ARENDALSUKA 2022

Heat: the forgotten word in renewable energy

LDES
LONG DURATION ENERGY STORAGE COUNCIL

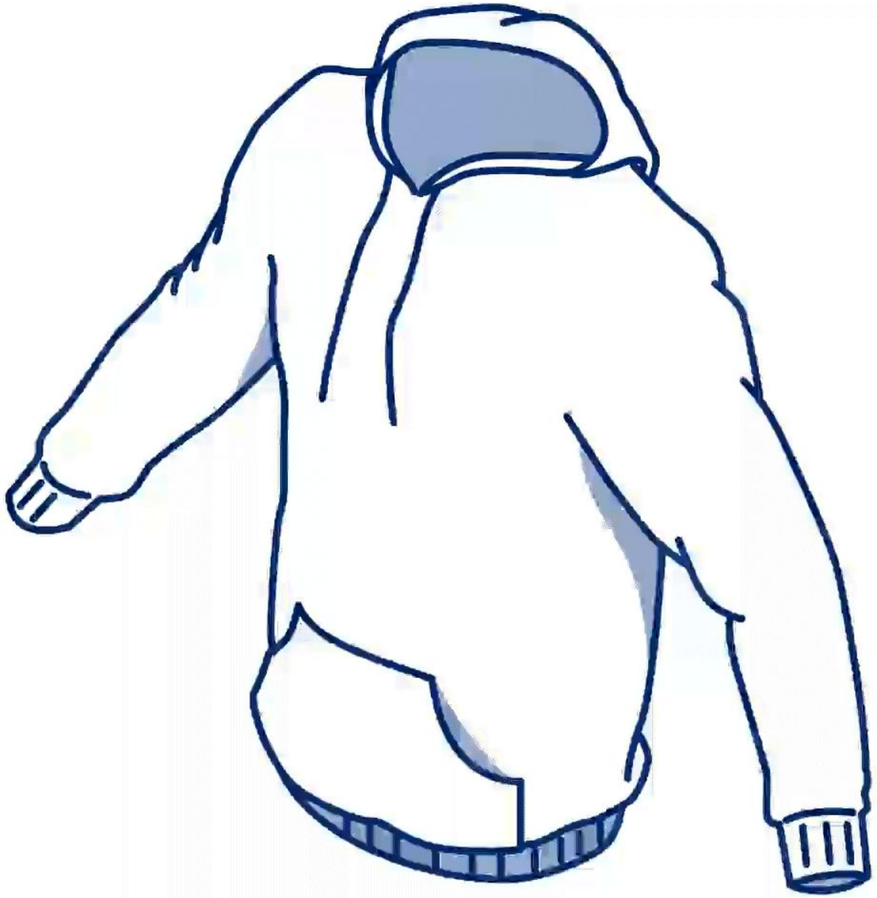
KYOTO

Lars Myhren Holand

Moderator

THE PROBLEM:

Humans need heat for almost everything.

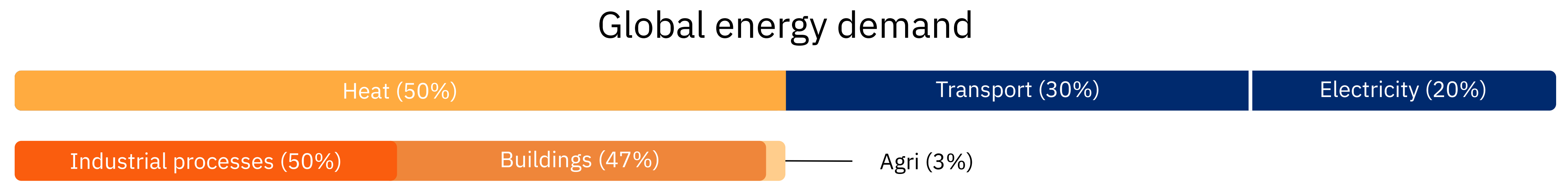


KYOTO

Camilla Nilsson

CEO at Kyoto Group

Heat accounts for half of global energy consumption



Global energy demand

Heat (50%)

Transport (30%)

Electricity (20%)

Industrial processes (50%)

Buildings (47%)

Agri (3%)

