Nuclear Energy from an International Perspective

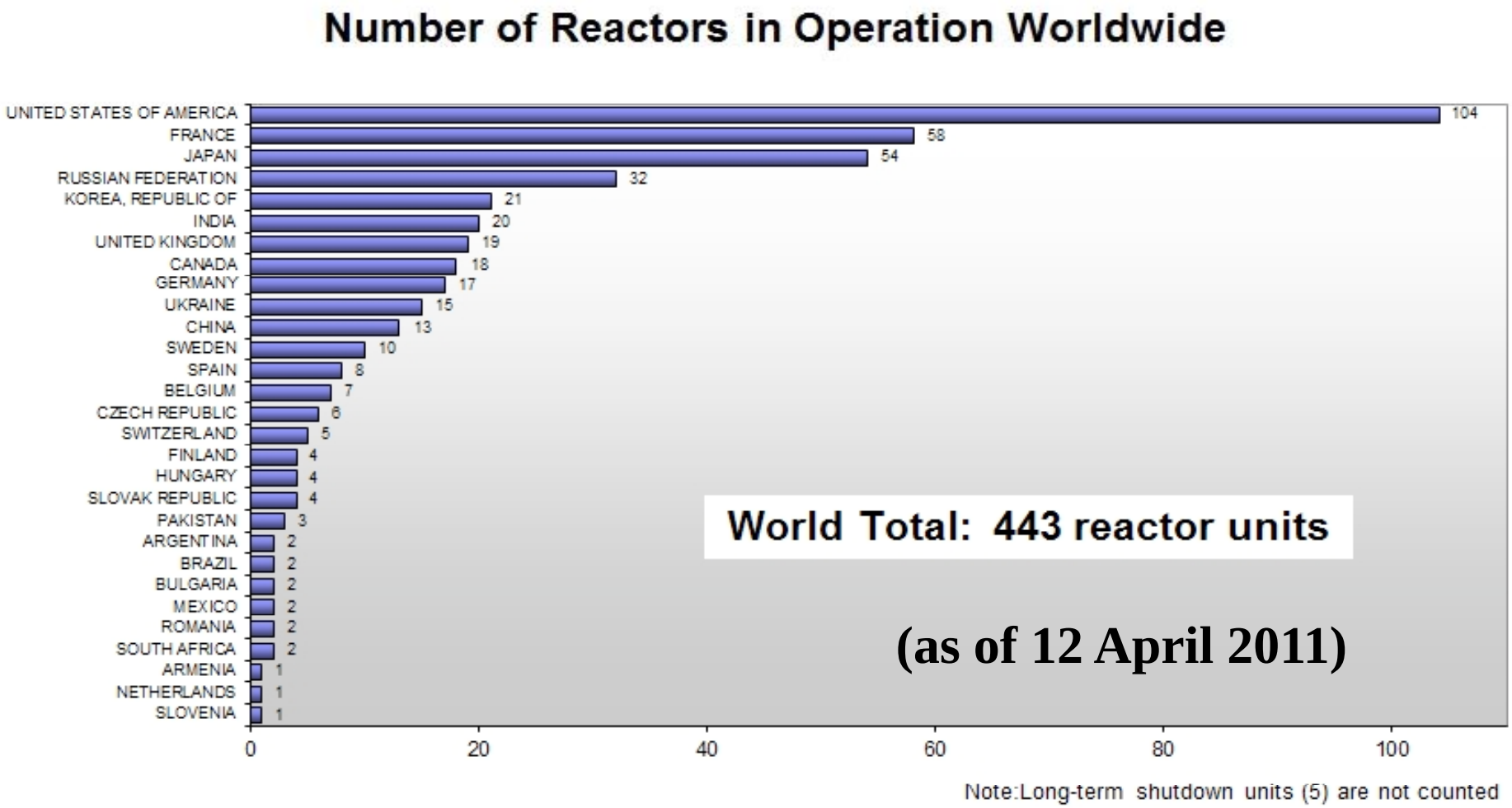
Alexander Stanculescu
Director, Nuclear Science and Engineering
Idaho National Laboratory

www.inl.gov

Idaho National Laboratory

Topics

- The role of nuclear power today
- EU approach
- Development of advanced nuclear plants
- Non-electric applications of nuclear energy
- Conclusions



Under Construction: 64 **Capacity: 62.6 GWe**

Operating Experience (up to 31 December 2007): 13036.4 RYs

2009 Electricity Production: 2558.1 TWh (13.8 % global electricity share)

(world totals include 6/2 reactors in operation/construction in Taiwan, China)

Source: IAEA, Power Reactor Information System (PRIS)

Beginning of a Renaissance?

- The 1970s – average 25 construction starts/year
- Last 13 years – construction starts:
  - 1998: 3 China (2), Japan (1)
  - 1999: 5 China (1), Rep. of Korea (2), Taiwan, China (2)
  - 2000: 5 China (1), India (2), Japan (2)
  - 2001: 1 Japan
  - 2002: 6 DPRK (1), India (5)
  - 2003: 1 India
  - 2004: 2 Japan (1), India (1)
  - 2005: 3 China (1), Finland (1), Pakistan (1)
  - 2006: 4 China (2), Rep. of Korea (1), Russia (1)
  - 2007: 7 China (2), France (1), Rep. of Korea (2), Russia (2)
  - 2008: 10 China (6), Rep. of Korea(2), Russia (2)
  - 2009: 11 China (9), Rep. of Korea(1), Russia (1)
  - 2010: 15 Brazil (1), China (9), India (2), Japan (1), Russia (2)

Nuclear Power will probably grow, but its share of global electricity may fall

- Some countries have phase-out policies
- Others see advantages for energy security
- Some plan to increase nuclear capacity (e.g. China, India, Japan, Republic of Korea)

Source: IAEA RDS-1/30 REFERENCE DATA SERIES NO. 1, 2010 Edition

Nuclear Power will probably grow, but its share of global electricity may fall – continued

- IAEA predicts growth of nuclear power generation from 2558 TW(e)h in 2009 (low-high estimates):
  - 3314 - 4006 TW(e)h by 2020
  - 4040 - 5938 TW(e)h by 2030
  - 4342 - 10436 TW(e)h by 2050
- However, the percentage of electricity produced by nuclear power may decrease from 13.8 % in 2009 (low – high estimates):
  - 14.6 - 16.0 % by 2020
  - 13.8 - 16.6 % by 2030
  - 7.1 - 17.0 % by 2050 *)

***) In 2050, the projection figure for total electricity generation is the arithmetic average between low and high estimates**

