CLIMATE CHANGE:
WHY NUCLEAR ENERGY IS PART OF THE SOLUTION

European Nuclear Young Generation Forum 2015
Paris, June 22nd-26th, 2015

Frank CARRE – CEA/Nuclear Energy Division
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Why Nuclear for Climate?

- Facts from the French and the European energy policies
- Challenges and potentialities of nuclear energy for mitigating climate change
- Rising awareness of nuclear energy benefits for climate
- "Nuclear for Climate Declaration" signed by 39 Associations during ICAPP’2015 (May 4th, 2015 - Nice)

- 1970 – Call for tenders for 6 x 900 MWe PWRs Westinghouse
- 1973 – Program of + 28 REP-900
- 1982 – Relinquishment of Westinghouse licence
- 1980s – Deployment of 20 REP-1300
- 1990s – Deployment of 4 REP-N4
- 1992 – Launch of EPR by NP-Intal (Framatome/Siemens)

Source: IEA Key Figures 2011

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Source: IEA Key Figures 2011

TWh

- 1950
- 1955
- 1960
- 1965
- 1970
- 1975
- 1980
- 1985
- 1990
- 1995
- 2000
- 2005
- 2010

- 1970
- 1975
- 1980
- 1985
- 1990
- 1995
- 2000
- 2005
- 2010

562 TWh

- Nuclear 78,6%
- Fossil 9,8%
- Hydro & renewable 11,6%
Nuclear Power Benefits for France’s CO₂ Emissions and Generating Costs

Energy Self-Sufficiency Rate (%) w. & wo. Nuclear Power

France without Nuclear Power

CO₂ Releases by the French Industry (Mt)

A significant reduction in spite of growth in demand

CO₂ Emissions (g /kWh) in the EU for Electricity Generation

Electric bill among the least expensive in Europe

Court of Auditors 2014 Report
Certified cost of Nuclear power ~59,8 €/MWh
(Waste, Dismantling, Safety upgrades…)

EU-15 Average 177,0 €/MWh
France 131,9 €/MWh

Steps towards an Energy Policy for Europe

Towards a Low-carbon Energy Future


- **March 2007** – *A new Energy Policy for Europe* proposed by the EC and endorsed by the Council
  → Negotiation of a European « Energy-Climate package »
  → *European Strategic Energy Technology Plan (SET-Plan)*
    - Setting European Commission goals for "2020 Climate-Energy Package"
    - 20% decrease in energy demand
    - 20% cut in greenhouse gas emissions
    - 20% of renewable power generation
  → Creation of « Technology Platforms »: Solar, Wind, CCS, 2G-Biofuels, Smart Grids… + *Sustainable nuclear Energy*

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- **<2005** – *European Union Emissions Trading System*
  - Price of released CO2 ton too low to spur reduction (<25 €)
Strategic orientations of research, industry and TSOs

- NUGENIA: NUCLEAR GENERATION II & III ASSOCIATION
- ESNII: EUROPEAN SUSTAINABLE NUCLEAR INDUSTRIAL INITIATIVE
- NC2I: NUCLEAR COGENERATION INDUSTRIAL INITIATIVE
# Towards a more Diversified Low-Carbon Energy System in France

## Developing Renewable Energies & Decreasing the Share of Nuclear Power

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<tr>
<td><strong>Energy Policy Act 7/13/2005</strong></td>
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<td>Sustainable development</td>
<td>14%</td>
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<td>Keeping the nuclear option open</td>
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<td>CO₂ emissions x1/4 by 2050 /1990</td>
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<td><strong>Act 2 7/13/2010</strong></td>
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<td>-20% EU GHG emissions (2020)</td>
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<td><strong>EU 2020 Climate-Energy Package</strong></td>
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<td>20% Renewable electricity in EU (2020)</td>
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<td>EE incentives in buildings</td>
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<td>Norms for new builds</td>
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<td>&lt;50 kWh/m²/y</td>
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<td>-20% EU energy demand (2020)</td>
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<td><strong>2015 Act for Energy Transition &amp; Green Growth</strong></td>
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<td>Decarbonization</td>
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<td><strong>EU 2030 Climate-Energy Package</strong></td>
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<td>-40% GHG emissions (2030)</td>
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<td>32% Renewable electricity (2030)</td>
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<td>-30% energy demand (2030) &amp; -50% (2050)</td>
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<td>500 000/y thermal insulation works in housing</td>
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<td>&gt;27% Renewable electricity in EU (2030)</td>
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<td>&gt;27% Energy savings in EU (2030)</td>
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<td>Nuclear capped to 63 GWe &amp; 50% of electric power in 2025</td>
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Four 2050 energy scenarios for reducing CO₂ emissions by a factor of 4

- **Business a usual scenario**
- **Energy Sobriety scenario**
- **Electrification scenario**
- **Diversification scenario (+ heat, H₂...)**
- **Nuclear & REn**

The Nuclear + Renewable Energies scenario (ELEC-V) makes it possible to avoid a new transient boost of emissions in the power sector in 2025.

