SMR/AMR Outlook in France

SFEN

Webinar Presentation

23 May 2025

CONFIDENTIAL

Disclaimer

Legal disclaimer

- This report (the « Report ») was prepared and is to stay under © 2025 Copyright of E-CUBE Strategy Consultants SAS, 8 rue Royale, 75008 Paris, France (« E-CUBE »). No part of this report may be reproduced in any form or by any means without prior permission in writing from E-CUBE. Any such permitted use or reproduction is expressly conditioned on the continued applicability of each of the terms and limitations contained in this disclaimer.
- By accepting delivery of this report, the Recipient acknowledges and agrees to the terms of this disclaimer.
- The Study is exclusively reserved for internal distribution of Société Française d'Energie Nucléaire (SFEN), which have acquired a copy (hereinafter "the Customers").
- The Customers agree, in accordance with the property rights, not to disclose the Study, in whole or in part, including but not limited to, illustrations, graphs, tables, figures and data, to a third party, this includes a partner, a financial institution, a consultant, or make it public.
- The internal distribution to the Customers of the Study shall be allowed subject to the following conditions: (1) these legal notices appear; (2) The copyright of E-CUBE is displayed on all copies.
- Any employee, officers, or director of the Customers to whom this document is provided because of its duties or just to have knowledge of the Study shall ensure strict confidentiality in the terms indicated above.
- All information contained in this report is confidential and intended for the exclusive use of the Recipient. The Recipient may transmit the information contained in this report to its directors, officers, employees or professional advisors provided that such individuals are informed by the Recipient of the confidential nature of this report. All other use is strictly prohibited.
- This Study has been prepared in part on the basis of information available in the public domain and provided by the Customers. None of the information on which the Study is based has been independently verified nor audited by E-CUBE Strategy Consultants. In preparing this Study, E-CUBE Strategy Consultants has relied upon and assumed the accuracy and completeness of all the information available from public sources or by a third party.
- Neither E-CUBE Strategy Consultants nor any of its respective shareholders, directors, officers or employees makes any warranty or representation, expressed or implied, concerning the accuracy or completeness of, and none of them shall have any liability with respect to, either the information or the analyses of information contained herein. Statements in this report involving estimates are subject to change and actual amounts may differ materially from those described in this report depending on a variety of factors.
- The financial, regulatory and forecast information contained within the Study include the economic, monetary, regulatory and market or other conditions prevailing on 15 April 2025 and are without prejudice to any amendments necessitated if these conditions were to change.
- E-CUBE hereby expressly disclaims any and all liability based, in whole or in part, on any inaccurate or incomplete information given to E-CUBE or arising out of the negligence, errors or omissions of E-CUBE or any of its officers, directors, employees or agents. Recipients use of this report and any of the estimates contained herein shall be at Recipients' sole risk.
- E-CUBE expressly disclaims any and all liability arising out of or relating to the use of this report. E-CUBE also hereby disclaims any and all liability for special, economic, incidental, punitive, indirect, or consequential damages. Under no circumstances shall E-CUBE have any liability relating to the use of this report.
- Unless otherwise stated, E-CUBE Strategy Consultants disclaims any obligation to update the Study.

Forward-looking statements

- Nothing in this report is or shall be relied upon as a promise or representation of future events or results. E-CUBE prepared this report based on information available at the time of its preparation (15 April 2025) and has no duty to update this report.
- Some information contained in this document contains forward-looking statements. These forward-looking statements include, without limitation, statements relating to markets, businesses and industries. The words "believe", "intend", "expect", "anticipate", "project", "estimate", "predict", "is confident", "has confidence", "plan", "believe", "seek", "see", "will", "would", "forecast", "target", "preliminary", "range", and similar expressions are also intended to identify forward-looking statements. These forward-looking statements are not historical facts. Rather, these forward-looking statements are based on the current beliefs, assumptions, expectations, estimates, and projections of E-CUBE about various markets, businesses and industries.
- These forward-looking statements are not guarantees of future evolution and are subject to risks, uncertainties and other factors, which are beyond our control and are difficult to predict. Consequently, actual results could differ materially from those expressed, implied or forecasted in these forward-looking statements.

SFEN has mandated E-CUBE Strategy Consultants study the markets and possible geographical location of SMRs/AMRs (fission only) in France

What **market** SMR/AMR technically address in France (decarbonised electricity and heat)?

How could they **distribute geographically** across continental France?

This report:

- Quantifies the « **technically addressable** » market for SMR/AMR
- Does not **quantify the « economically addressable » nor « commercially addressable »** market for SMR/AMR, which depend on the specific cost, price, acceptance and time-to-market parameters of each SMR/AMR project. On these aspects, the report provides **qualitative insights**.

The E-CUBE report covers 5 markets for SMR/AMR (4 heat + electricity)

Markets for heat

Existing markets
(sites already in operation with significant heat / electricity consumption)

Prospective, high-potential markets
(commissioning of first sites expected in 2025 or later)

1 INDUSTRIAL HEAT

SMR/AMR can be used in 100% heat generation or combined heat and power configurations to supply **industrial processes** (incl. by addressing the **preheating** stages of high-temperature processes)

2 DISTRICT HEATING

SMR/AMR could substitute or complement fossil energy sources and biomass to supply **large district heating networks**, whose development is accelerating through expansions and the setup of new networks

3 CARBON CAPTURE

Carbon capture technologies require **heat to regenerate solvents**

4 HIGH-TEMPERATURE ELECTROLYSIS

Producing hydrogen from high-temperature electrolysis requires heat to vaporise water