Source: IAEA RDS-1/30 REFERENCE DATA SERIES NO. 1, 2010 Edition

Further Statistical Info

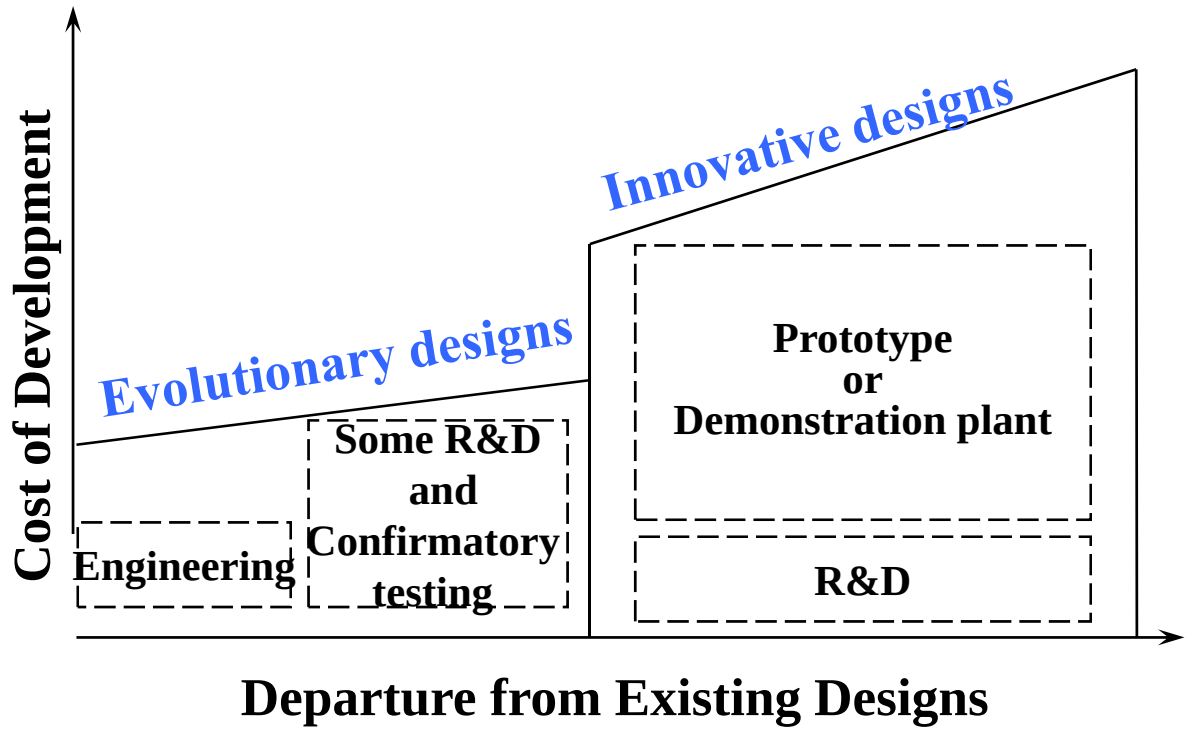
- **IAEA Power Reactor Information System (PRIS)**
  http://www.iaea.or.at/programmes/a2/
- **Energy, Electricity and Nuclear Power Estimates for the Period up to 2050, RDS-1/30**
  REFERENCE DATA SERIES NO. 1, 2010 Edition
- **STI/PUB/1304, Energy, Electricity and Nuclear Power: Developments and Projections - 25 Years Past and Future**

Several Factors Will Influence Nuclear Energy's Future Contribution

- **The degree of global commitment to greenhouse gas reduction**
- **Continued vigilance in safety**
- **Continued vigilance in safeguards**
- **Technological advances; economic competitiveness; and financing arrangements for new NPPs**
- **Implementation of nuclear waste disposal**
- **Public perception, information and education**

Advanced Designs - *(defined in IAEA-TECDOC-936)*

- 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



Euratom's "Fission" programme implementation mechanisms are the Framework Programmes (FPs) for research and training activities: "… a collection of actions at EU level to fund and promote nuclear energy research"

- One call for proposals per year, ~ €50M per call
- FP6: 2003 – 2006, FP7: 2007 – 20011
- Starting with FP5
  - Increased integration with national & industrial programs
  - Larger projects and Co-ordination Actions (CAs) play key role
  - Introduction of the Technology Platforms (TPs)

cordis.europa.eu

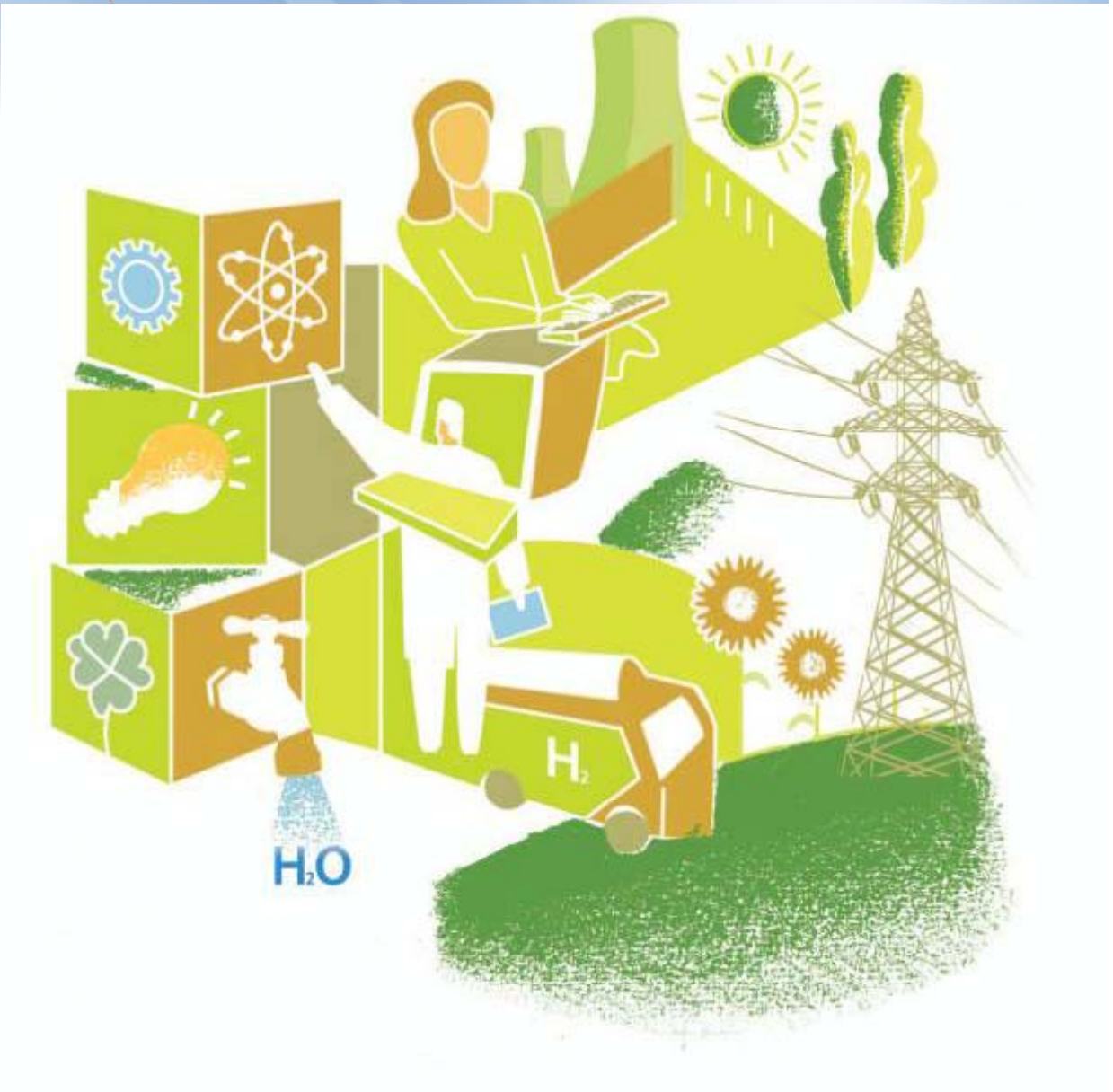
Technology Platforms (TPs)

- **The TPs belong to their stakeholders – not to the EC. The EC supports the creation and operation of the TPs when it fits with the objectives and policies of the EU**
- **Stakeholders, usually led by industry, come together to agree a common vision for the technology**
- **Stakeholders define a Strategic Research Agenda (SRA) setting out medium and long term objectives for the technology - Stakeholders develop a Deployment Strategy (DS, ways and means of SRA implementation)**
- **Stakeholders implement the Strategic Research Agenda with the mobilisation of significant human and financial resources**
- **TP Structure/organisation: Forum of Stakeholders or General Assembly, Advisory or Steering Group, Executive Group, Secretariat, Working Groups (SRA, DS, Education & Training, Communication and Dissemination, Funding Mechanisms,…)**

