# Industrial Perspectives (ESNII plus WP4)

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# WP4 Industrial Perspectives Objectives

- **Support the European industrial strategies**
  - evaluation of energy market needs & solutions offered by next generation nuclear systems
- **Explore potentialities and industrial perspectives of ESNII reactor concepts (ALFRED, ALLEGRO, ASTRID)**
  - *Supply chain*: assess the current and planned industrial capacities and identify critical components for manufacturing or R&D
  - *Small modular reactors*: assess the industrial and economic potentialities of "SMFR" and evaluate deployment scenarios and economic models
  - *Cogeneration*: evaluate suitable applications for Fast Reactors, identify requirements, and evaluate cogeneration costs
- **Final outcome**
  - comprehensive review of ESNII concepts with reference to market perspectives, status, industrial capacity, economic impact
  - support to for definition of R&D roadmap and industrial plans for ESNII concepts implementation

# WP4 Tasks, Deliverables & Milestones

- **Task 4.1: Prospective analysis of supply chain**
  - Task leader: Patricia Cuadrado (EA)
  - Participants: AMEC, ANSALDO, AREVA, LGI
  - **D411** (*Status and perspectives of supply chain for Fast Reactors)* → ***M36***
- **Task 4.2: Study on the potential of Small Modular Fast Reactor**
  - Task leader: Marco Ricotti (CIRTEN)
  - Participants: ANSALDO, AREVA, CEA, LGI, NRG
  - **D421** (*Potential of small modular fast reactor)* → ***M36***
- **Task 4.3: Study on the potential of cogeneration fast reactor**
  - Task leader: Ferry Roelofs (NRG)
  - Participants: ANSALDO, AREVA, LGI, NNL
  - **D431** (*Potential of small modular fast reactor)* → ***M36***
- **M41** (Draft studies results to support WP2) → ***M28***

# Task 4.1: Prospective analysis of supply chain

**Objectives:**

- Assessment of the current and planned industrial capacities
- Identification of critical components related to industrial manufacturing and needed R&D activities

**Activities:**

- Analysis of FRs and Cogeneration technologies, systems and components supplier capabilities in Europe
- Adapt and evaluate the FRs and Cogeneration Technical Solutions of existing European potentialities in research, engineering and manufacturing capacities to cover the full supply chain
- Analysis of key aspects that will be future inherent requirements of the nuclear industry
- Definition of new Business models and contractual approaches for the non technological area and deployment

# Task 4.1: Prospective analysis of supply chain

## Activities performed

- Proposed D411 Table of Contents (ToC) with Division of responsibilities
- Main parameters for critical components of the three ESNII concepts (ASTRID, ALFRED, ALLEGRO) identified

## Aactivities ongoing

- D411 Drafted (ToC updated)
- Chapters completed:
  - Challenges of the EU nuclear industry with respect to fast reactors
    - Nuclear industry overview and leadership
    - Specific nuclear challenges for suppliers
  - Supply chain and critical components
    - Overview of the supply chain for current reactors and approach to the supply chain for fast reactors
    - Identification of fast reactors critical components and main parameters (ASTRID, ALFRED, ALLEGRO)
  - Applicable Codes and Standards in the EU
    - Approach to regulations, Nuclear safety regulations, Nuclear codes and standards

# Task 4.1: Prospective analysis of supply chain

## D411: Detailed TOC

# Identification of main parameters for critical component (example – 1/2)

| | | REACTORS | | |
|---|---|---|---|---|
| **EQUIPMENT** | UNITS | ALFRED | ASTRID | ALLEGRO (Starting Core) |
| **Power** | | | | |
| **Thermal Power** | MWth | 300 | 1500 | 75 |
| **Electrical Power** | MWe | ~125 | 600 | N/A |
| **Thermal Efficiency** | % | 41.5% or better | 42.5% or better | N/A |
| **Fuel and Core** | | | | |
| **Fuel Type** | | MOX (inner21.7&; outer 27.8%) | MOX | MOX fuel, steel clad, 25% Pu. |
| **Fuel Material** | | Clad 15-15/Ti | AIM1 | Clad_15-15Ti (AIM1 grade) |
| **Core inlet temp.** | ºC | 400 | 400 | 260 |
| **Core outlet temp.** | ºC | 480 | 550 | 530 |
| **Coolant composition** | | Pb (Lead) | Na (Sodium) | Helium |
| **Coolant mass flow** | kg/s | 25458 | 7900 | 53.5 |
| **Reactor Vessel** | | | | |
| **Material** | | AISI 316LN | AISI 316LN | $9Cr1Mo_{mod}$ (RCCM A3-18S) or SS316LN (A3-1S) |
| **Height/Diameter** | m | 10.7/8.0 | 18.65/15.58 | 14.0/4.6 |
| **Design Pressure** | MPa | 0.125 | < 0.05 | Service pressure: 7.0<br>Test pressure: 8.0 |
| **Design Temperature** | ºC | 480 | 550 | N/A |
| **Reflector Type / material** | | Exagonal Dummy Assemblies with ZrO2-Y2O3 rods | Dummy assemblies / MgO | Hexagonal Dummy Assemblies with 15-15/Ti Steel rods |
| **Internals material** | | AISI 316LN; T91 | AISI 316LN | N/A |

