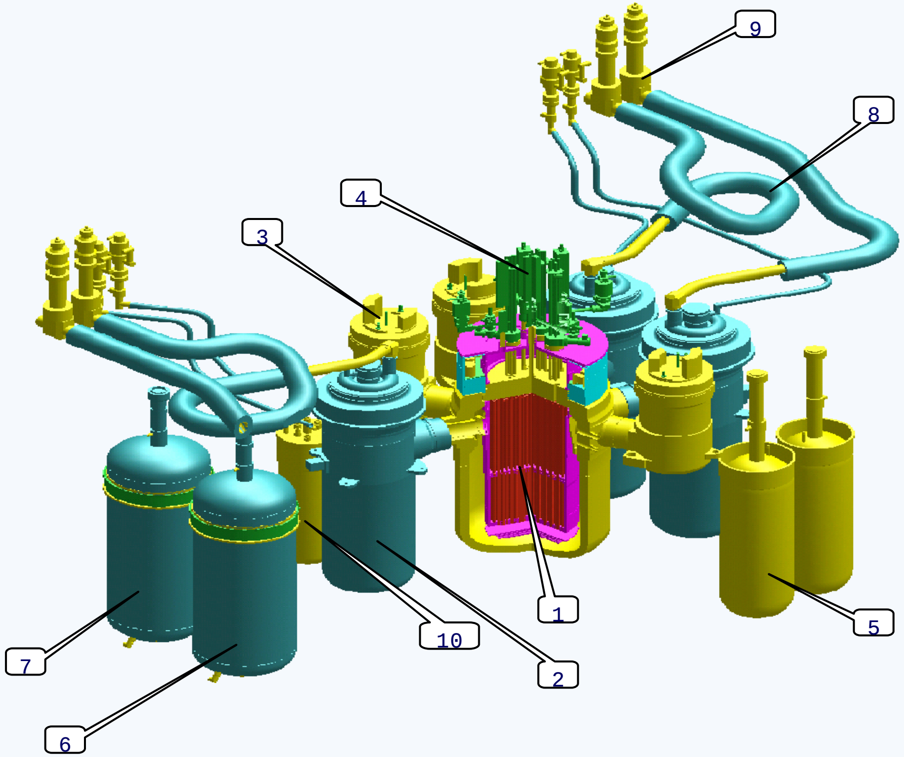
MORE EXAMPLES OF INNOVATIVE WATER-COOLED REACTORS

- Designs for conversion of Th^{232} or U^{238} (addressing sustainability goals)
  - India's Advanced HWR
    - fuel with ThO_2 to produce U^{233}
    - vertical pressure tube design with natural circulation
  - Japan's high conversion LWR concepts
    - for U^{238} conversion with Pu fuel (tight lattice; low moderation)
    - build on ABWR technology
      - RMWR (JAEA et.al.)

        Concepts range from 300 – 1300 MWe
      - RBWR (Hitachi) – 1300 MWe

KLT-40 (OKBM)





- **floating small NPP design for electricity and heat**
- **Construction of pilot plant (2 units) started 4.2007**

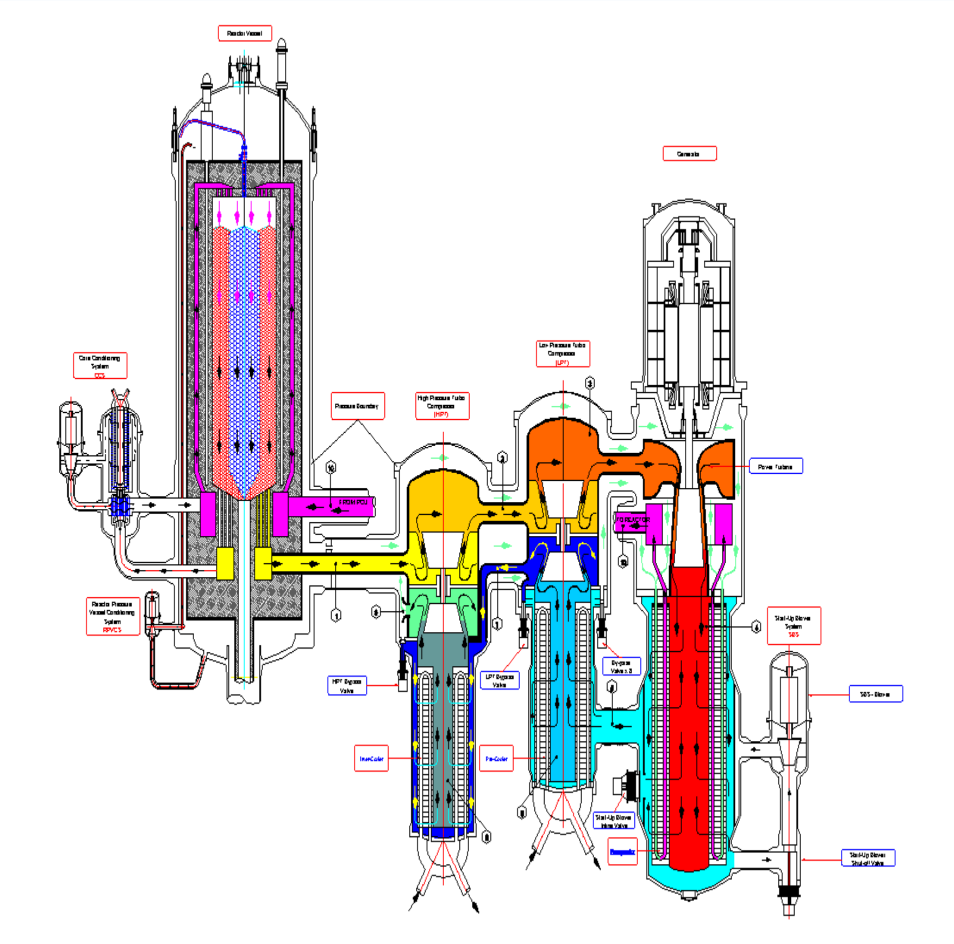
1 Reactor; 6&7 Pressurizers; 2 Steam generator; 8 Steam lines; 3 Main circulating pump; 9 Localizing valves;