Markets for electricity

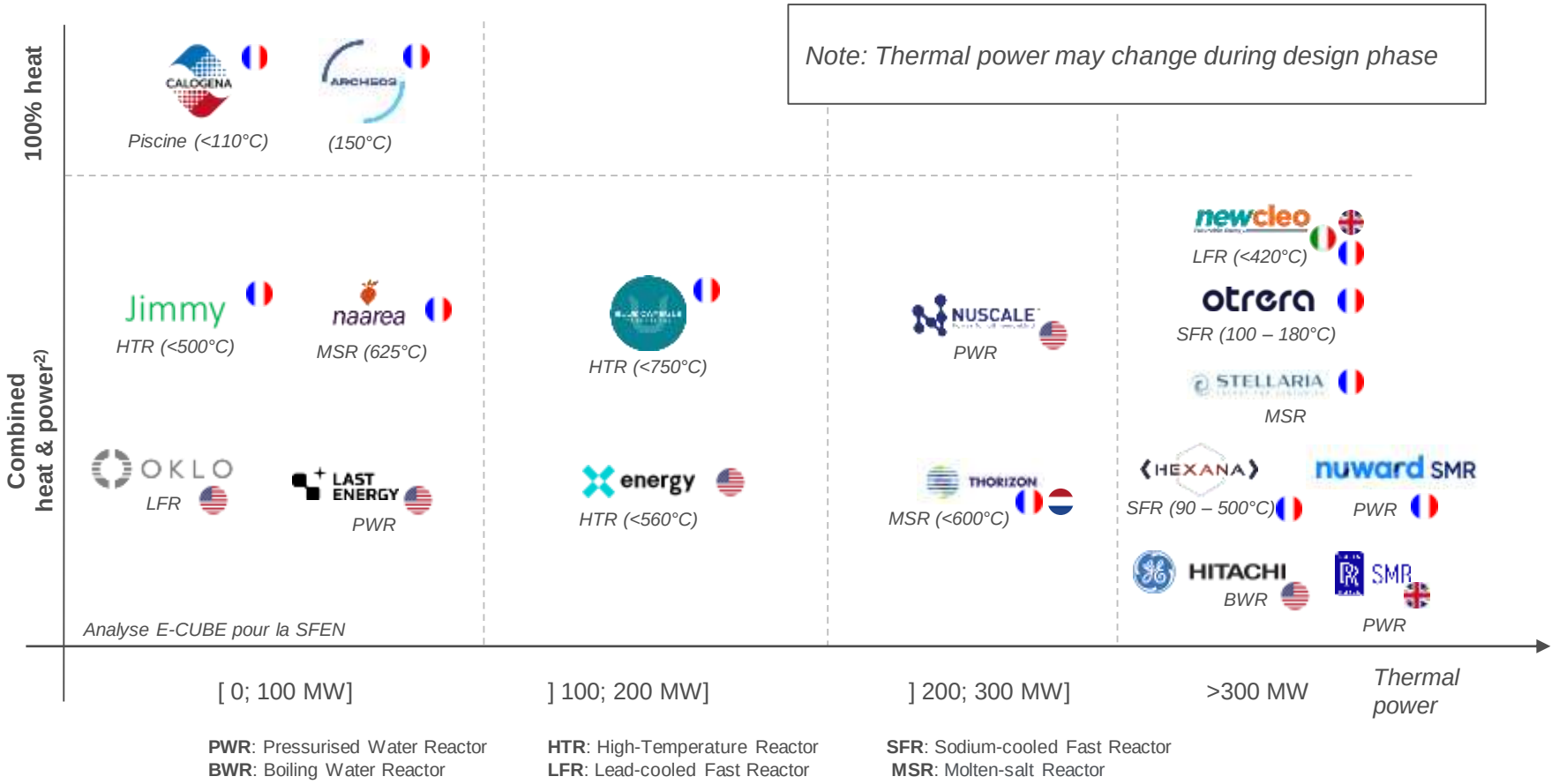
5 ELECTRICITY GENERATION

SMR/AMR (used in 100% heat generation or combined heat and power configurations) can generate electricity :

- Either to **complement the national electricity mix** by injecting electricity into the national grid
- Or to **supply locations or areas with specific needs**: self-generation, network constraints due to an increase in electricity consumption

SMR/AMR encompass several technological groups, with varied technical specifications

SELECTION OF SMR/AMR (100% HEAT GENERATION OR COMBINED HEAT & POWER CONFIGURATIONS)[1)]



PWR: Pressurised Water Reactor
BWR: Boiling Water Reactor
HTR: High-Temperature Reactor
LFR: Lead-cooled Fast Reactor
SFR: Sodium-cooled Fast Reactor
MSR: Molten-salt Reactor

1) Notably including 10 projects supported by the France 2030 program, ARCHEOS, and a selection of international players
2) The « combined heat & power » category includes all SMR/AMR projects for which combined heat & power is announced or considered, even if the possible heat/electricity split is not known at this stage

Sources: CEA, Interviews, Press review / E-CUBE Strategy Consultants analysis on behalf of SFEN

The geographical distribution of SMR/AMR will be partly guided by local demand, and constrained by technical limitations and local acceptance

MAIN DRIVERS OF SMR/AMR GEOGRAPHICAL DISTRIBUTION

	Heat	Electricity
Location drivers	▪ Demand from **industrial** sites ▪ Demand from **district heating networks** ▪ Opportunities to **jointly supply** industrial sites and/or district heating networks (existing or future connections)	To complement the national electricity mix: **notably sites that have already hosted electricity generation** (e.g. former thermal generation plants), **or that have hosted nuclear activity** **To supply locations or areas with specific needs:** ▪ **Connection constraints** to the transmission grid (RTE) ▪ Opportunities **for self-generation**
Technical constraints	▪ Available **land** ▪ Accessible transmission / distribution **grid connection capacity** ▪ **Water supply** (depends on SMR/AMR technology) ▪ Acceptance, industrial safety ▪ Other: **seismic** activity, **submersion** risk	

On a local scale, several technical constraints may limit possible locations: the nature and the extent of these constraints depend on each SMR/AMR technology

Nature of the constraint	Details on the constraint
Available land	Availability of land to build the **plant** (including security perimeter) and set up a **construction perimeter**, while complying with soil artificialisation rules: detailed criteria are ▪ **Distance between plant location and energy consumption location** ▪ Availability of **large enough land tracts** (e.g. brownfield industrial site) to secure the site (security perimeter, guards etc)
Accessible transmission / distribution grid connection capacity	**Feasibility of a connection to the medium or high voltage grid:** ▪ **Distance to the grid** ▪ **Grid congestion risk** ▪ In certain cases: **redundancy** (separate feeders on several transformers)
Water supply (depends on SMR/AMR technology)	Access to water supply that fits the safety requirements and cooling needs of the reactor ▪ **Distance between plant location and water source (sea, lake, river, canal, water table…)** ▪ **Minimum flow** *Note: certain SMR/AMR technologies use cooling systems that do not require access to a water sources (ex: closed-loop cooling). In addition, for technologies that do require it, the constraint is all the smaller as the % of energy used to generate electricity is lower (as opposed to generating heat).*
Other: seismic activity, submersion risk…	Criteria pertaining to site security

The heat demand that SMR/AMR can address would exceed 100 TWh_{th} by 2050

SIZING OF THE MARKET FOR DECARBONISED HEAT THAT SMR/AMR CAN TECHNICALLY ADDRESS [2050]

> 100 TWh_{th} technically addressable by 2050

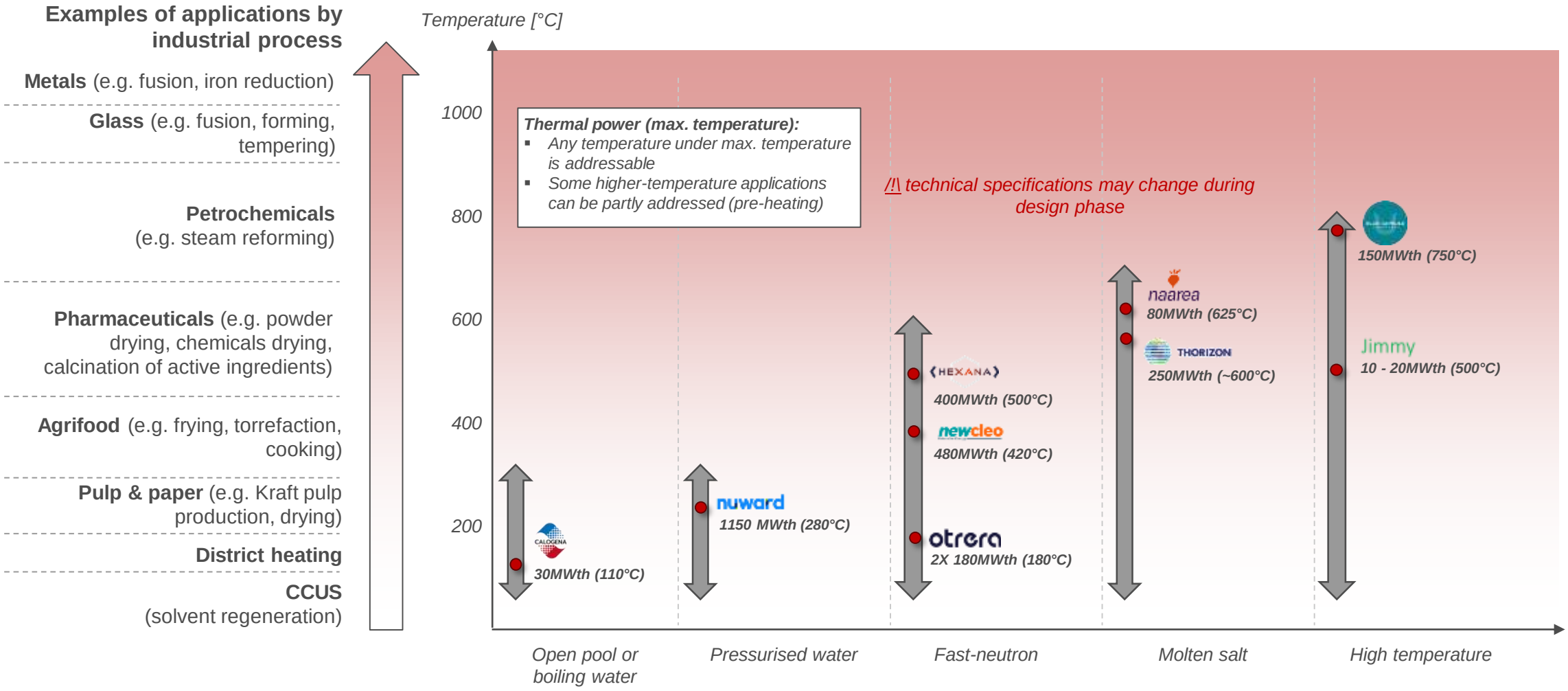
Material markets
(sites already in operation with significant heat / electricity consumption)

