

DE LA RECHERCHE À L'INDUSTRIE



# 39 Annual IAEE International Conference

Energy, expectations and uncertainties

## A COMPREHENSIVE TAXONOMY OF NUCLEAR NON-ELECTRIC MARKETS: APPLICATION TO THE MARKET PERSPECTIVES FOR FRANCE

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# Overview of nuclear non-electric applications

## COGENERATION OF HEAT & ELECTRICITY

### ■ District heating and cooling

→ 52 commercial reactors through 8 countries for over 30 years

### ■ Desalination of sea water

→ 18 commercial reactors worldwide, 12 in Japan for over 30 years

### ■ Other industrial applications

→ 4 commercial reactors, e.g.: heavy water production, process heat for a cardboard factory  
→ Research on high temperature nuclear reactors: Larger range of market applications

## EXTENSION OF ELECTRIC APPLICATIONS

### ■ Hydrogen production

→ Low temperature electrolysis represents less than 1% of total hydrogen production, but costs are decreasing

→ Market for hydrogen is expected to grow: mobility, biofuel production

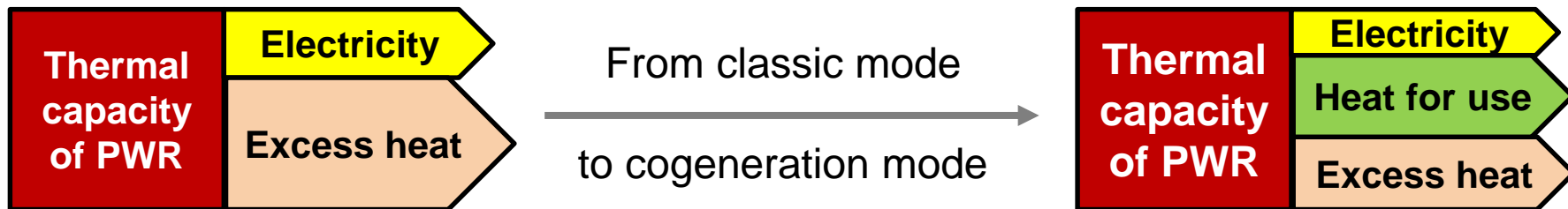
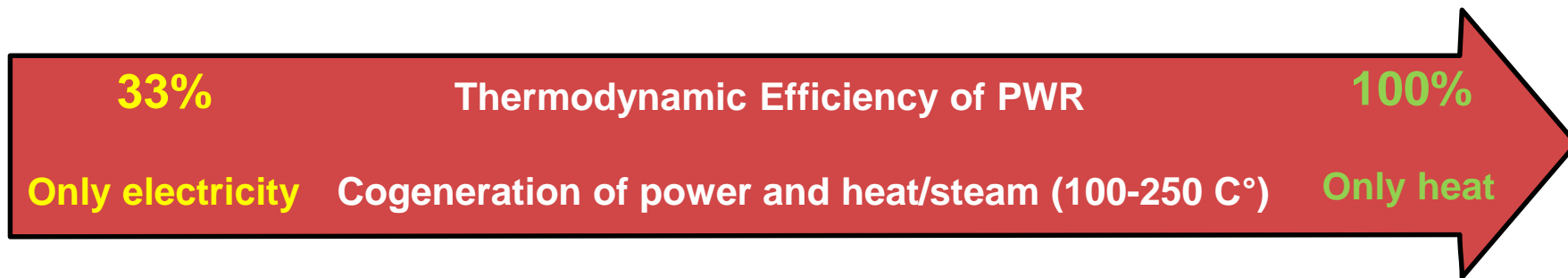
→ Research (e.g. Japan, Canada, France) on high temperature (>500C°) electrolysis

### ■ Niche applications

→ Ship propulsion, space applications, sterilizing insects ...