Reduction by 4 of GhG emissions
Nuclear power will remain an important share of electric generation

Meeting the factor-4 reduction of $CO_2$ calls for technology breakthroughs

The increasing share of intermittent renewables calls for sufficient monitorable generation for grid stability

The management of intermittency & Factor 4 on $CO_2$ rely on:

- Smart grids & CCS (SOB)
- Storage of electricity (ELEC)
- Cogeneration (DIV)

Assumptions: 50% nuclear electricity in 2025, 100% back-up with gas power stations
Towards a Low Carbon Energy System

France’s Primary Energy Consumption in 2010: 266 Mtoe

- **50% of primary energy needs**
  - Growing cost towards unbearable levels:
    - 2003-2005: 10% of export revenues (25 G€)
    - 2010: 25% of export revenues (48 G€)
    - 2011: 35% of export revenues (> 60 G€)

- **9% of primary energy needs**
  - (15% of electricity generation)

- **41% of primary energy needs**
  - (75% of electricity generation)

<table>
<thead>
<tr>
<th>Year</th>
<th>Coal</th>
<th>Oil</th>
<th>Gas</th>
<th>Renewables</th>
<th>Others</th>
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<tbody>
<tr>
<td>2010</td>
<td>4%</td>
<td>31%</td>
<td>15%</td>
<td>8%</td>
<td>1%</td>
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Elements of France’s Energy Policy

2030 goals of Energy Transition & Green Growth Act → CO₂ releases x 1/4 by 2050

- Reduction by 30% of the global primary energy consumption
- Reduction by 40% of greenhouse gas emissions (compared to 1990)
- 32% share of renewable energy in the energy mix

Efficiency/Sobriety
- in industrial processes
- in housing
- in transport

Nuclear and Renewable Energies:

Two pillars of the 2020 French energy mix:
- Renewables: intermittent supply
- Nuclear power: dispatchable power supply

Preserve the use of fossil energies where they cannot be replaced

Final energy consumption in France (2011)

- Building: 21%
- Transport: 44%
- Industry: 3%
- Agriculture: 32%
## Nuclear cogeneration: 50 years of experience

<table>
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<tr>
<th>Reactor</th>
<th>Application</th>
<th>Country &amp; Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWR CANDU</td>
<td>District Heating</td>
<td><strong>Russia</strong>: Beloyarsk, Kolskaya, Kursk, Novovoronnezh, Rovno… <strong>Czech Rep.</strong>: Temelin, <strong>Sweden</strong>: Agesta, <strong>Slovakia</strong>: Bohunice, <strong>Switzerland</strong>: Beznau &amp; Goesgen</td>
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<tr>
<td>RNR-Na</td>
<td>Dessalination</td>
<td><strong>Japan</strong>: Ikata, Ohi, Genkai, Takahama, Kashiwazaki <strong>Kazakhstan</strong>: Aktau (BN-350) (1973-1999)</td>
</tr>
<tr>
<td>RHT</td>
<td>Hydrogen</td>
<td><strong>Germany</strong>: Schmehausen (THTR, Project PNP-500)</td>
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*Bohunice*: district heating, Slovakia, (VVER, 61 MWth)  
*Ohi*: nuclear dessalination, Japan  
*Aktau*: nuclear dessalination, Kazakhstan (BN350,100 MWth)  
*Bruce*: industrial site, Canada (8 CANDU, 5 300 MWth)  
*Schmehausen*: $H_2$ (CH4 reforming), Germany (THT-300, PNP-500 Project)  

~ 1,800 reactor x years of experience
District Heating from LWR Discharge Heat

Heat extraction from a Pressurized Water Reactor

- District heating of Helsinki metropolitan area with a 100 km long transfer pipeline from Loviisa-3 project (> 2020)
- 4 Mtons/y CO₂ not released

from Harri Tuomisto, Fortum Power, Finland,
Loviisa 3 project - October 2010
CEREN study shows how needs for process heat > 250°C are distributed among industrial sectors: ~10Mtep/110 TWh in 2011

Agri-food Industry 30%
Chemical Industry 28%

Consommation de chaleur <250°C en 2011 par filière industrielle
Towards Non-Electricity Products with LWRs

Low carbon electricity generation: nuclear, hydraulic, renewables... + Import

Offer and demand management

Decentralized and flexible units able to adapt their electricity consumption to electricity available on the grid

Electricity demand + Export & Grid losses

H₂ & syn-HyC fuels as storable & versatile energy carriers to supplement electricity

H₂O Electrolysis

H₂

Petro-Chemistry, Recycle of CO₂ + ...