Prospective, high-potential markets
(commissioning of first sites expected in 2025 or later)

1	2	3	4
INDUSTRIAL HEAT	**DISTRICT HEATING**	**CARBON CAPTURE**	**HIGH-TEMPERATURE ELECTROLYSIS** *(heat demand only)*
~70 TWh_{th}	**~30 TWh_{th}**	**10-15 TWh_{th}**	**0,5-3 TWh_{th}**
~60 clusters	**~20 clusters**		

E-CUBE Strategy Consultants analysis on behalf of SFEN

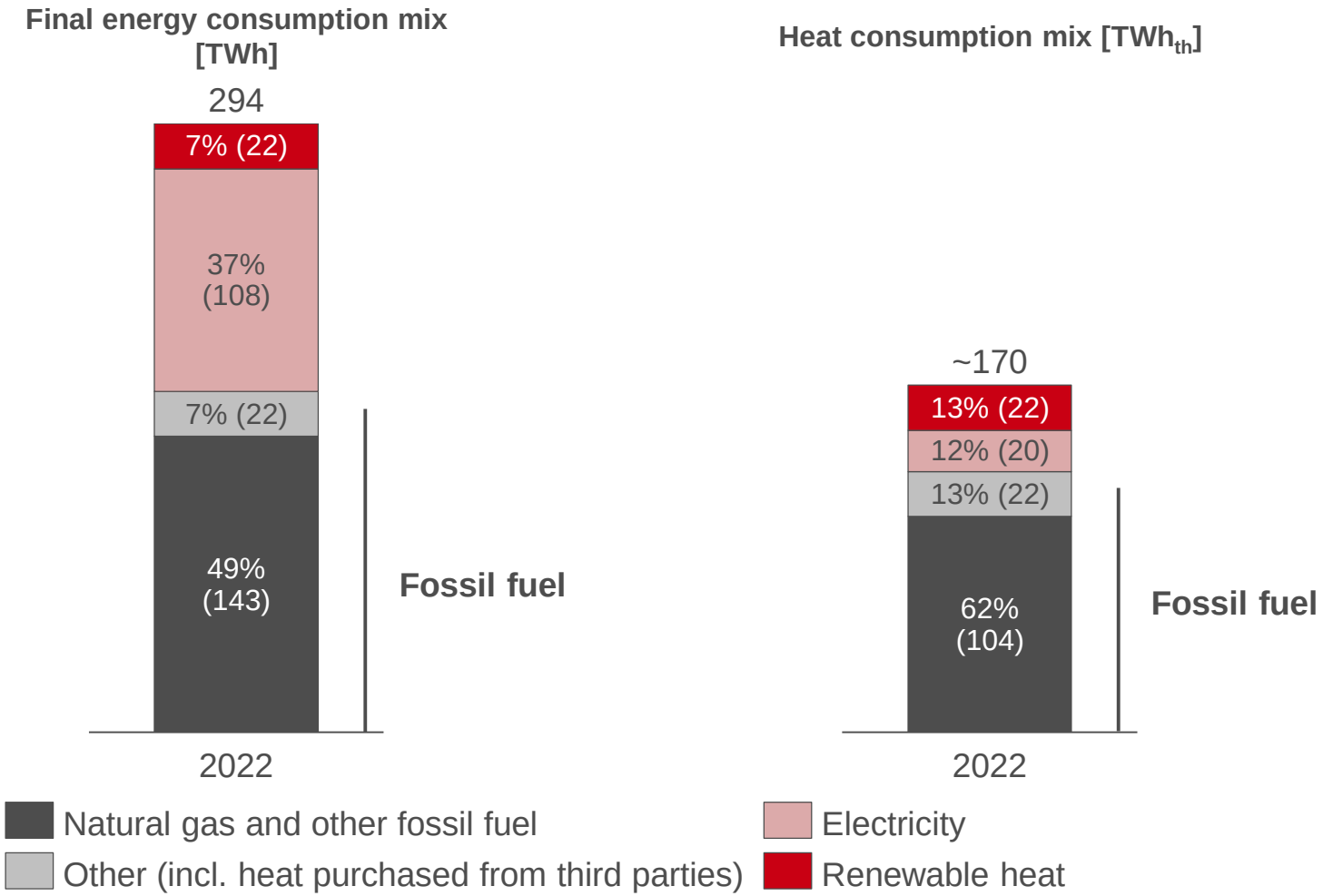
Each SMR/AMR concept could address certain types of heat demand: the end uses that fit each reactor depend on its power and output temperature range



Sources: CEA, Interviews, Press review / E-CUBE Strategy Consultants Analysis

In France, most industrial heat is supplied by fossil fuel

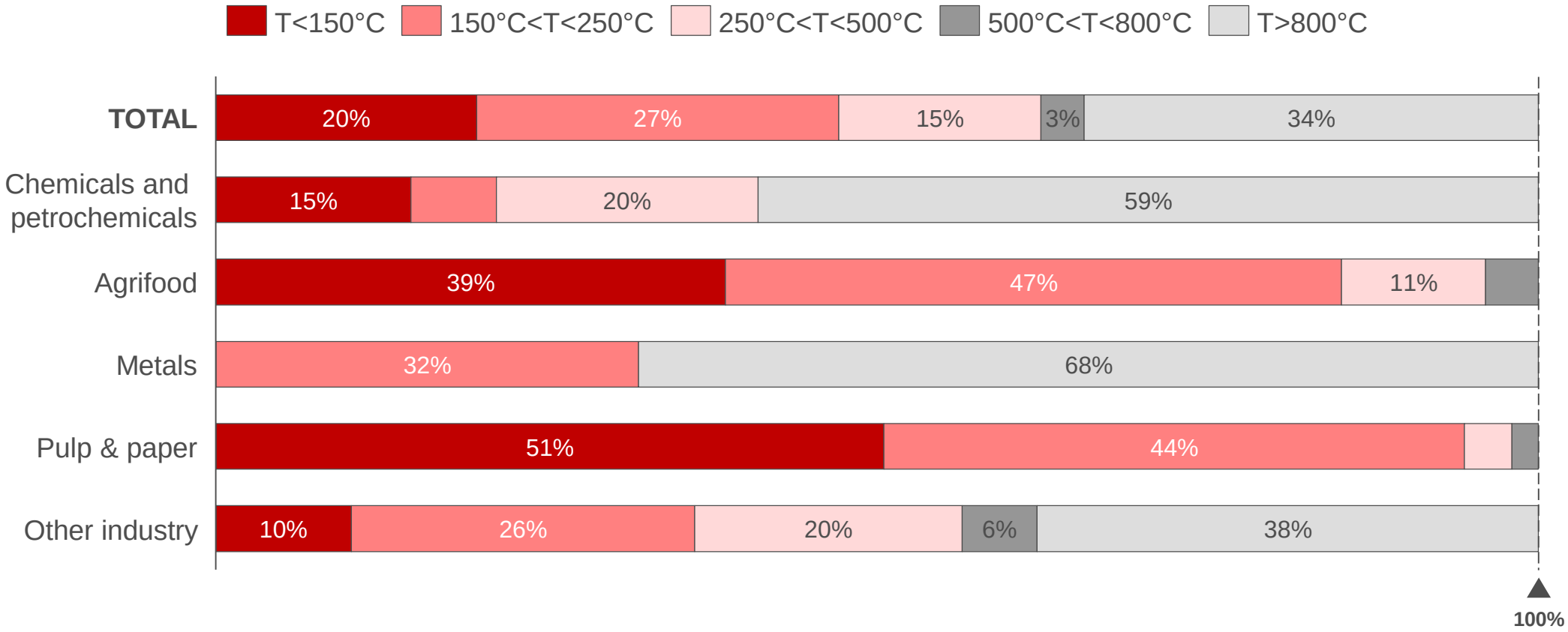
FINAL INDUSTRIAL ENERGY CONSUMPTION IN FRANCE [TWH, 2022]