# A short term perspective: cogeneration with PWR

- **Pressurized Water Reactors (PWR)** are the most common type of nuclear plants in operation (277 out of 438) or under construction (59 out of 70) - (IAEA, 2015)



→ Electricity losses depend on the amount, temperature and pressure of the heat extracted

- For 1000 MW(th) of heat at 130 C° / 4 bar, power lost ratio  $\approx 1/6^{\text{th}}$  to  $1/4^{\text{th}}$

Directive 2012/27/EU: +20%  
energy efficiency by 2020

Long distance heat  
transportation (reduction of  
heat losses)

### *An additional driver for France*

- High share of nuclear power (about 75%)
- Increasing share of intermittent renewables

⇒ Opportunity for considering nuclear non-electric applications

**We investigate the possibility for nuclear non-electric applications to participate to load-following while producing valuable by-products**

Obligation to consider recovering  
the excess heat from industries

The Interest for « Ecoparks » is  
growing

## ■ Three axes of analysis:

POTENTIAL MATCHING

### 1. Nuclear technologies:

- Technology Readiness Level
- Range of temperatures
- Volume available

### 1. Customers:

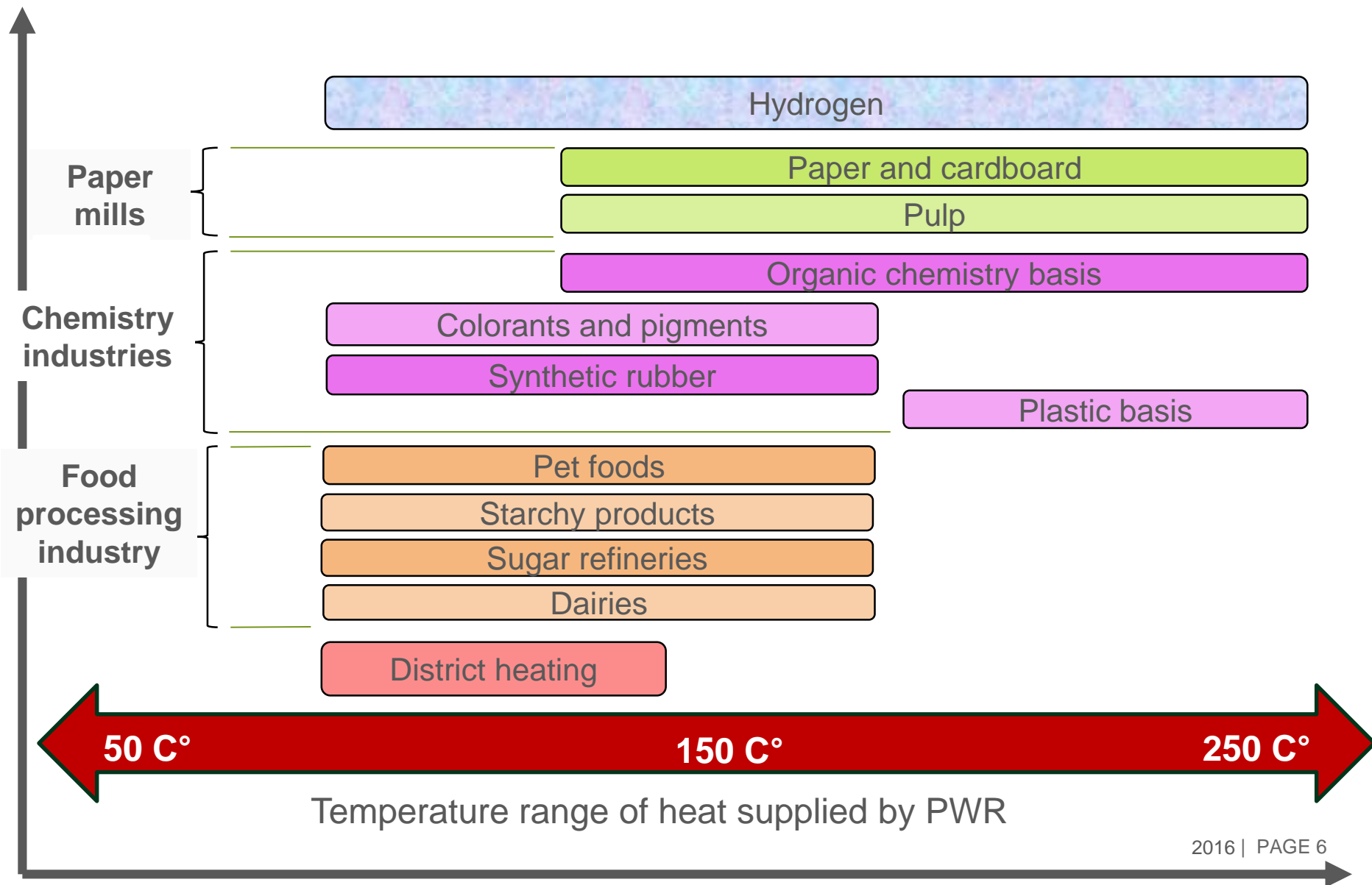
- Volume
- Temperature
- Location

## Potential matching for France:

- Nuclear cogeneration with PWR for district heating and low temperature industrial process heat
- Production of hydrogen with PWR from low temperature electrolysis

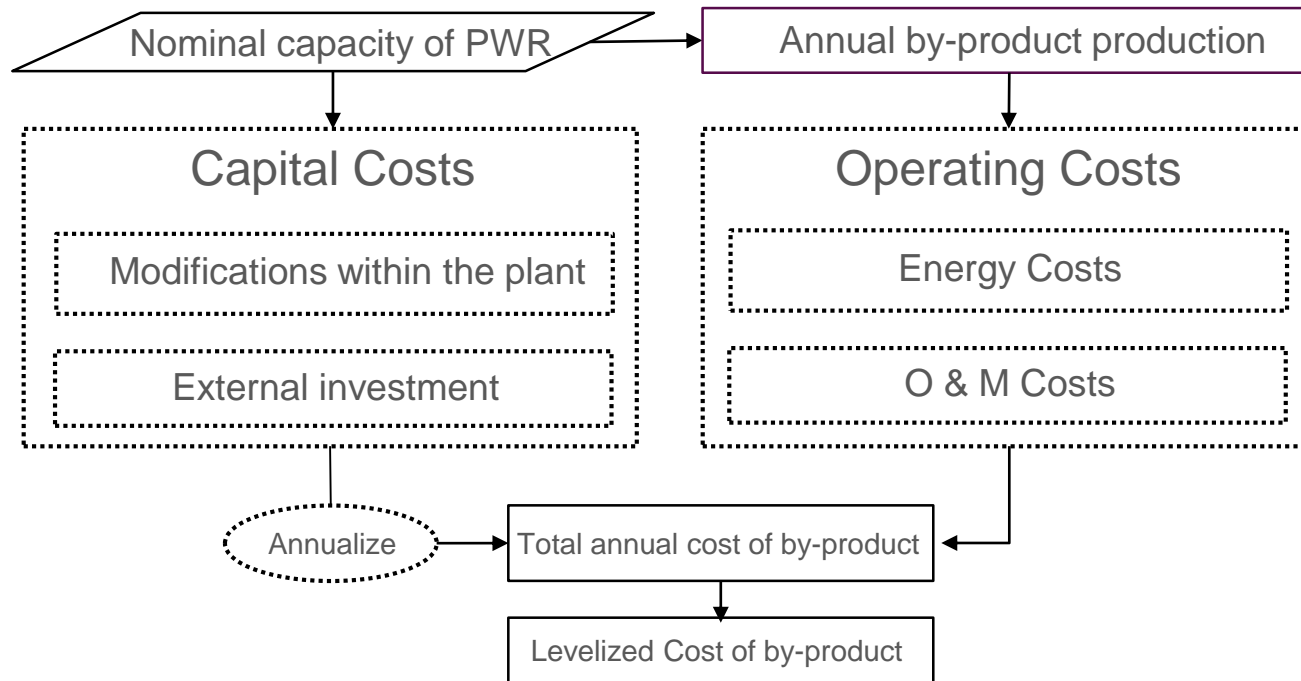
# Nuclear non-electric applications in France