# Identification of main parameters for critical component (example – 2/2)

| | | REACTOR | | |
|---|---|---|---|---|
| **EQUIPMENT** | UNITS | ALFRED | ASTRID | ALLEGRO (Starting Core) |
| **Safety vessels** | | | | |
| **Description and number** | | Anchored to the reactor pit; 1 | Safety vessel suspended | Cylindrical 'Guard Vessel', 1 |
| **Material** | | AISI 316LN | AISI 316LN | Reinforced concrete with steel liner |
| **Height/Diameter** | m | 10.7/8.4 | 15.13/16.13 | 30 / 17 |
| **Fluid** | | Nitrogen | Nitrogen | N/A |
| **Inner liner thickness** | mm | | | 20 (steel) |
| **Outer wall thickness** | m | | | 1 (concrete) |
| **Primary Pumps** | | | | N/A – See Item 10 |
| **Number** | | 8 | 3 | - |
| **Pump Type** | | Mechanical axial | Mechanical radial | - |
| **Power** | kW | 60 (each) | N/A | - |
| **Mass flow** | kg/s | 3247.5 (0.31 m3/s) | 2837 (3.32 m3/s) | - |
| **Design pressure** | MPa | N/A | N/A | - |
| **Discharge head** | MPa | .15 | 0.37 | - |
| **……..** | | | | |
| **………** | | | | |
| **………** | | | | |

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# Task 4.2: Study on the potential of Small Modular Fast Reactor

## Objective:

- Assessment of the industrial and economic potentialities of SMFRs
- Evaluate deployment scenarios and economic models

## Activities:

- Evaluation of the possible SMRs and SMFRs international market
- Evaluation of both specific and common SMFRs technological items and industrial potentialities
- identification of critical aspects and future R&D needs
- Energy generation cost evaluation of an SMFRs using G4ECONS tool
- Economic and financial simulation of SMFRs deployment scenarios in comparison with Large Reactors

## Temporary results:

- The following results are the product of LGI's work

# Small Modular Fast Reactor Potential Application in Europe

| Application | Description | Feasibility in Europe for SMFR |
|---|---|---|
| **Power supply for isolated or remote electricity grids** | SMRs would be used to power isolated installations which does not have high-quality energy service.<br>SMRs would be installed close to the installations and would not be connected to the Grid. | SMFRs are suitable for this application.<br>Generally remote areas are found in large countries or in countries with difficult living conditions.<br>In Europe this application could target only a few areas. |
| **Non-electrical applications** | These applications involve the simultaneous production of electricity and heat (cogeneration). | Nuclear cogeneration is already a reality in Europe for district heating (Sweden, Switzerland and Hungary).<br>Possible application of FRs for cogeneration is analyzed in the dedicated Task 4.3 |
| **Stabilizing role as complement to intermittent Energy Sources** | Future energy systems will have increasing share of Renewable Energy Sources.<br>Most of these energy sources are intermittent (wind, solar, etc.) making difficult electrical grid operation.<br>SMR can address this issue by generating base-load power. | Europe is a potential market for this application due to the increase of EU energy produced by renewable resources.<br>Fast reactors can have a strong advantage compared to other type of reactor: recycling nuclear waste should be well perceived in an environmental-friendly context. |