E-CUBE Strategy Consultants analysis on behalf of SFEN

Each SMR/AMR technology can address part of industrial heat demand: temperature varies widely depending on the industrial process

ESTIMATED INDUSTRIAL HEAT DEMAND IN FRANCE BY TEMPERATURE[1)] [2022; TWH_{TH}]



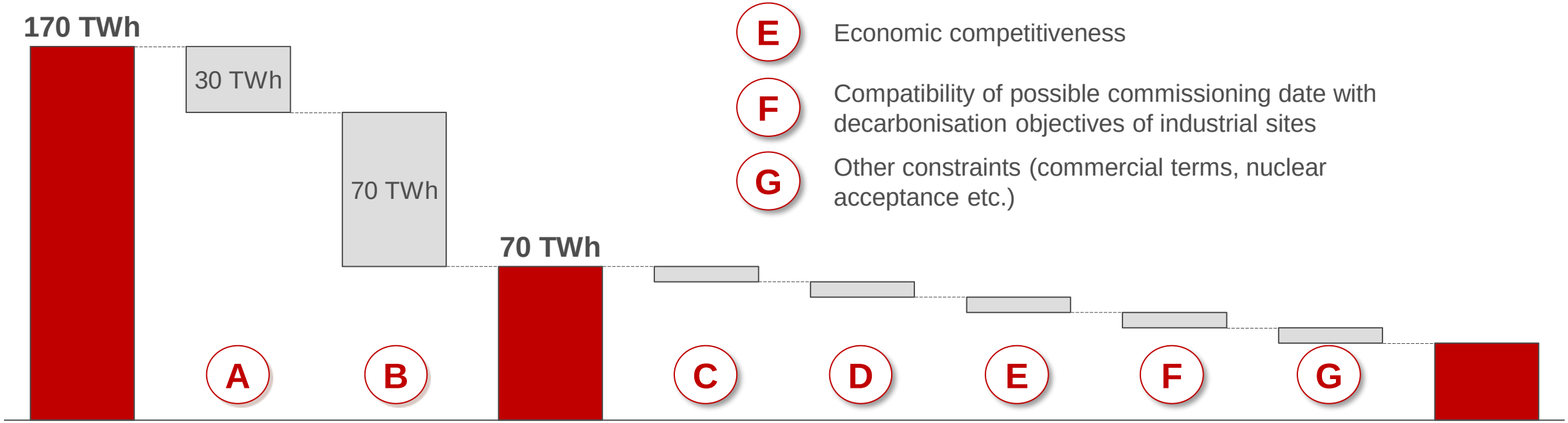
E-CUBE Strategy Consultants analysis on behalf of SFEN

Industry is the main target market for heat produced by SMR/AMR: it amounts to ~70 TWh_{th} technically addressable by SMR/AMR

FOR ALL TYPES OF SMR/AMR

SPECIFIC TO EACH SMR/AMR TECHNOLOGY (not quantified in this report)

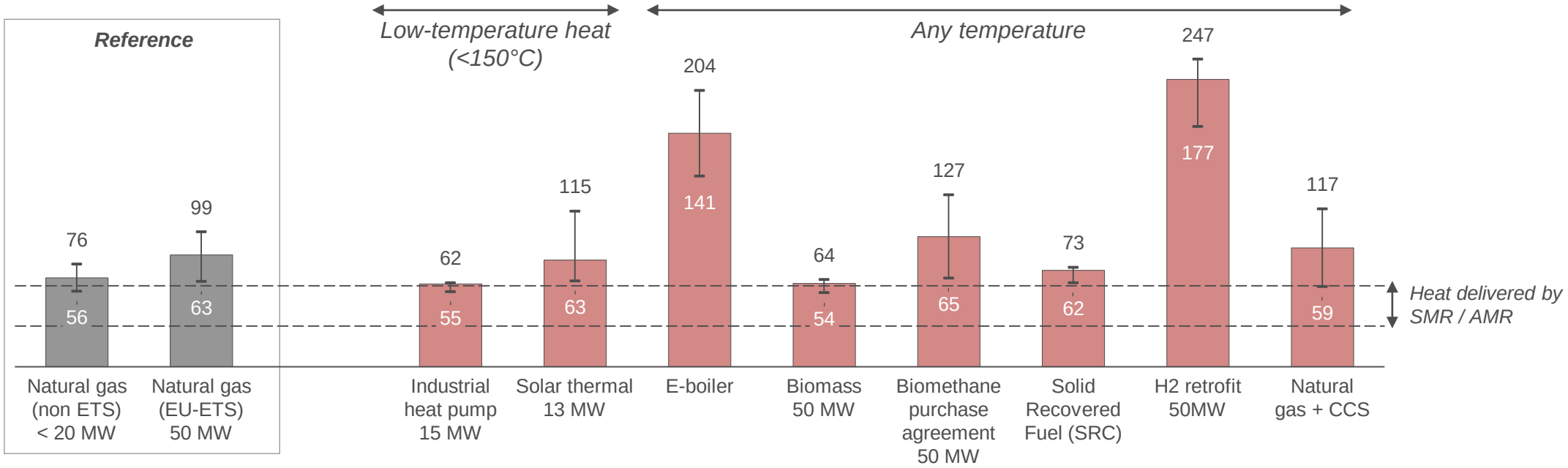
- **A** Temperature compatibility
- **B** Critical size
- **C** Specific temperature and size compatibility
- **D** Technical constraints
- **E** Economic competitiveness
- **F** Compatibility of possible commissioning date with decarbonisation objectives of industrial sites
- **G** Other constraints (commercial terms, nuclear acceptance etc.)