Chemicals

Syn-Fuels

Off-peak hours Production (electricity at marginal cost)
Production load following inversely the loads on the grid
Peak hours downturn (downturn valorization)

N. Collignon & M. Lecomte
Challenges of Nuclear Energy

Conditions for Successful Deployment Worldwide

- **Reliability & Safety**
  - *Fukushima accident-proof design* + Enhancement of Emergency preparedness
  - Progress towards *internationally harmonized design codes & safety standards*, QA

- **Security** *(Proliferation resistance, Physical protection…)*
  - Safeguarding by IAEA, Euratom…
  - Export control of sensitive technologies

- **Economics**
  - *Competitiveness with other energy sources* in spite of rising costs for Gen III reactors
  - *Adapted / customized funding schemes* to favor investments in nuclear in a liberalized energy market

- **Sustainability**
  - *Minimization of waste burden* → Implementation of HLW repository in some countries
  - *Minimization of environmental impact*
Common goals

- Energy efficiency
- Reduction of GHG
- Growth of renewable energies

Specific features

- Historic energy mix (coal, nuclear, hydro)
- Energy networks & storage + capacity
- Integrating variable renewable energies

Issues

- ~40% variable power limit for grid stability
- Control must-take power from abroad
- Account for system costs for renewables
  - Back-up, Balancing
  - Grid connection & extension

Source: IEA
Global Nuclear Construction Plans
→ 700-1500 GWe by 2050?

- 443 nuclear reactors operating in 30 countries (372 GWe)
- 66 reactors currently under construction in 15 countries
- 164 reactors planned in 27 countries over next 8-10 years
- 317 reactors proposed in 37 countries over next 15 years

- 45 new builds in China (25), Russia (9), India (6) & Korea (5)
- 6 reactors in 3 newcomer countries: Belarus (2), Iran (1) & UAE (3)

- Spent fuel reprocessing:
  - Industrial: France, UK
  - Developing: Russia, India, Japan, China, Korea

- Fast Neutron Reactor Programs:
  - Russia, India, Japan, France, USA, China, Korea

Source: IAEA information & news reports

**World Experience in Sodium Fast Neutron Reactors**

**United States**
- EBR-1 1951
- EBR-II (20 MWe) 1963 → 1994
- FFTF (400 MWth) 1980 → 2000
- Clinch River Project cancelled 1983
  + R&D on fuel cycle
  + Strategy under development

**Europe (France, Germany & UK)**
- Rapsodie (20 MWth) 1967 → 1983
- DDFR (60 MWth), KNK II (17 MWe) 1978 → 1991
- Phenix (250 MWth) 1973 → 2009
- PFR (250 MWe) 1975 → 1994, SNR300
- Superphenix (1200 MWe) 1986 → 1998
  + Industrial nuclear fuel cycle in France & the UK
  + R&D on closed nuclear fuel cycle

**Russian Federation**
- BOR-60 (60 MWth)
- BN350 (90 MWth) 1973 → 1999
- BN600 (600 MWth) 1980 →
- BN800 (800 MWth) 2015 →
  + Developing closed nuclear fuel cycle

**Japan**
- Joyo (140 MWth)
- Monju (280 MWth) 1994 →
  + Developing closed fuel cycle

**Rep. of Korea**
- R&D on reactor & closed fuel cycle

**Rep. of China**
- CEFR (25 MWe) 2010 →
  + Developing closed fuel cycle

**India**
- FBTR (40 MWth) 1985 →
- PFBR (500 MWe) 2015 →
  + Developing closed fuel cycle

**GNEP**: a strategy to enable expansion of nuclear power in the U.S. and around the world, promote nuclear nonproliferation goals, and help resolve nuclear waste disposal issues
Next generation Sodium Fast Reactor (SFR) Technology Demonstrator ASTRID

- Preliminary Options
- 17/12/2012 Decision to implement preliminary design phase 2
- Milestone: Decision of Construction
- Fuel Loading and Start Up


- Preliminary design Phase 1
- Preliminary design Phase 2
- Detailed design
- Construction

- Feasibility Report on Minor Actinides Partitioning
- Position Report on Minor Actinides Partitioning & Transmutation
- Fuel Treatment Facility (ATC)

- R&D on Plutonium Multi-Recycling

High Temperature Reactors in the World

Japan: HTTR, 30MWth, in operation since 1998 + Demo of H₂ production?