# Small Modular Fast Reactor Potential Application in Europe

| Application | Description | Feasibility in Europe for SMFR |
|---|---|---|
| **Access to nuclear power for the first time (new nuclear countries)** | Investors and governments might be reassured by the reduced investment and construction risk offered by SMRs. | Some countries in Europe are actively considering embarking upon nuclear power programs.<br>SMFRs might suffer from their innovative status with less past feedback experiences. PWR SMRs might be more reassuring for new nuclear countries. |
| **Generation and demand matching** | SMRs can be built individually or as modules in a larger plant.<br>They can represent an interesting solution in markets where anticipated electricity demand is projected to increase incrementally. | Europe has not a rapid population growth and this SMRs feature is not necessary. |
| **Replacement of fossil fuel Power Plants** | Due to carbon emission regulation or aging power plants, governments will have to replace existing fossil fuel power plants. | Fossil fuel power plants produce the majority of electricity in Europe, mainly through pulverised coal combustion.<br>SMFRs are adapted to replace the fleet of fossil fuel power plants due to their similar power size. |
| **Power source for military applications** | This is the original application of SMRs. Today, several nations use nuclear reactors to power ships and submarines. | Several European countries use nuclear energy to power ships and submarines. |

# Small Modular Fast Reactor Opportunity in Europe

Political, Economic, Social, Technological, Environmental, and Legal (PESTEL) analysis has been performed to identify the main threats and opportunities for SMR in the European Market.

Preliminary conclusions are:

- There is no market for SMR in Europa for now. It does not means that it is impossible to develop and build SMRs, but:
  - There is not enough needs to allow SMRs to be produced in chain in manufacturing plants to decrease production costs.
  - The presence of a dense electric grid in almost all Europe highly decreases the interest of the SMR technologies.
  - A market might appear when the old nuclear power plants will have to be replaced.
- When the market will open it will be protected. Nuclear sector is framed by legal barriers (licensing, nuclear transportation laws, non-proliferation laws) that:
  - will have as consequences the protection of the market from new entrants, and
  - will advantage the stakeholders of the nuclear field to develop the market.

# Small Modular Fast Reactor Opportunity in Europe

- SMRs market opportunity is closely linked to the increasing of energy prices
  - SMR technologies are for now expensive ways to produce electricity, they will be competitive If the prices of energy increases.
  - Exploitation of shale gas would be a real brake for SMR market development.
- Absence of common direction of the nuclear stakeholders is another brake to the SMR market development
  - Stakeholders are developing different kinds of SMR technologies and there is no lead direction.
  - SMR market would be developed only if there is a consensus of direction, and a real will from all the stakeholders.
- Social acceptance of new nuclear power plants is the main barrier for the development of an SMR market
  - There is a real need of lobbying of communication on the SMR technologies safety improvements comparing to old other nuclear technologies.
  - The nuclear stakeholders must thwart the demonization of nuclear field explaining the advantages of the new nuclear technologies.

# ALFRED as SMFR Economic Assessment

- Preliminary Top-Down cost estimate performed for ALFRED as SMFR
  - Cost estimate performed using the excel based l **G4-ECONS** (Generation 4 Excel Calculation Of Nuclear Systems) tool developed by GIF EMWG (Economic Modelling Working Group) for economic assessment of Gen IV systems including fuel cycle

- Resulting ALFRED-SMFR Nominal Cost (based on € 2014):
  - Nominal Construction Cost NOAK (Engineering, Licensing & Construction, First Core, Decommissioning & Decontamination and Contingencies) excluding (~30%) uncertainty: **750 M€** (6000 €/kWe)
  - Nominal Construction Cost FOAK: ~**1300 M€**
  - Operation & Maintenance: 135 €/kWe/a
  - Fuel Cycle: 5.8 €/MWh
  - Energy Generation: 40.8 €/MWh

- Preliminary comparison for SMFR/ALFRED (electricity only) with LEADER data for ELFR shows:
  - Engineering, licensing & construction costs are slightly higher
  - Operation and maintenance costs are slightly higher
  - Fuel cycle costs are slightly lower
  - Energy generation costs are comparable

# Task 4.3: Study on the Potential of Cogeneration Fast Reactor

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**Objective:**

- Assessment of the industrial and economic potentialities of FRs for cogeneration
- Identify requirements and evaluate FRs cogeneration costs

**Activities:**

- Assess the cogeneration markets applicable for fast reactors
- Summarize different scenarios for which FRs are applicable, and for which large potential can be envisaged, and give recommendations for system specifications and requirements to facilitate FRs cogeneration implementation
- Evaluation of energy generation cost for ESNII concept FRs employing cogeneration using the G4ECONS tool