E-CUBE Strategy Consultants analysis on behalf of SFEN

If the levelised cost of heat (LCOH) delivered amounts to €40-60 /MWh$_{th}$ (public communication from certain players), SMR/AMR could be competitive with most sources of decarbonised heat

LCOH OF DECARBONISED HEAT SOURCES FOR INDUSTRY, WITHOUT SUBSIDIES [€2035/MWH; INVESTMENT ASSUMED IN 2035]

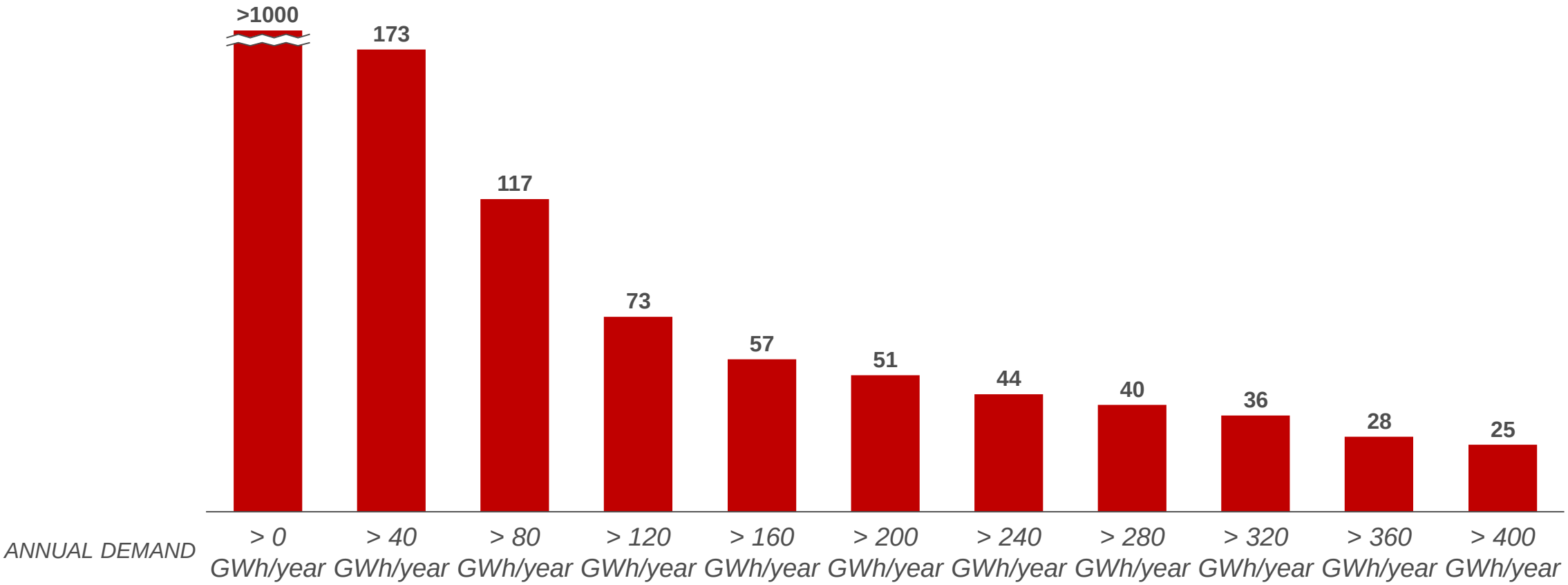


Commodity price range *(assumption for 2035, unless otherwise stated)*

Gas	Gas	Elec.	Elec.	Biomass	BioCH4	SRC	H2	Gas
[28 – 46] €/MWh	*[28 – 46] €/MWh*	*~[73 – 110] €/MWh*	*~[73 – 110] €/MWh*	*[19 – 35] €/MWh*	*[60 – 120] €/MWh*	*[-12 – -4] €/MWh*	*[106 – 214] €/MWh*	*[38 – 46] €/MWh*
	ETS *[135 – 250] €/tCO$_2$ 2050*	*Selon disponibilité de chaleur fatale (couteuse à transporter)*						CCS *[126–330] €/tCO$_2$*

E-CUBE Strategy Consultants analysis on behalf of SFEN

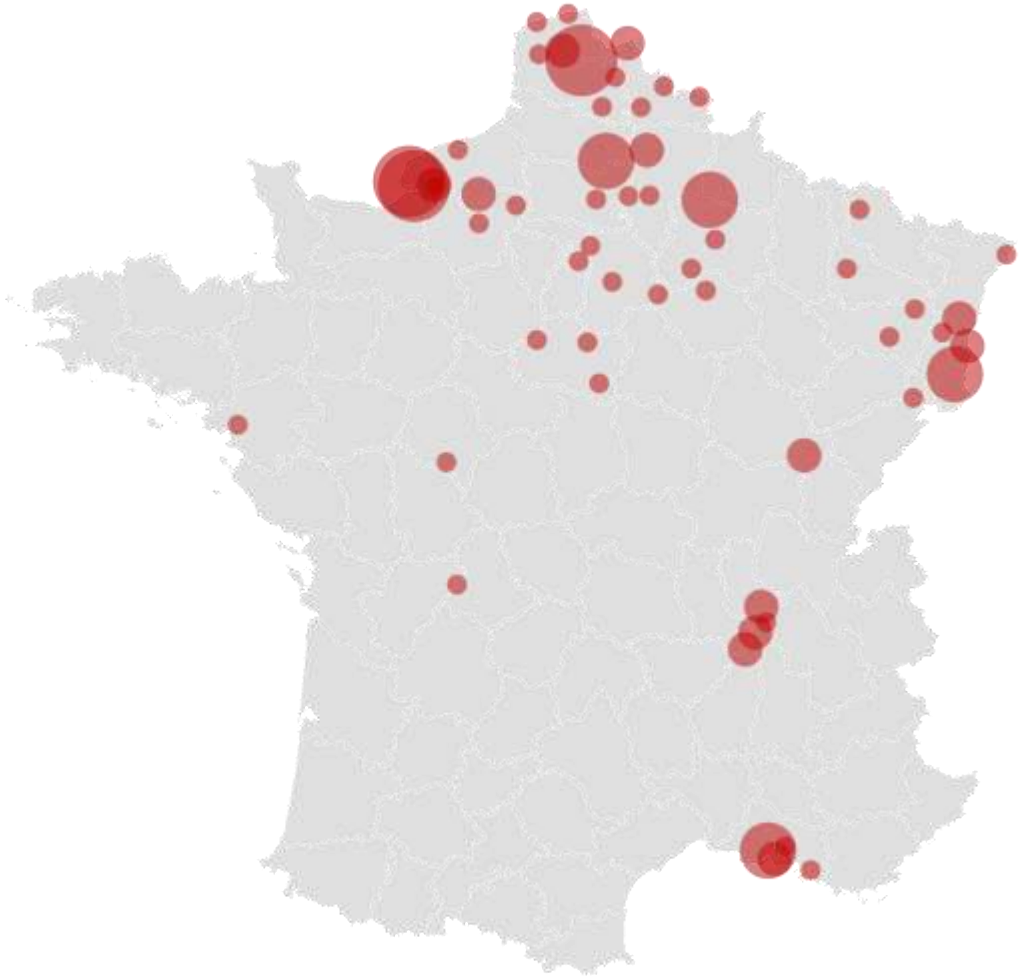
E-CUBE numbered 57 industrial clusters with heat demand over 160 GWh_{th}/year



E-CUBE Strategy Consultants analysis on behalf of SFEN

The technically addressable industrial heat market for SMR/AMR in France (combination of all SMR/AMR technologies) is comprised of about 60 clusters, most of which are located in the North and East

INDUSTRIAL CLUSTERS WITH HEAT DEMAND TECHNICALLY ADDRESSABLE BY SMR/AMR [2050]