4 CPS drives; 10 Heat exchanger of purification and cooldown system; 5 ECCS accumulator

SUMMARY OF GAS-COOLED REACTOR DEVELOPMENT

- 1400 reactor-years experience
- CO_2 cooled
  - 18 reactors (Magnox and AGRs) generate most of the UK's nuclear electricity [23 more have been shut down]
  - have also operated in France, Japan, Italy and Spain
- Helium cooled
  - have operated in UK (1), Germany (2) and the USA (2)
  - current test reactors:
    - 30 MW(th) HTTR (JAEA, Japan)
    - 10 MW(th) HTR-10 (Tsinghua University, China)
  - In South Africa a ~ 165 MWe plant is being designed
  - The US is designing a plant ["NGNP"] for hydrogen and electricity production

The South African "Pebble Bed Modular Reactor" (PBMR) promises high thermal efficiency and safety



- **being developed by Eskom, SA's Industrial Development Corporation, and Westinghouse**
- **a direct cycle helium turbine provides thermal efficiency of ~ 41- 43%**
- **inherent features provide a high safety level**

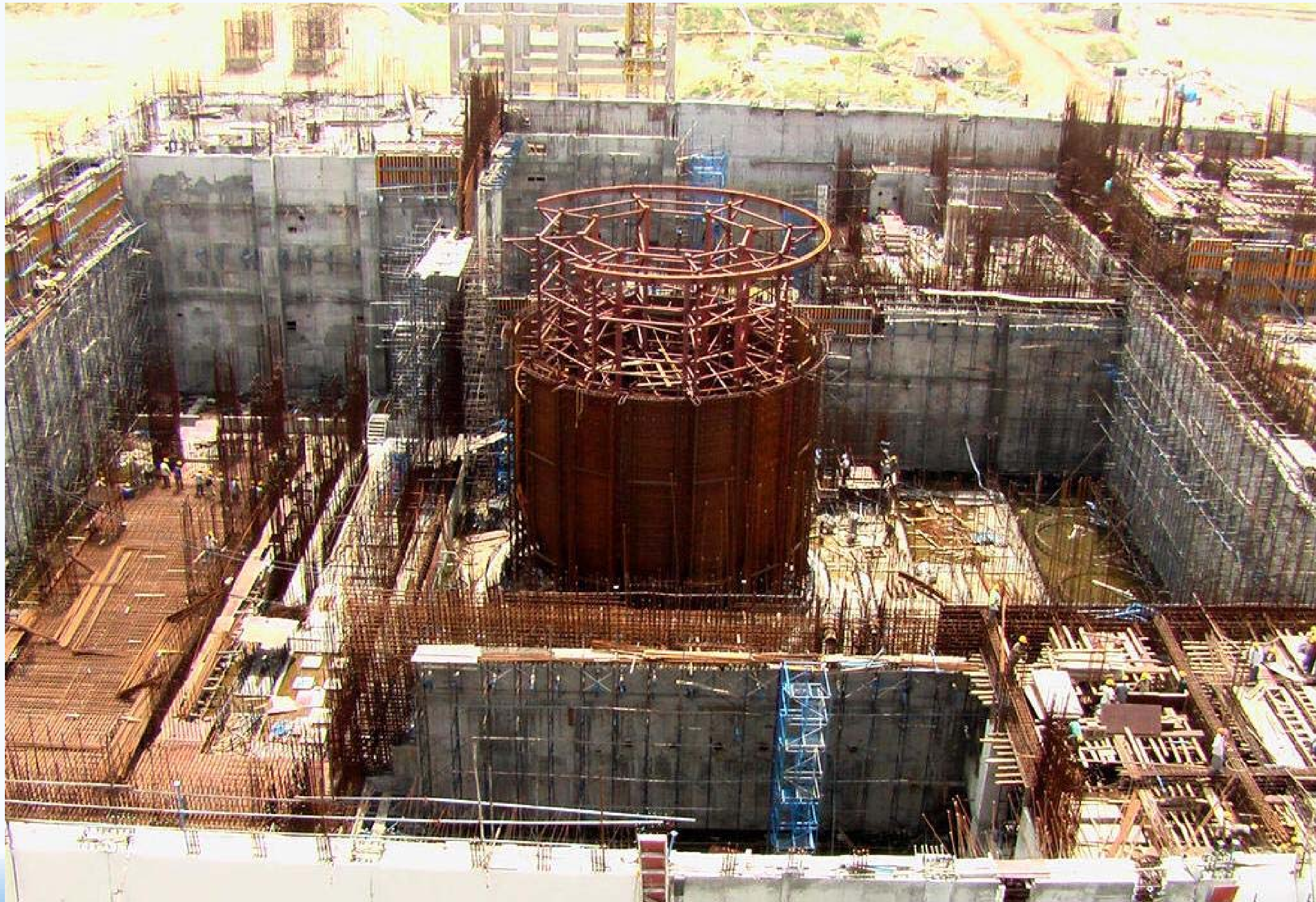
Fast Reactor Development

- France:
  - Conducting tests of transmutation of long lived waste & use of Pu fuels at Phénix
  - Designing 300-600 MWe Advanced LMR Prototype for commissioning in 2020
  - Performing R&D on GCFR
- Japan:
  - ➢ MONJU restart planned for 2008
  - Operating JOYO experimental LMR
  - Conducting development studies for future FR Systems
- India:
  - Operating FBTR
  - ➢ Constructing 500 MWe Prototype Fast Breeder Reactor (commissioning 2010)
- Russia:
  - Operating BN-600
  - ➢ Constructing BN-800
  - Developing other Na, Pb, and Pb-Bi cooled systems
- China:
  - ➢ Constructing 25 MWe CEFR – criticality planned in 2009
- Rep. of Korea:
  - Conceptual design of 600 MWe Kalimer is complete
- United States
  - ➢ In GNEP, planning development of industry-led prototype facilities:
    - Advanced Burner Reactor
    - LWR spent fuel processing

China's 25 MWe Experimental Fast Reactor
(commissioning scheduled - 2009)

India is constructing a Prototype FBR (500 MWe)

(commissioning scheduled - 2010)