# Task 4.3: Study on the Potential of Cogeneration Fast Reactor

## Status

### Activity Performed

- Assessment of Cogeneration Market
  - Draft (v3) provided

### Activity Ongoing

- Recommendations for System Specification
  - Summarize in which cogeneration (large potential) scenarios the different fast reactors are applicable
  - Recommendations for Availability, Reliability, Licensing potential (safety), Economics
  - Based on ESNII Key Performance Indicators
- Economic Assessment
  - Economic assessment of cogeneration FR will be based on the economic assessment for SMFR
    - Selection of cogeneration application to be done based on cases available in open literature and other nuclear cogeneration related input like e.g. NC2I

# Draft Table of Contents D431

# Nuclear Cogeneration Market for Fast Reactors

## FRs Relevant for Nuclear Cogeneration

| Fast reactor | Design | Country | Status | Thermal Power (MWth) | Electric Power (MWe) | System Temperature (°C) |
|---|---|---|---|---|---|---|
| SFR | ASTRID | EU | Pre-Conceptual Design | 1,500 | 600 | 400-550°C |
| | 4S | Japan | Detailed Design | 30 | 10 | 510 |
| | PRISM | USA | Detailed Design | 840 | 311 | 484 |
| | CEFR | China | Operating | 65 | 20 | 530 |
| | PFBR-500 | India | Under Construction | 1250 | 500 | 547 |
| LFR | ALFRED | EU | Conceptual Design | 300 | 125 | 400-480 |
| | ELFR | EU | Conceptual Design | 1,500 | 630 | 400-480 |
| | SVBR-100 | Russia | Detailed Design | 280 | 101 | 500 |
| | BREST-OD-300 | Russia | Detailed Design | 700 | 300 | 540 |
| | G4M | USA | Conceptual Design | 70 | 25 | 500 |
| GFR | ALLEGRO | EU | Pre-conceptual Design | 75 | - | 260-530°C |
| | GFR | EU | Pre-conceptual Design | 2400 | 1120 | 400-850 |
| | $EM^2$ | USA | Conceptual Design | 500 | 240 | 850 |

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# Nuclear Cogeneration Market for Fast Reactors

## ESNII FNRs Possible Applications

| Reactor | Primary coolant core Inlet/Outlet Temperature | Steam Generator Inlet/outlet Temperature | Possible Cogeneration Applications |
|---|---|---|---|
| **ALFRED (LFR)** | 400-480°C | 335-450 °C (water-steam) | - Chemical industry<br>- Coal-To-Liquid (Direct process)<br>- Soda ash |
| **ASTRID (SFR)** | 400-550°C | 245-500 °C (water-steam) | - Oil refining<br>- Pre-heating (non-ferrous metal, lime, steel) |
| **ALLEGRO (GFR)** | 260-530°C | 127-197 °C (water-water) | (*)<br>- H2 production (SMR, HTE, TC)<br>- Aluminium production (calcination)<br>- Oxygen production at HT (under development) |

(*) Possible cogeneration applications refer to industrial size GFR (2400 MWth)

# Nuclear Cogeneration Market for Fast Reactors

## Opportunities for FNRs Cogeneration (preliminary conclusions)

| Possible FNRs application | Pros | Cons |
| --- | --- | --- |
| **Chemical Industry** | Cogeneration widely used<br>Interesting Opportunity | Competition with gas<br>Needs of back-up supply during FNRs refuelling & Maintenance |
| **Soda Ash** | Interesting Opportunity<br>No explosive products (except ammonia) | Needs of back-up supply during FNRs refuelling & Maintenance<br>Soda ash plants are located closed to cities: public acceptance Issue |
| **Coal-To-Liquid (CTL)** | | Not interesting Opportunity: only few plants<br>Competition with coal |
| **Oil Refineries** | Appealing application | Competition with gas<br>Safety issues: presence of explosive products |
| **Alumina Production** | Interesting Opportunity but limited to the pre-heating phase | |
| **Aluminium Production** | | Not interesting opportunity |
| **Oxygen Production** | | Not interesting opportunity |
| **Hydrogen Production** | | Entry barriers can be difficult to overpass<br>Safety issues: presence of explosive product |
| **Pre-heating of Industrial** | FNRs may supply steam for the first processes steps and supply electricity for the second one | FNRs cannot provide steam at the required high temperatures |

*Thank you for your attention*