≥ 2000 GWh / year

[1000 – 2000[GWh / year

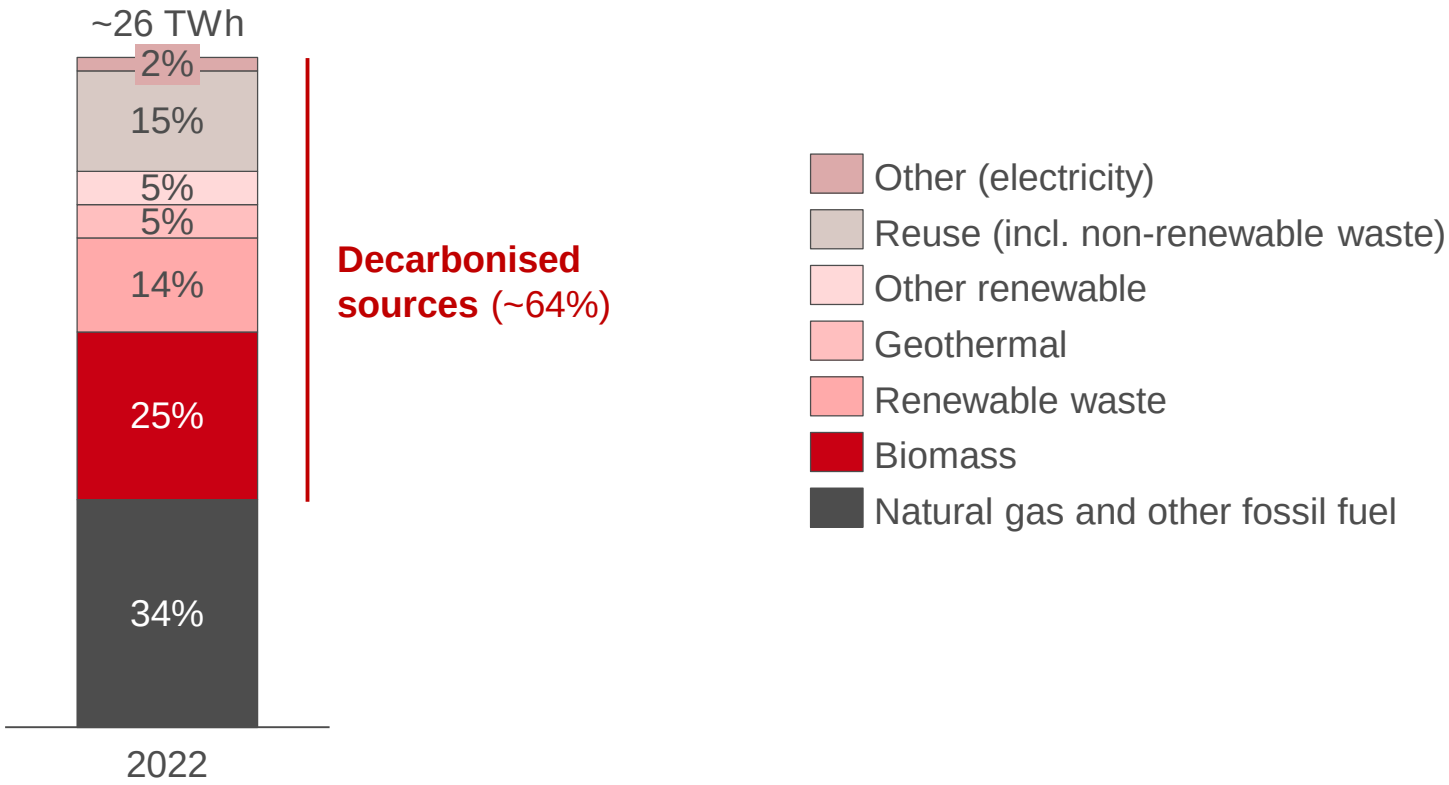
[500 – 1000[GWh / year

[100 – 500[GWh / year

E-CUBE Strategy Consultants analysis on behalf of SFEN

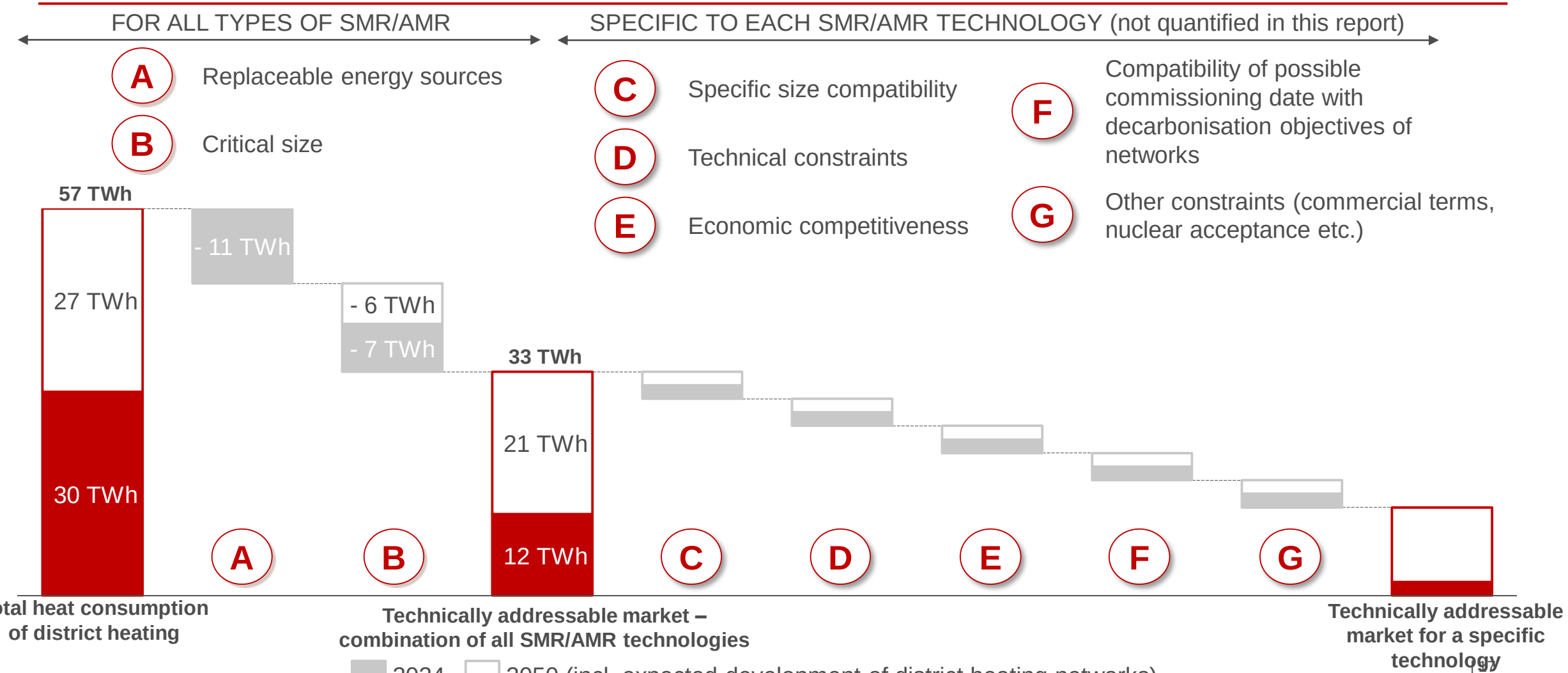
District heating networks are already mostly supplied with decarbonised heat

FINAL ENERGY CONSUMPTION MIX OF DISTRICT HEATING NETWORKS IN FRANCE [TWH_{TH}]