Source: Marc Defrennes, European Commission

Sustainable Nuclear Energy Technology Platform (SNETP)

www.snetp.eu



Launched
21 SEPTEMBER 2007

Utilities

EDF
EnBW Energie braucht Impulse
endesa
Enel L'ENERGIA CHE TI ASCOLTA.
e·on
Fortum
IBERDROLA
RWE
SUEZ
TVO
VATTENFALL

Technology Providers

AnsaldoNucleare Una Società Finmeccanica
AREVA
EMPRESARIOS AGRUPADOS

Consultancy/Other industry

amec
IBM
Deloitte.
tecnatom

TSO

European TSO Network
IRSN GRS AVN

Research Organisations

AEKI
cea
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
CIRTEN
CNRS Centre National de la Recherche Scientifique
ENEA
FZJ
Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft
IAEA
ichtj
IPJ
itn
Institut "Jožef Stefan"
EUROPEAN COMMISSION DIRECTORATE-GENERAL Joint Research Centre
NRG
nexiasolutions
PAUL SCHERRER INSTITUT PSI
SCK•CEN STUDIECENTRUM VOOR KERNENERGIE CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE
RAAN SCN PITESTI
VTT
ÚJV
vúje
VGB

Universities

The University of Manchester Dalton Nuclear Institute
University of Latvia Institute of Physics
SAPIENZA UNIVERSITÀ DI ROMA
Universität Karlsruhe (TH) Research University • founded 1825

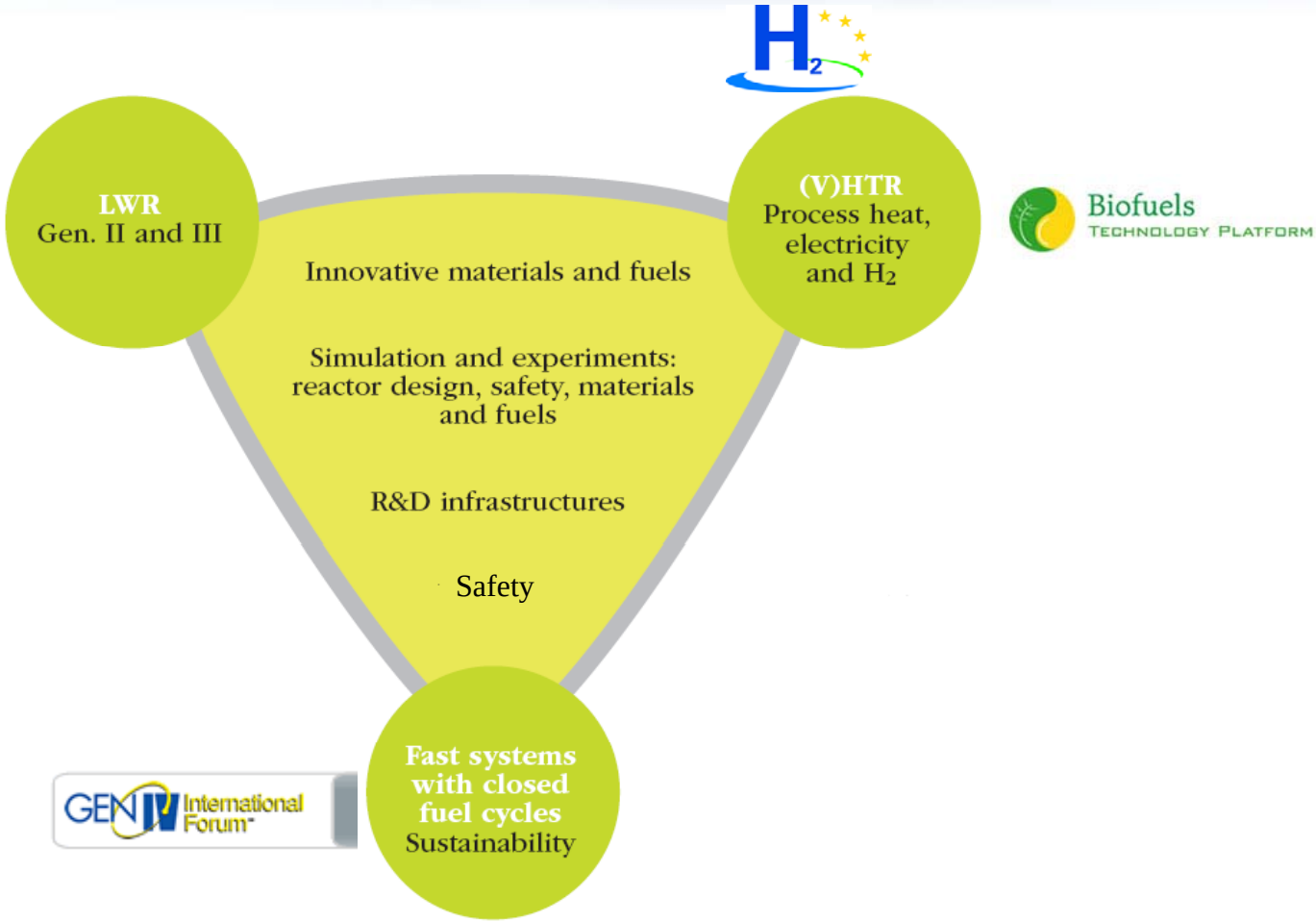
NGO

Sauvons le Climat
AEPN
SLC

EU Organisations

FORATOM
enen

SNETP Scope (Vision Document)

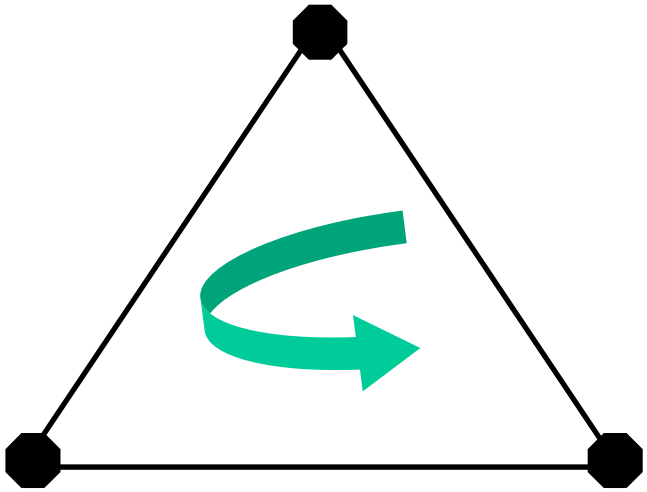


www.snetp.eu/www/snetp/index.php?option=com_content&view=article&id=63&Itemid=36

SNETP: corner point in the triangle of European «Nuclear Fora»

High Level Group Safety and Waste Management

(Regulation)



European Nuclear Energy Forum

(Policy, Economics)

Sustainable Nuclear Energy Technology Platform

(R&D)

Source: Marc Defrennes, European Commission

European Sustainable Nuclear Industrial Initiative (ESNII)