## Potential matching



# Nuclear non-electric applications in France

## Economic modelling



- Assessment of the potential for the overall society :
  - For nuclear cogeneration, it accounts the costs of electricity losses
  - For nuclear district heating, it accounts the cost of the main transport line, the cost of the networks to build and the heat back-up needed
  - « Integrated systems in partial equilibrium »
  
- Environmental assessment
  - Data collection for the studied territory
  - Emission factors: ADEME (2010)

**From 2009 to 2013:**

No increase in the energy delivered by district heating networks

+10% from renewable energies and excess heat recovery

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**Even though the share of renewables is increasing,  
the building dynamic is very low**

**To achieve the 2020 targets, many networks must be built in the following years**

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**There is room for alternative low carbon centralized heat  
sources**

**Nuclear cogeneration could enhance the deployment of  
district heating networks**



### From the Nogent-Sur-Seine nuclear reactor to Paris: BASE SCENARIO

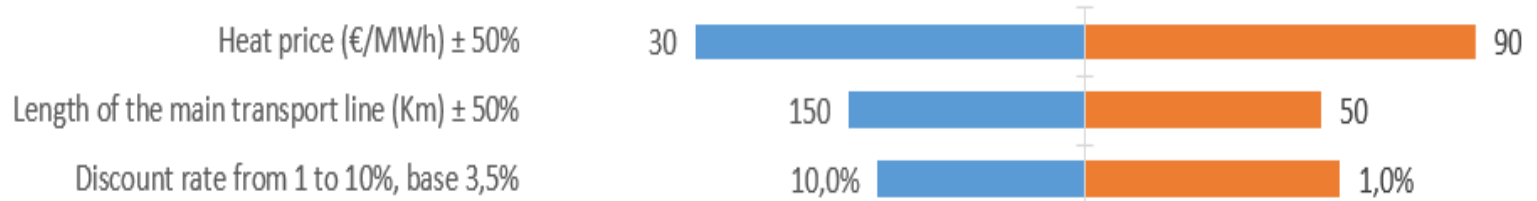
With the assumptions made in the Base scenario:

**Net Present Value  $\approx$  650 million euros**  
**Mitigated CO<sub>2</sub> emissions  $\approx$  1 million ton yearly**

**The joint use of district heating networks and nuclear cogeneration plants can **result in competitive advantages****

- Total Investment cost  $\approx$  1.5 billion euros (about 1 billion for the heat transport)
- Annual heat delivered to network  $\approx$  4.5 TWh(th) of heat
- Levelized Cost of Heat  $\approx$  50 €/MWh(th)

### Sensitivity Analysis of the main economic parameters (compared to the base scenario)



The main parameters are:

Heat price, length and cost of the main line, discount rate, thermal output, operational lifetime

Monte-Carlo analysis would help **framing the uncertainty**

-800 -600 -400 -200 0 200 400 600 800

# Nuclear non-electric applications in France

Potential matching with low temperature heat needs of industries

**Paper mills:**  
Paper & Cardboard,  
pulp

**Food-Processing Industry:**  
Starchy products, dairies, sugar  
refineries, pet food ...

There is room for nuclear plants to **provide a large amount of low temperature process heat**

Further economic modelling is required to determine whether or not a particular project is profitable, environmentally and economically.

**Chemistry:**  
Organic chemistry basis,  
colorants & pigments,  
synthetic rubber, plastic  
basis ...

**Source:**

ANCRE (French National Alliance for Energy Research Coordination, 2015). Using data from CEREN for 2011

*Notes: See Appendix B for methods*

### Integration of Biorefineries and Nuclear Cogeneration Power Plants (Green et al., 2009)



In France, the low temperature heat consumption for bio-fuels is equal to 10 TWh(th) yearly, and the production will be larger and larger in the future.