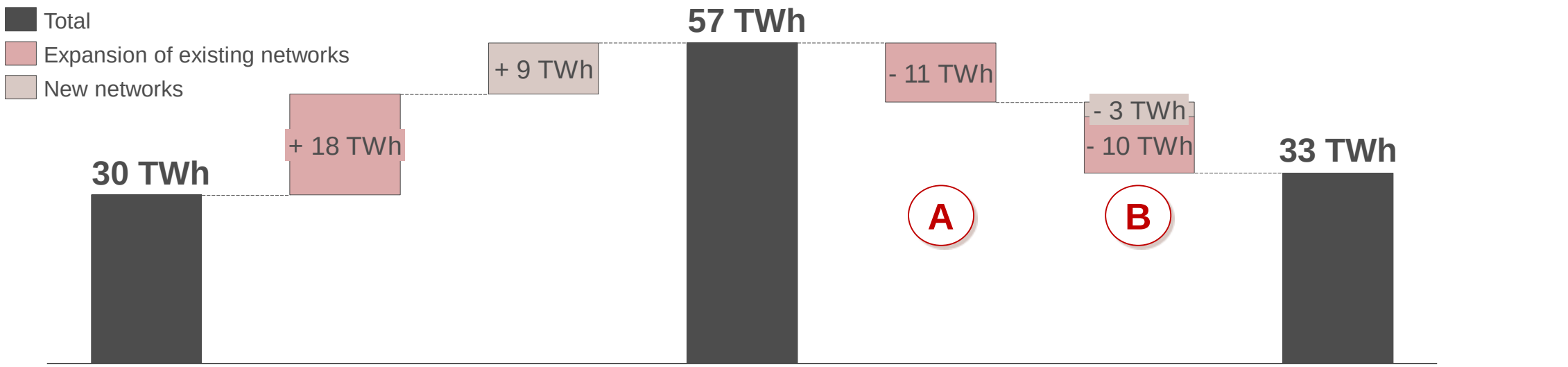
E-CUBE Strategy Consultants analysis on behalf of SFEN

The technically addressable district heating network market for SMR/AMR amounts to 12 - 33 TWh_{th}/an in 2050



E-CUBE expects heat delivered by district heating networks to increase due to the growth of existing networks and the development of new networks

HEAT DELIVERED BY DISTRICT HEATING NETWORKS IN FRANCE
[PRODUCED TWH_{TH}, 2022 – 2050]



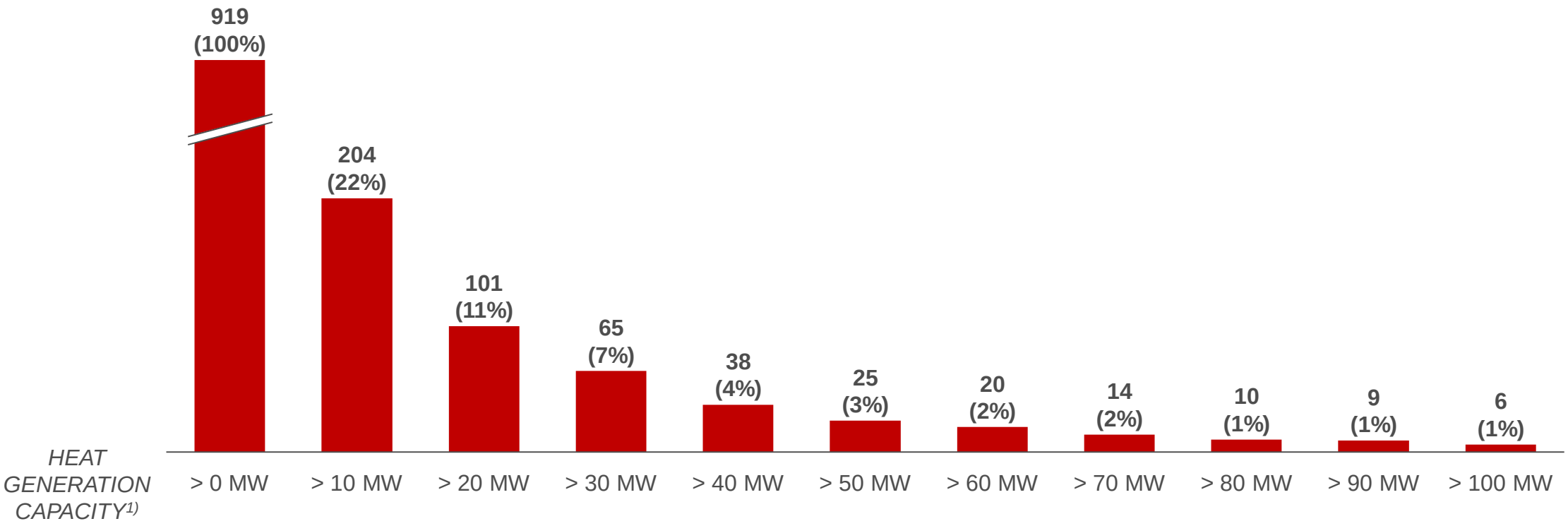
A Replaceable energy sources *(exclusion of energy from waste and geothermal)*

B Critical size *(exclusion of clusters with demand <160GWh/an)*

E-CUBE Strategy Consultants analysis on behalf of SFEN

There are only a limited number of « large » district heating networks in France (~20 with heat generation capacity >= 60 MW_{th})

NUMBER OF DISTRICT HEATING NETWORKS BY HEAT GENERATION POWER IN 2022

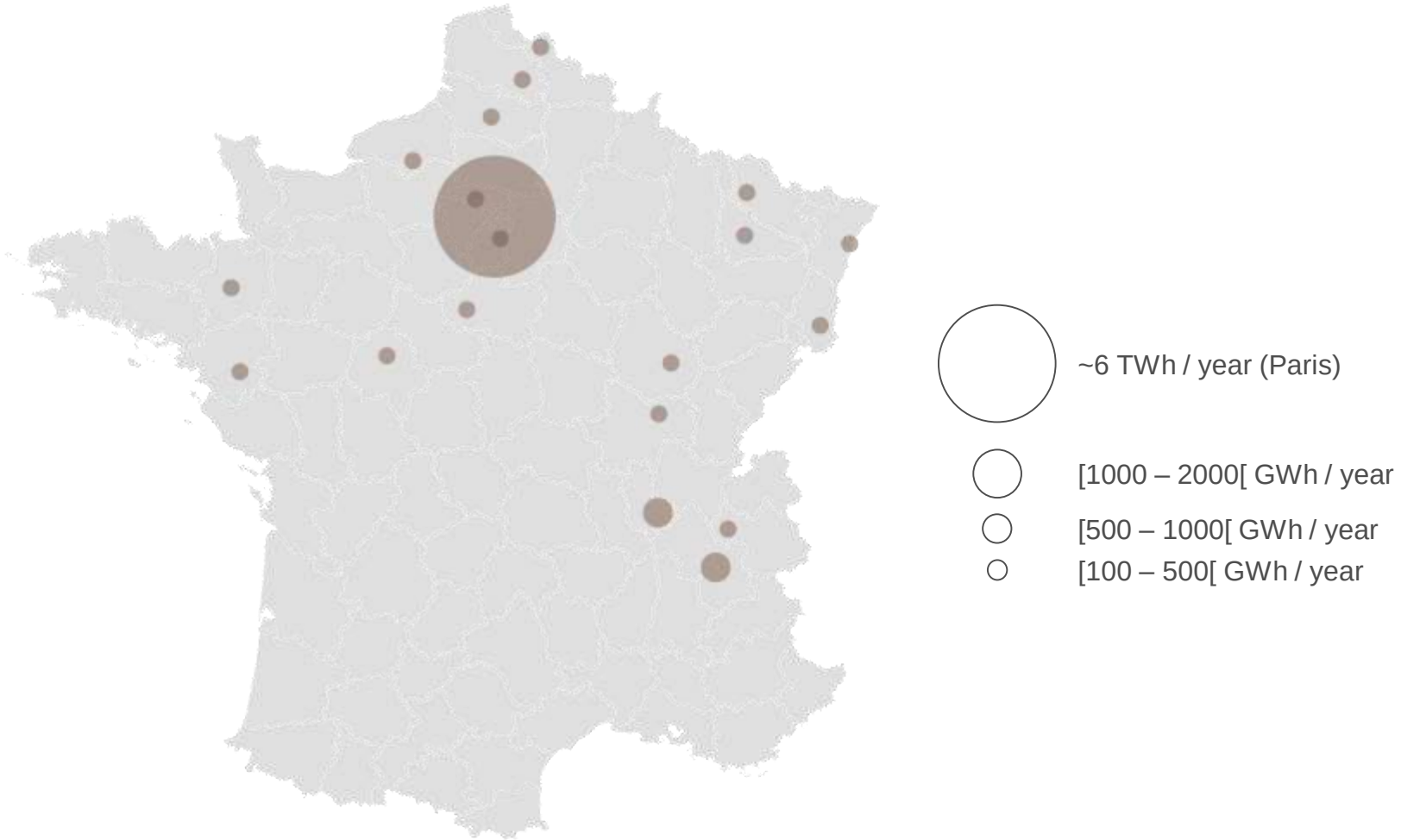


1) Heat generatino power is estimated based on heat consumption per year, assuming 40% load factor