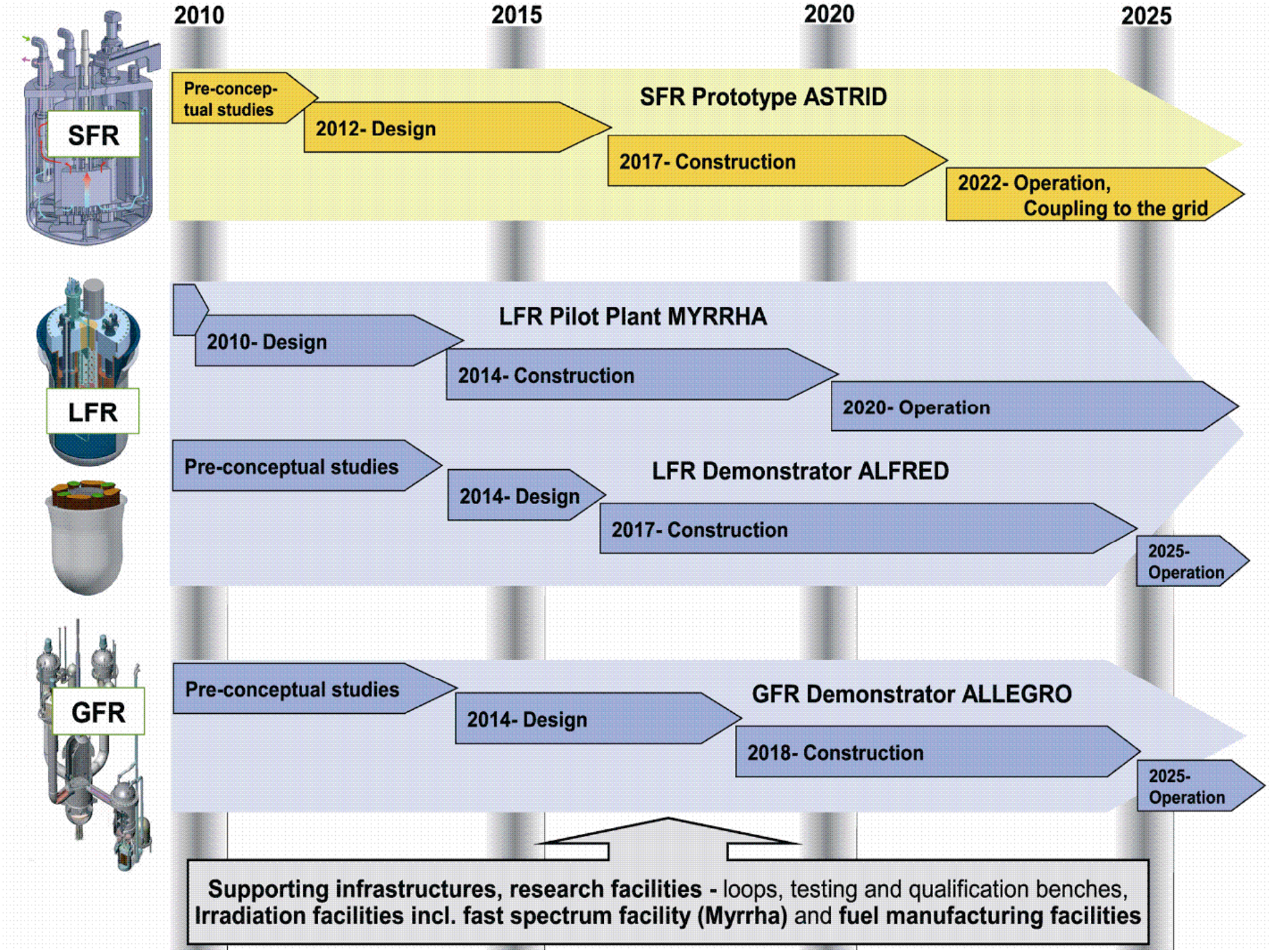
- **One of the European Industrial Initiatives (EIIs) launched by the European Commission (EC)**
- **EIIs are "joint large scale technology development projects between academia, research and industry" aiming at focusing and aligning "… the efforts of the Community, Member States and industry in order to achieve common goals and to create a critical mass of activities and actors, thereby strengthening industrial energy research and innovation on technologies for which working at the Community level will add most value"**

setis.ec.europa.eu/activities/initiatives

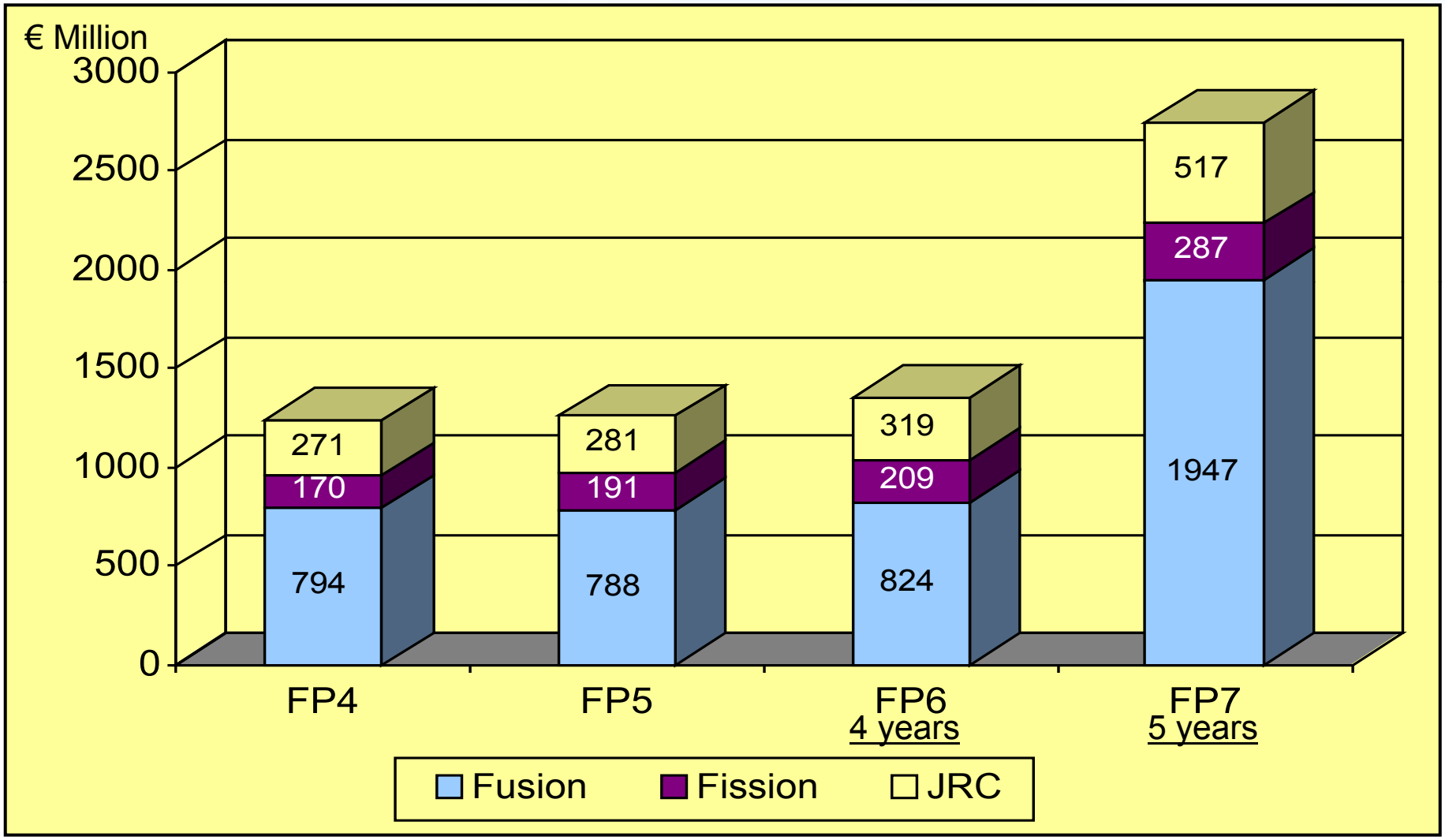
European Sustainable Nuclear Industrial Initiative (ESNII), cont'd