Benefits from regional symbiosis between nuclear cogeneration plant, biorefinery and biofarm are threefold:

- 1) Higher efficiency of the nuclear reactor
- 2) Low carbon process heat for biofarms & biorefineries
- 3) Recovery of valuable bio-products

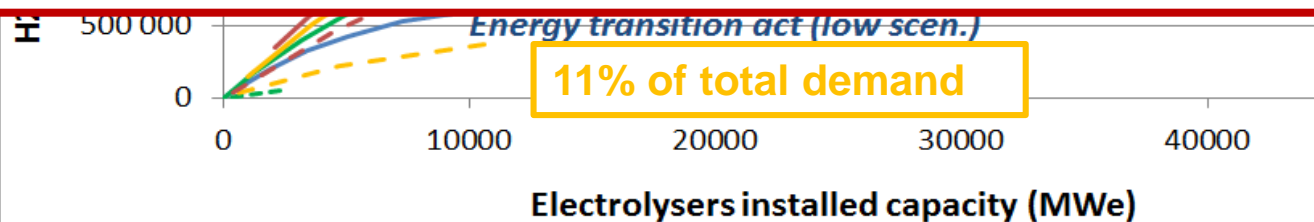
— nuclear capacity: 60 GW; wind and solar share: 16.5%

— nuclear capacity: 60 GW; wind and solar share: 23%

Production of hydrogen with nuclear plants allow to **make an efficient use of electricity**

In 2030, if the nuclear installed capacity is to remain stable, nuclear plants could cover 40 to 80% of the French hydrogen needs **without reducing the provision of electricity to the network**

In 2050, nuclear plants could provide half of the hydrogen needs even if the nuclear installed capacity decreases to 50%



France, 2030 (with carbon price)

H<sub>2</sub> production cost ranges

Production of hydrogen with nuclear plants can be **competitive**

The size of the attractive market **depend on the business model** chosen for the coupling of hydrogen and nuclear plants

**The largest market is reach in case of an integrated system**, where the hydrogen production plant is owned and operated by the nuclear plant operator



- **PWR non-electric applications:**

- Technically and safely feasible
- An alternative to further analyze in energy models and scenarios

- **Benefits of PWR non-electric applications:**

- Increasing thermal efficiency of the reactor
- Production of valuable by-products
- Nuclear load-following

- **In France:**

- Nuclear energy can help managing the penetration of renewables in the energy mix
- Increasing share of renewables = opportunity to consider nuclear non-electric applications
- Markets exist for low carbon, centralized heat sources. The evolution of markets for mobility may also lead to large hydrogen markets.

ANCRE, 2015. Decarbonization Wedges Report.

Cany, C., Mansilla, C., Da Costa, P., Mathonnière, G., Duquesnoy, T., Baschwitz, A., 2016. Nuclear and intermittent renewables: Two compatible supply options? The case of the french power mix. Energy Policy 95, 135-146.

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Safa, H., 2012. Heat recovery from nuclear power plants. Int. J. Electr. Power Energy Syst. 42, 553–559.

STUK, 2009. Preliminary Safety Assessment of the Fennovoima Oy Nuclear Power Plant Project.