E-CUBE Strategy Consultants analysis on behalf of SFEN

The market for district heating in existing networks that is technically addressable for SMR/AMR in France (combination of all SMR/AMR technologies) is comprised of about 20 clusters that amount to ~12 TWh_{th}

CLUSTERS OF EXISTING DISTRICT HEATING NETWORKS THAT ARE TECHNICALLY ADDRESSABLE BY SMR/AMR [2022]



E-CUBE Strategy Consultants analysis on behalf of SFEN

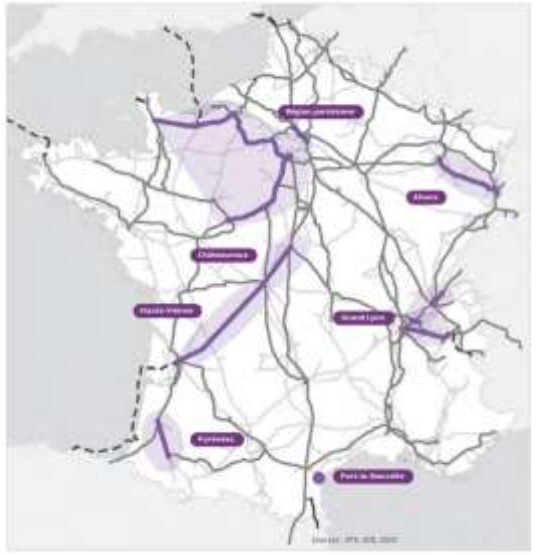
In RTE's N3 scenario, SMR/AMR produce 27 TWh_e of electricity by 2050[1] : they could notably address growing demand from large consumers

- In RTE's N3 scenario, **SMR/AMR produce 27 TWh_e of electricity by 2050,** which could correspond to ~4 GW_e of installed electricity generation capacity[1]
- **Electricity-generating SMR/AMR can generate electricity:**
  - Either to **complement the national electricity mix** by injecting electricity into the national grid
  - Or to **supply locations or areas with specific needs**: self-generation, network constraints due to an increase in electricity consumption
- In particular, by 2035 building and SMR/AMR may be considered as an **alternative or a complement to electricity supply** when network reinforcement is necessary to set up a large load: in most cases, SMR/AMR could **lower the need to build up the electricity network, without entirely substituting it**

Areas where the national grid needs to be built up to accommodate additional industrial or data centre load, according to RTE's ten-year network development plan

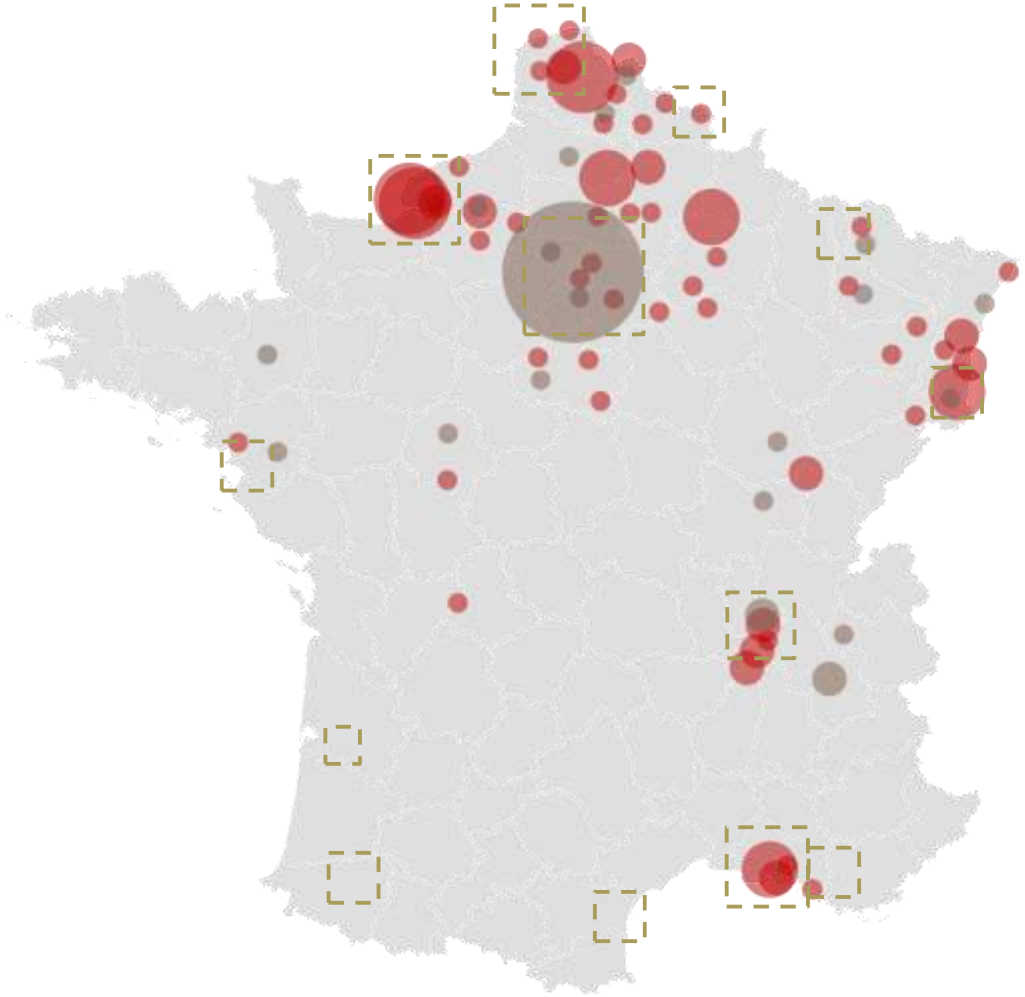
Priority 1 and Priority 2

Priority 3



1) 27 TWh_e of electricity correspond to ~4 GW_e of electricity generation capacity, assuming ~7,000 full load hours
E-CUBE Strategy Consultants analysis on behalf of SFEN

All markets combined, SMR/AMR developments would mostly target large industrial areas and large district heating networks



Heat consumption that SMR/AMR can technically address

- ~6 TWh / year (Paris district heating network)
- ≥ 2000 GWh / year
- [1000 – 2000[GWh / year
- [500 – 1000[GWh / year
- [100 – 500[GWh / year
- District heating
- Industry

Areas with high potential for electricity load growth

- Main industrial and data centre clusters with high expected growth in electricity demand by 2040

E-CUBE Strategy Consultants analysis on behalf of SFEN


E-CUBE
STRATEGY
CONSULTANTS