- **ESNII objective based on SNETP vision**
  - **To demonstrate the sustainability of nuclear energy by proving the technological, industrial and economic viability of advanced fast neutron reactors (Generation-IV)**
- **ESNII scope/main activities**
  - **Research enabling a final decision in 2012 on building an industrial 250 – 600 MWe SFR prototype operational ~2020**
  - **Research to enable selection by 2014 of alternative (gas or lead-cooled) fast reactor technology & decision on demonstration plant construction**
  - **Development of the associated closed fuel cycle technologies, with decision in 2012 on construction of pilot fuel manufacturing facilities**
  - **Construction and operation of research infrastructure**
    - **Jules Horowitz Reactor (JHR, construction on-going)**
    - **Fast neutron multipurpose irradiation facility (MYRRHA, operational ~2020)**
    - **Specific testing and qualification facilities for component design, systems development and code validation**

www.snetp.eu/www/snetp/index.php?option=com_content&view=article&id=22&Itemid=12


2010
2015
2020
2025
SFR
Pre-concep-
tual studies
2012- Design
SFR Prototype ASTRID
2017- Construction
2022- Operation,
Coupling to the grid
LFR
2010- Design
LFR Pilot Plant MYRRHA
2014- Construction
2020- Operation
Pre-conceptual studies
2014- Design
LFR Demonstrator ALFRED
2017- Construction
2025-
Operation
GFR
Pre-conceptual studies
2014- Design
GFR Demonstrator ALLEGRO
2018- Construction
2025-
Operation
Supporting infrastructures, research facilities - loops, testing and qualification benches,
Irradiation facilities incl. fast spectrum facility (Myrrha) and fuel manufacturing facilities

Euratom's FP budget at a glance



Source: Marc Defrennes, European Commission

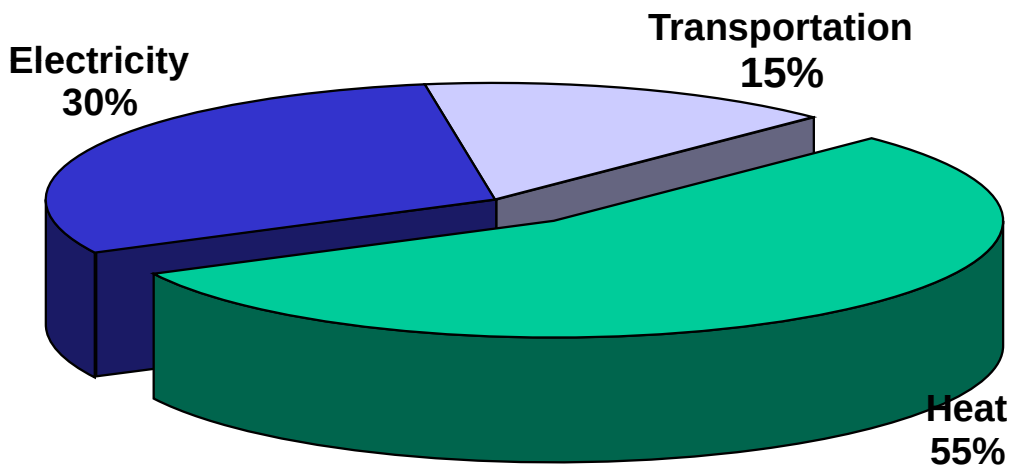
Generation IV Reactor Designs

- Several design concepts are under development to meet goals of
  - Economics
  - Sustainability
  - Safety and reliability
  - Proliferation resistance and physical protection
- All concepts (except VHTR) are based on closed fuel cycle
- Concepts include small, modular approaches
- Most concepts include electrical and non-electrical applications
- Significant R&D efforts are still required
- International cooperation needed for pooling of resources

STATUS OF INNOVATIVE SMRs

- **TECDOCs-1485 &-1536 and Nuclear Energy Series Report NP-T-2.2 address all reactor lines (LWRs, HWRs, GCRs, LMRs)**
- **Describe**
  - **Features pursued to improve economics**
  - **Provisions for efficient resource utilization**
  - **Design features to achieve defence in depth**
  - **Proliferation resistance and physical protection features**
  - **Enabling technologies requiring further R&D**

The Potential For Non-Electric Applications Of Nuclear Energy Is Large

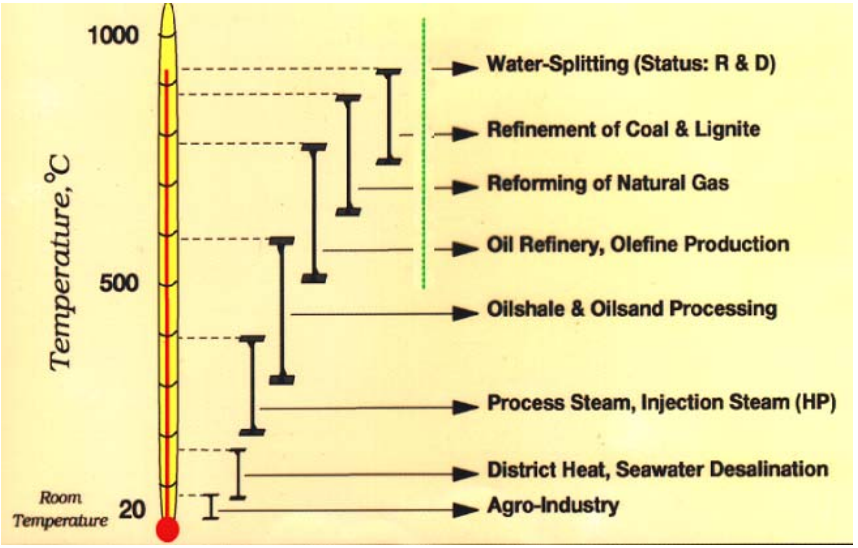


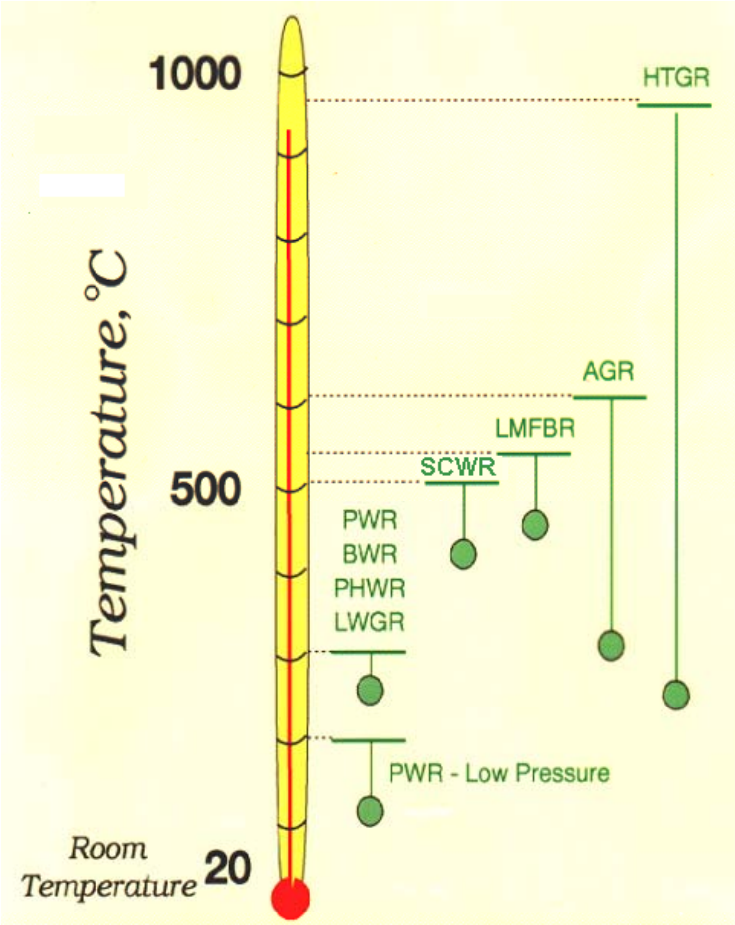
Energy consumption by application

Examples Of Advanced (Non-Electric) 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