Korea: NHDD Project

China: HTR-10, 10MWth, in operation since 2000

China: HTR-PM, Industrial Prototype, 2x250 MWth, start in 2017

Russia: GT-MHR Project

AREVA SA: ANTARES 600 MWth Heat/Electricity generation

USA: NGNP, Industrial Prototype Heat/Electricity & Hydrogen > 2011 → R&D

PBMR 400 MWth

Japan: GTHTR 300, 600 MWth

Le monde

Global map of high temperature reactors with key locations and notes on reactor types and operation dates.
Potential Market for HTGRs

Petrochemical (150)

Sasol Secunda Plant

Coal-to-Liquids (100s)

Fertilizers/Ammonia (100+)

Oil Sands/Shale (200+)

1 Million Metric Tons CO$_2$/year avoided for every HTGR (500 MWth) used in lieu of Natural Gas
**Traveling Wave Reactor**

Turns depleted uranium into electricity, using a simple fuel cycle without requiring separations.

| SIZE     | 600 MWe (Prototype Plant)  
|          | 1150 MWe (Commercial Plant) |
| TEMPERATURE | 510°C |
| PRESSURE    | Low (Atmospheric) |
| PRIMARY FUEL | Depleted Uranium |
| COOLANT     | Sodium |
| ENERGY CONVERSION | Steam (Rankine Cycle) |
| WASTE REPROCESSING | Not Required |

**Integral Fast Reactor**

Sodium Reactor Evolution

**Colocated Reactor & Recycle Facility**

**Transportable sealed & retrievable SMR with a long lifetime: An option for moderately reliable/stable newcomer nuclear countries?**

**Nuclear systems with reactor & recycle facilities recycled: IFR? MSFR?... From fresh fuel to ultimate waste on the same site?**

**Molten Salt Fast Reactor**
- **Prof. James E. Hansen** *(Univ. Columbia, US Academy of Science)*
  - *Climate is changing 10 times faster than ever*
    - Extermination of species, Rising of sea level,
      **Climatic extreme events** *(storms, fires, floods...)*
    - Multiple Man-made stresses  ➔ Concerns for next generations
  - "To those influencing environmental policy but opposed to nuclear power"

Open letter of 4 climate scientists (Nov. 17, 2013)

- A plea to fellow environmentalists that nuclear energy needs to be part of the global climate change solution
- Confidence in technology progress to make nuclear safer, more efficient and more proliferation resistant

- Prof. Hansen advocacies:
  - Need for a clean energy portfolio standards (not only renewables)
  - Urgency of a clean air act incentive
  - Modular reactors, largely factory built / Safety, reduction of cycle time
  - China to lead, West to cooperate
Statement from Nuclear Societies on Nuclear for Climate

"We proudly believe that nuclear energy is a key part of the solution in the fight against climate change"

A charter signed by 39 nuclear/atomic and other learned societies from the whole world
WE THE UNDIAMONDED,

Scientists, engineers, and professionals representing regional, national and international scientific societies, as well as numerous technical organizations dedicated to the development and peaceful use of nuclear technology,

Gathered here today in Nice - France

ACKNOWLEDGE the unanimously accepted conclusions reached by the majority of climatologists, as stated in the peer-reviewed Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) that "human activities have contributed to changes in the Earth's climate";

are HOPING for results at the outcomes of the Climate Change Conference that will take place in Paris in December 2015 - COP 21 (Conference of Parties);

are CONVINCED of the fact that, according to OECD (Organisation for Economic Cooperation and Development), while the global population is expected to reach about 9.6 billion, with increasing development, electricity demand is currently on track to double by 2050;

are CONSCIOUS that this presents a massive challenge which will require the deployment of all available low-carbon technologies;

are ANNOYED by the powerful vested interests trying to block the necessary action on climate change;

are CONVINCED that the world needs to take immediate steps to reduce greenhouse gas emissions, as a large share of the carbon budget has already been consumed, and that we cannot wait for new technologies to be ready for deployment before launching our decarbonization efforts.

RECOGNIZE that nuclear energy is one of the handful of options available today which can help to reduce greenhouse gas emissions, and would emphasize that this view is shared by the OECD (Organisation for Economic Cooperation and Development) and IPCC.

Hereby declare that:

WE PROUDLY BELIEVE THAT NUCLEAR ENERGY IS A KEY PART OF THE SOLUTION IN THE FIGHT AGAINST CLIMATE CHANGE.

We DECLARE that each country needs access to the widest possible portfolio of low-carbon technologies available, including nuclear energy, in order to reduce CO2 emissions and meet other energy goals;

CALL FOR the new UNFCCC (United Nations Framework Convention on Climate Change) Protocol to recognize nuclear energy as a low-carbon energy option, and to include it in the climate financing mechanisms, as is the case for all other low-carbon energy sources.

Have DECIDED to jointly sign this declaration and would like to bring it to the attention of decision-makers.