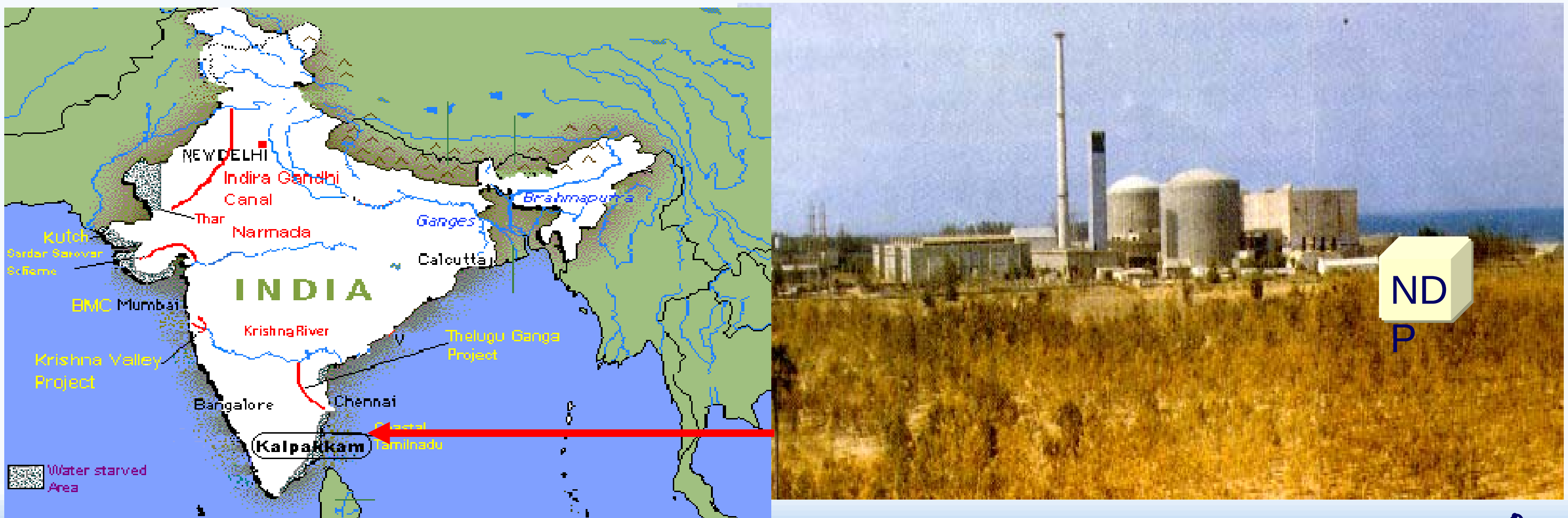


EXAMPLES OF ADVANCED APPLICATIONS OF NUCLEAR ENERGY

- **Sea-water desalination**
- **District heating**
- **Heat for industrial processes**
- **Electricity for Plug-in Hybrid Vehicles**
  - **Carbon free, base load, stable prices; versus**
  - **Continued reliance on gasoline with high CO_2/km emission**
- **Hydrogen production**
  - **At “fuelling stations” by water electrolysis**
  - **At central nuclear stations by**
    - **high temperature electrolysis**
    - **thermo-chemical processes**
    - **hybrid processes**

Desalination of seawater with nuclear energy

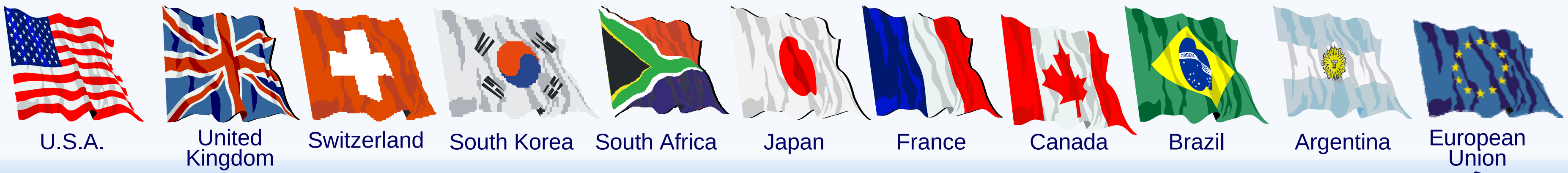
- **Kazakhstan: BN-350 produced electricity + heat for desalination (approx. 80,000 m³ / day) from 1973 until 1999**
- **Japan: Several NPPs produce both electricity and desalinated water for plant use**
- **Pakistan: A Desalination Demonstration Plant (4800 m³ / day) scheduled for commissioning at KANUPP in June, 2008**
- **India: A demonstration plant (6300 m³/d) coupled to the HWR at Kalpakkam is in operation**



FUTURE NUCLEAR ENERGY TECHNOLOGY IS BEING ADDRESSED THROUGH INTERNATIONAL COOPERATION (1/2)

The GENERATION IV International Forum (GIF)

- ✓ **US DOE**