Nuclear Plants Can Provide The Heat Required For Many Processes

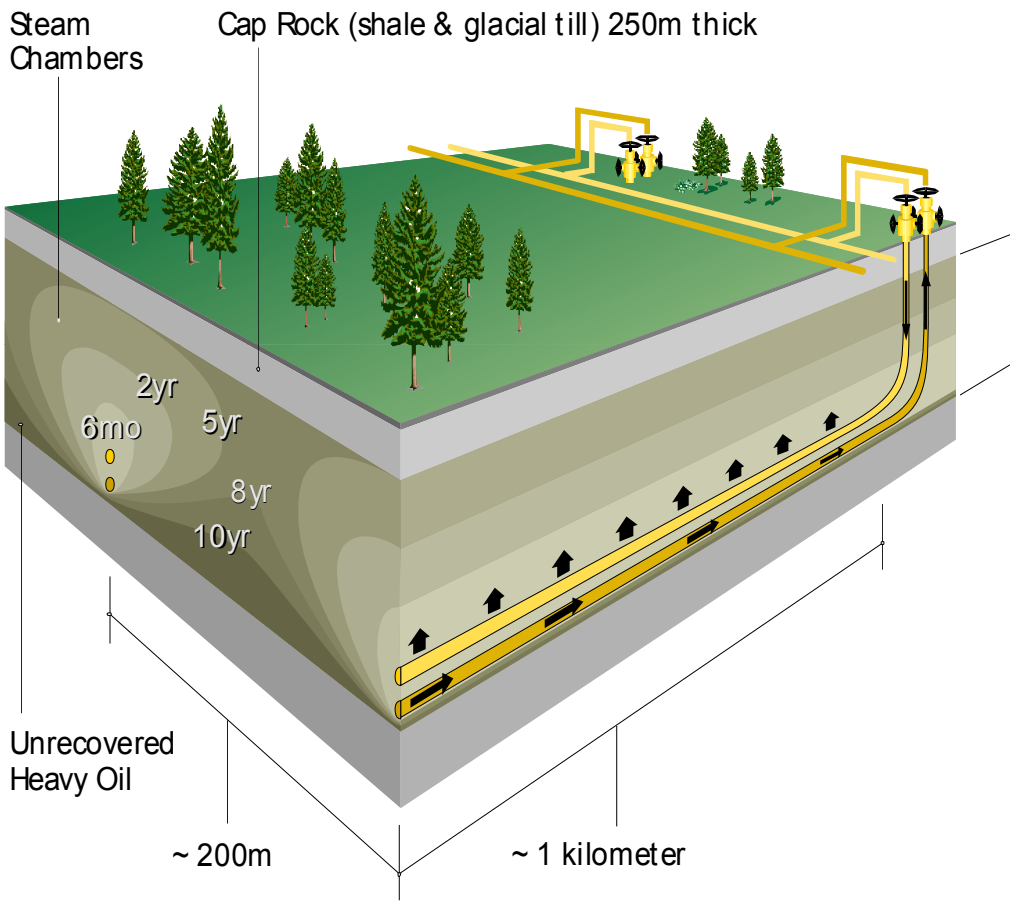




Steam For Industrial Applications
Example: Mining Alberta's Oil Sands

- Steam assisted gravity drainage bitumen extraction
- Requires steam at 2-6 MPa
  - ✓ Currently produced by burning natural gas (18 % of the energy content of the mined bitumen)
- Scale – in Alberta
  - ✓ Current: 1.1 Mbbl / day of bitumen
  - ✓ 2010: 2 Mbbl / day
  - ✓ 2030: 5 Mbbl / day

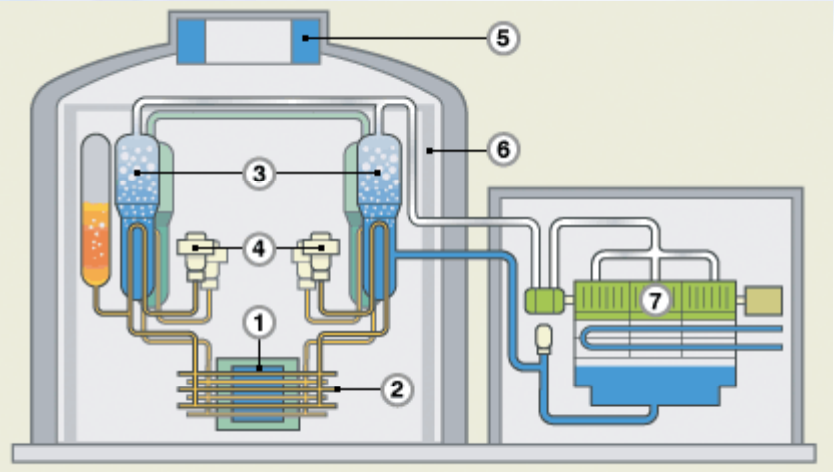
  (Ref: Alberta Chamber of Resources)
- An ACR-700 could supply steam for 0.22 Mbbl / day; or steam + electricity

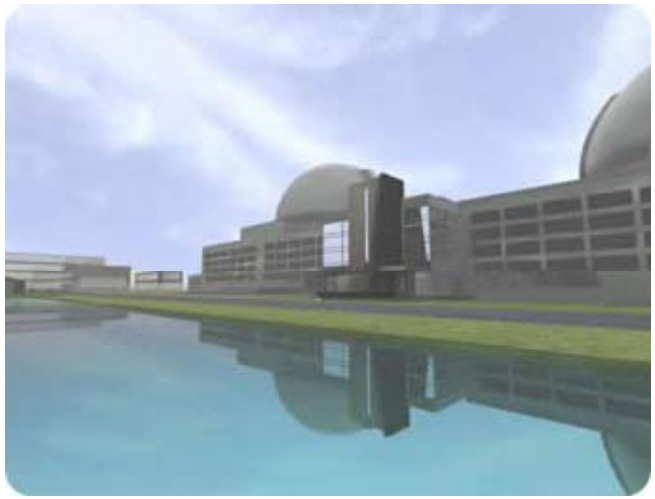


Each barrel of bitumen requires 2.5 – 4.0 barrels of steam

ACR-700 & ACR-1000

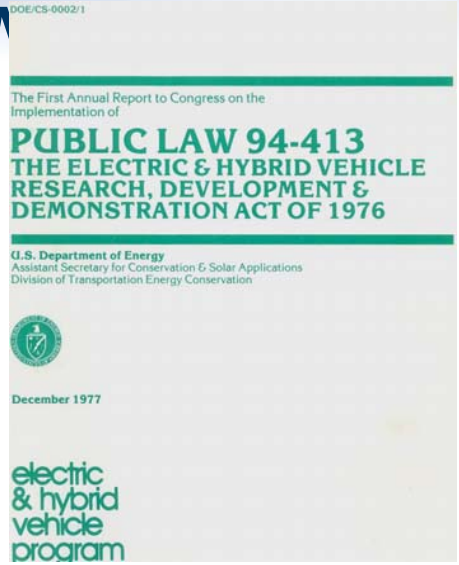
- AECL
- 284 / 520 horizontal channels
- Low enriched uranium (2.1%)
- 60 yr design life
- Continuous refueling
- Combination of active and passive safety systems
- CNSC has started “pre-project” design review
- Energy Alberta has filed an Application with the CNSC for a License to Prepare Site (siting up to two twin-unit ACR-1000s)