**Thank you very much for your attention!**

**Please feel free to send your comments and suggestions to:**

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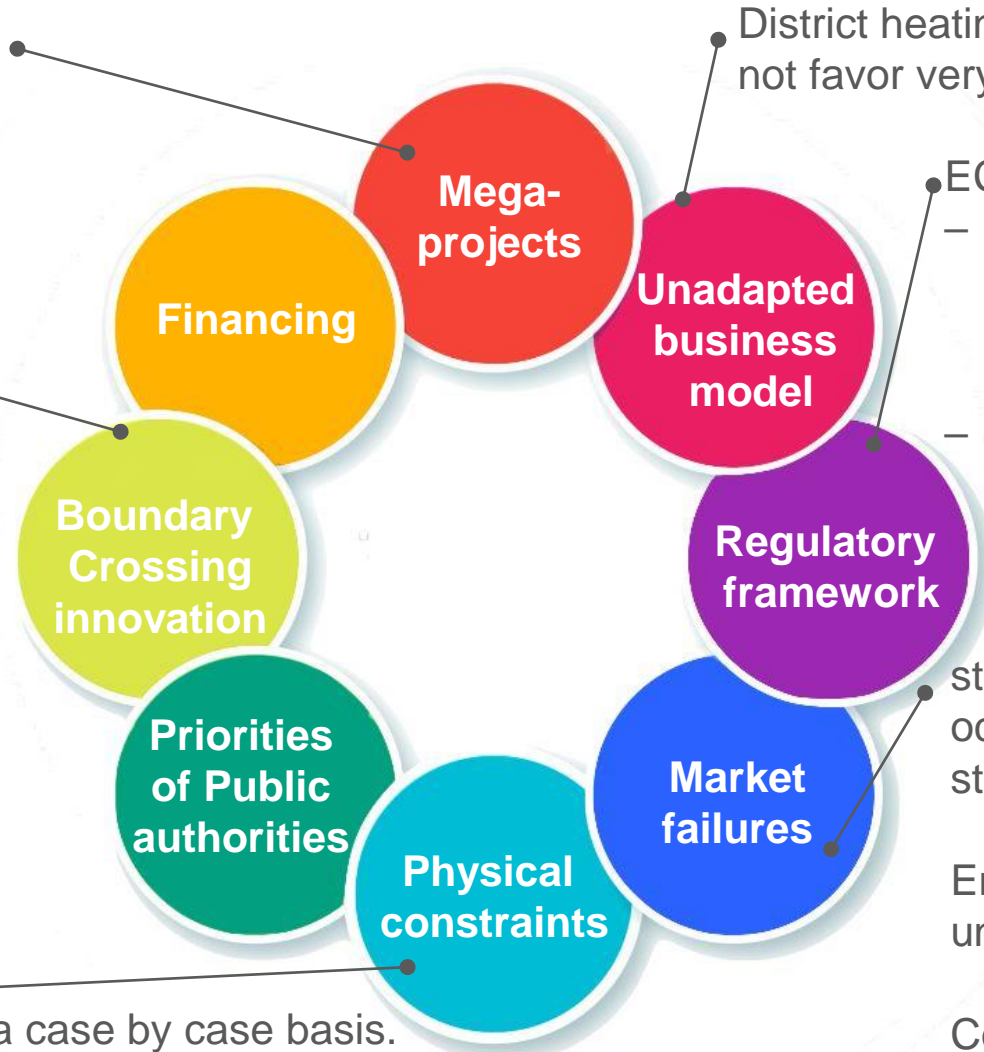
# Appendix A: Limits to nuclear non-electric applications

Uncertainty of key economic and social parameters

Challenging to connect nuclear and heat regimes, made of deeply rooted and distinctive actors

The penetration of hydrogen in markets for mobility is uncertain

To be determined on a case by case basis. Yet, clashes about the technical feasibility are not merely technical debates, but highly political contests that revolve around social ideology, values and power



District heating networks operators do not favor very large scale projects

- EC directives are not:
- Allowing the provision of financial support for excess heat recovery projects
  - Recognizing nuclear wasted heat

strong split incentives may occur between stakeholders

Energy prices are highly unstable

Complexity of establishing contractual rules

ANCRE (French National Alliance for Energy Research Coordination, 2015)  
Using data for 2011

### Criteria to determine which industrial sites are likely to be interested by nuclear low temperature heat in France:

- **Volume:** consuming >10 GWh per year
- **Temperature:** low temperature (<250 C°)
- **Location:** <100 km from the nearest nuclear power plant
- **Interest:**
  - Economically impacted by low temperature heat cost
  - Using >75% of low temperature heat compared to the total process heat consumption (i.e. cannot recover condensat from a higher temperature process)
  - Highly seasonal activities have been discarded

# Appendix C: Cost breakdown analysis of modifying a nuclear power plant to provide district heat