- ✓ **Established Jan 2000**
- ✓ **Selected 6 systems for development – to be ready by 2030:**
  - **Gas-cooled Fast Reactor**
  - **Pb or Pb-Bi Cooled FR**
  - **Sodium Cooled FR**
  - **Super-critical Water-cooled Reactor**
  - **Very High Temperature Reactor**
  - **Molten Salt Reactor**



FUTURE NUCLEAR ENERGY TECHNOLOGY IS BEING ADDRESSED THROUGH INTERNATIONAL COOPERATION (2/2)

- **IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)**
  - **Established following General Conference Resolution in 2000**
  - **Argentina, Armenia, Belarus, Belgium, Brazil, Bulgaria, Canada, Chile, China, Czech Republic, France, Germany, India, Indonesia, Japan, the Republic of Korea, Morocco, the Netherlands, Pakistan, the Russian Federation, Slovakia, South Africa, Spain, Switzerland, Turkey, Ukraine, USA, and the European Commission**
  - **Developed Basic Principles for Innovative Nuclear Energy Systems**
  - **Published Guidance for the evaluation of innovative nuclear reactors and fuel cycles – economics, sustainability and the environment, safety, waste management, proliferation resistance and cross-cutting issues**
  - **Presently examining User Criteria of Developing Countries, and planning some Joint Initiatives among INPRO Members**