HYBRID VEHICLE DEVELOPMEN

1903 Kriegar Hybrid-Electric Automobile


DOE/CS-0002/1

The First Annual Report to Congress on the Implementation of

PUBLIC LAW 94-413
THE ELECTRIC & HYBRID VEHICLE RESEARCH, DEVELOPMENT & DEMONSTRATION ACT OF 1976

U.S. Department of Energy
Assistant Secretary for Conservation & Solar Applications
Division of Transportation Energy Conservation

December 1977

electric & hybrid vehicle program

Reaction to OPEC Petroleum embargo (1973-74)

2005 Toyota Prius, a current hybrid

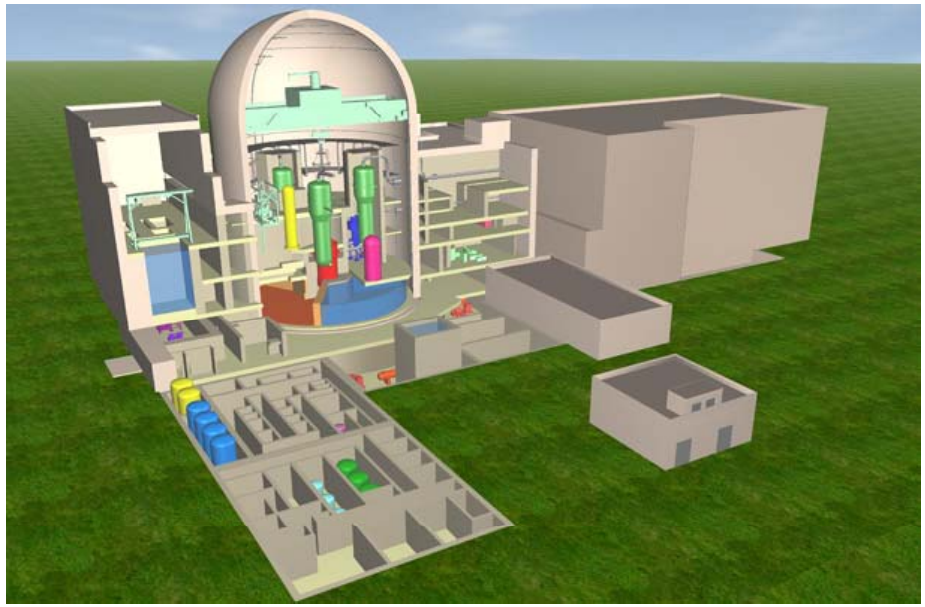
Conclusions

- Nuclear energy contributes significantly to the world's electricity supply
- Several countries have rising expectations
- New NPP designs are being developed to meet high performance and safety goals
- Nuclear power can also be used for
  - Desalination of seawater
  - Hydrogen production, …
- Nuclear power faces challenges, including
  - maintaining high safety levels
  - continuing vigilance in safeguards
  - implementing high level waste disposal
  - improving public acceptance
  - continuing to achieve technology advances to assure economic competitiveness

Backup Slides

ATMEA

- 1100 MWe, 3 loop plant
- Combines AREVA & Mitsubishi PWR technology
- Relies on active safety systems & includes core catcher
- Design targets:
  - 60 yr life
  - 92% availability
  - 12 to 24 month cycle
  - 0-100% MOX



SMART

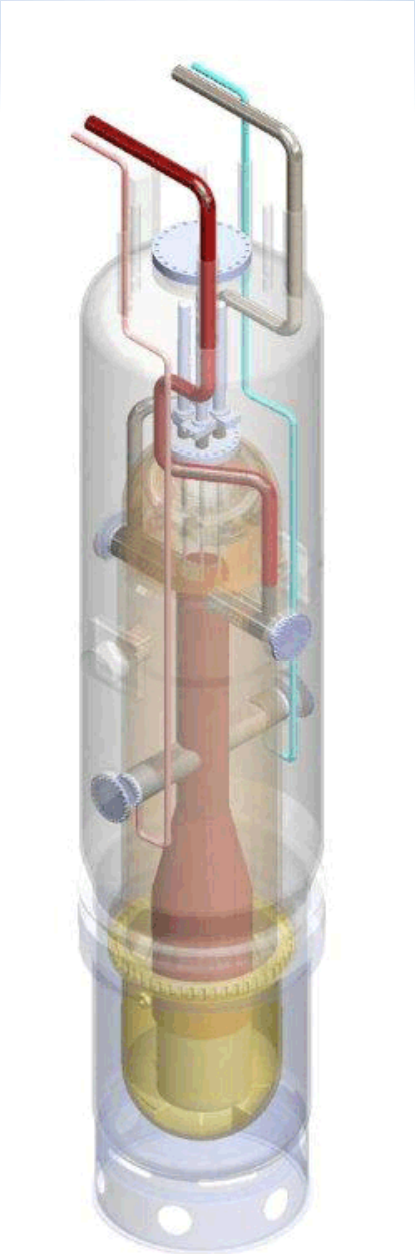
- Korea Atomic Energy Research Institute
- 330 MWe
- Used for electric and non-electric applications
- Integral reactor
- Passive Safety

CAREM (Central Argentina de Elementos Modulares)

- Developed by INVAP and Argentine CNEA
- Prototype: 25 MWe
- Expandable to 300 MWe
- Integral reactor
- Passive safety
- Used for electric and non-electric applications
- Nuclear Safety Assessment under development
- Start of prototype construction planned for 2012 in Argentina's Formosa province

NuScale

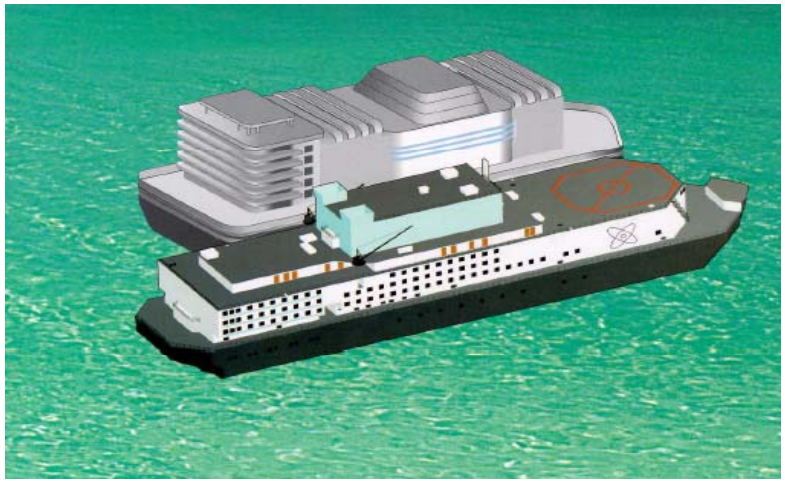
- Oregon State University (USA)
- 45 MWe
- 90% Capacity Factor
- Integral reactor
- Modular, scalable
- Passive safety
- Online refueling



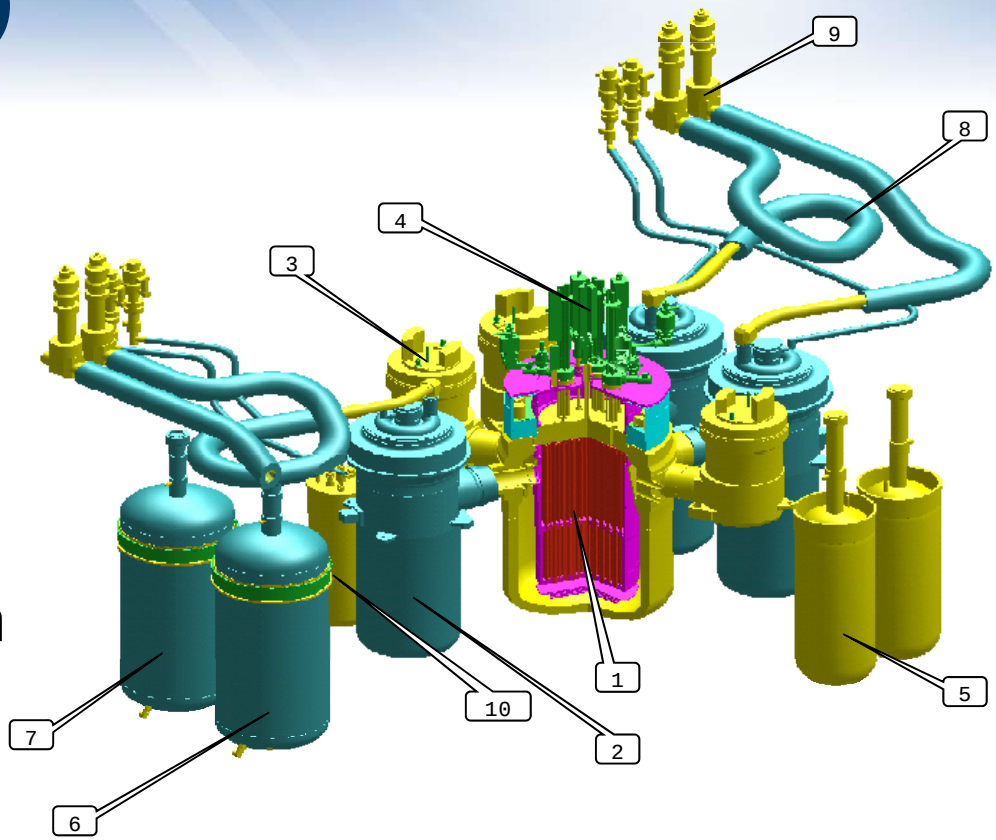
B&W mPower

- Integral reactor
- Scalable, modular
- 125 – 750 MWe
- 5% enriched fuel
- 5 year refueling cycle
- Passive safety
- Lifetime capacity of spent fuel pool

Floating NPPs (OKBM)



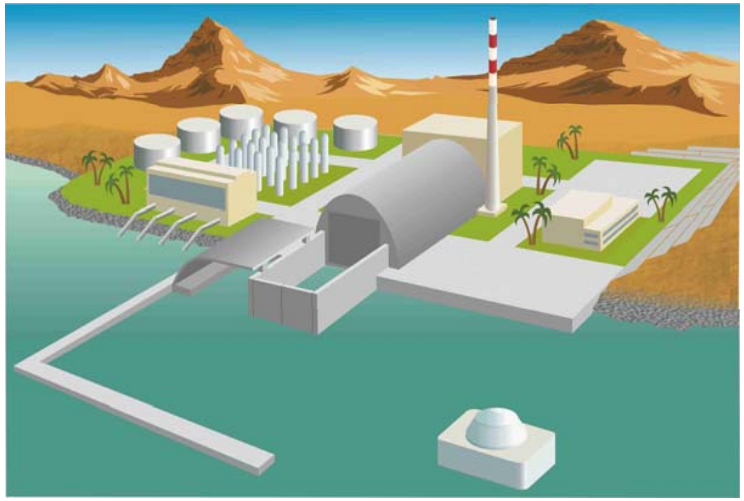
- Floating small NPP design for electricity and heat – KLT-40S
- Construction of pilot plant (2 units) started April 2007
- Deployment targeted in 2012

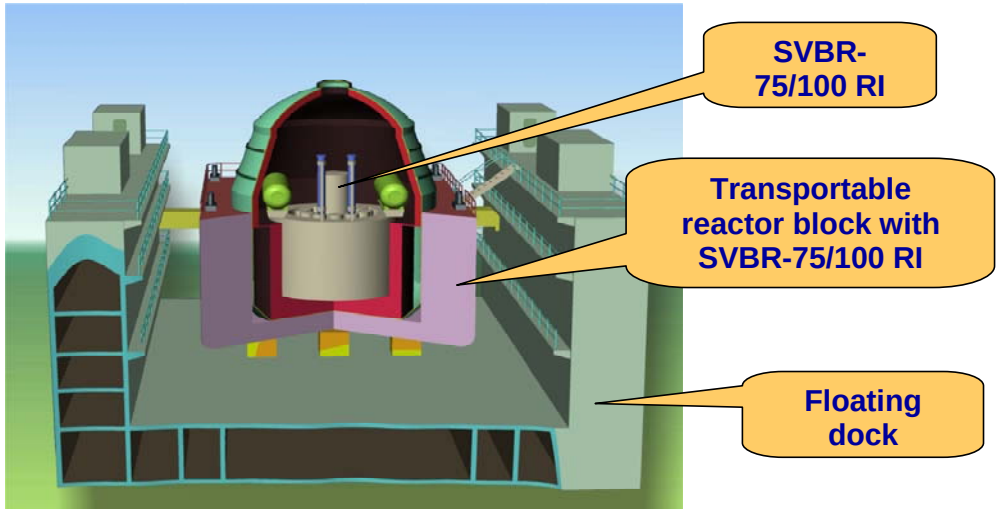


1 Reactor; 6&7 Pressurizers; 2 Steam generator; 8 Steam lines; 3 Main circulating pump; 9 Localizing valves;

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

Lead-bismuth Cooled Small Reactors without On-site Refuelling





Floating NPP for Pb-Bi cooled reactor SVBR-75/100
IPPE – Gidropress (Russia)

- SVBR-100 reactor module for land based NPPs
- Fast spectrum core, Pb-Bi coolant, experience of Russian Alpha-class submarines
- Deployment date 2019, developed by En+ Company - a joint venture between Rosatom and RUSAL

Fast Reactor Development

- ***Renewed interest in nuclear energy***
- ***Sustainability ⇒ spent fuel utilization and breeding returning to centre stage ⇒ fast reactor necessary linchpin***
- ***Fast reactor deployment likely to be accelerated***
  - **Restart in May 2010 of the industrial prototype Monju (Japan)**
  - **First Criticality of China's 25 MWe Experimental Fast Reactor (CEFR) in July 2010**
  - **Commissioning, at the time horizon 2011 – 2023, of 6 power fast reactors in India (PFBR series, in addition to the 600 MWe prototype PFBR, start-up planned for 2012)**
  - **Planned construction by 2020 of the prototype fast reactor ASTRID (France)**
  - **Construction projects in India, Russia, Japan and the Republic of Korea**

NEW GENERATION OF SFR

- ASTRID (~2020)
  - 250 – 600 MWe
  - Test-bed for innovation (systems, technologies)
  - Capability for materials and fuel testing
  - Advanced recycle modes demonstrations (U/Pu, MA)
  - Improved U utilization
  - Improved waste form