89%

of heat produced by fossil and non-renewable fuel sources make up

40%

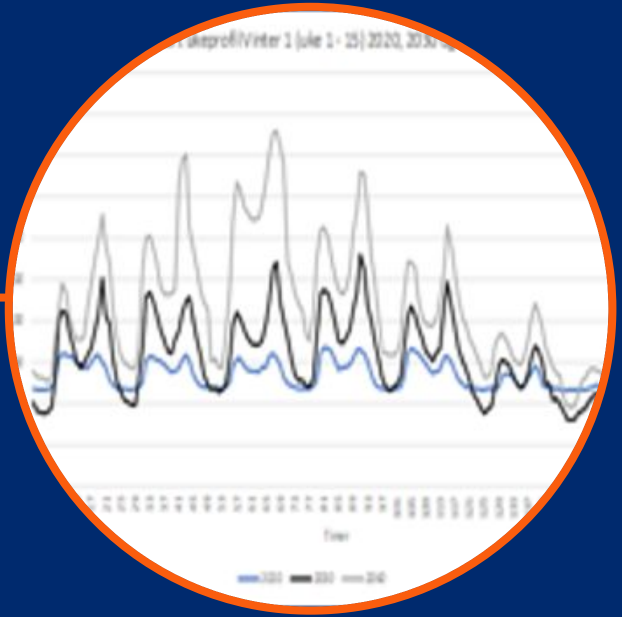
of global CO_2 emissions

https://iea.org/reports/renewables-2020/renewable-heat

The resulting challenge: increasing price volatility

CO_2 is cooking the planet

Electrification through renewables



The challenge: increasing volatility

The Heatcube

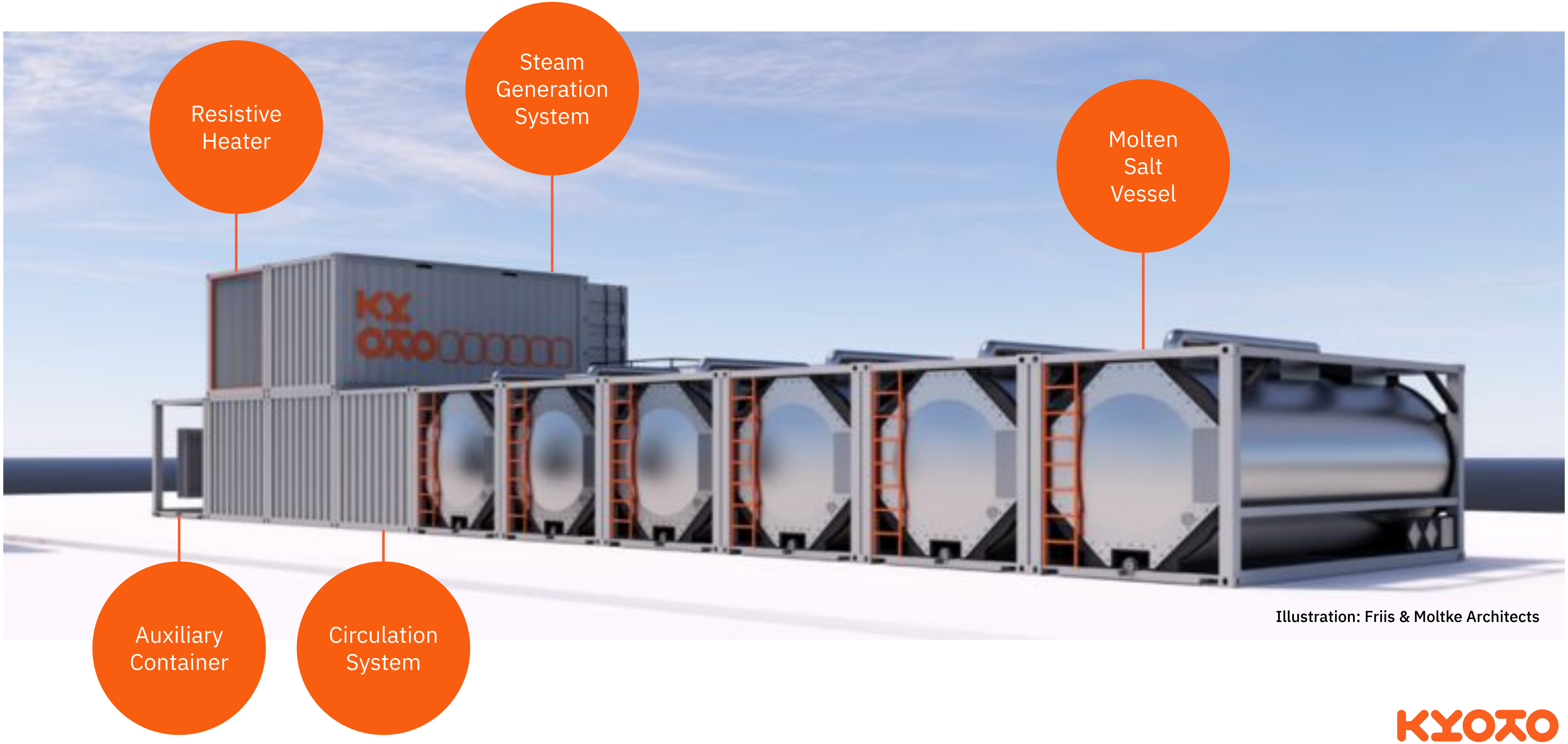


Illustration: Friis & Moltke Architects

What is the size of the market for electrified industrial heat globally?

An electrified system that can deliver heat up to 500°C can serve c. 45% of all industrial heat demand

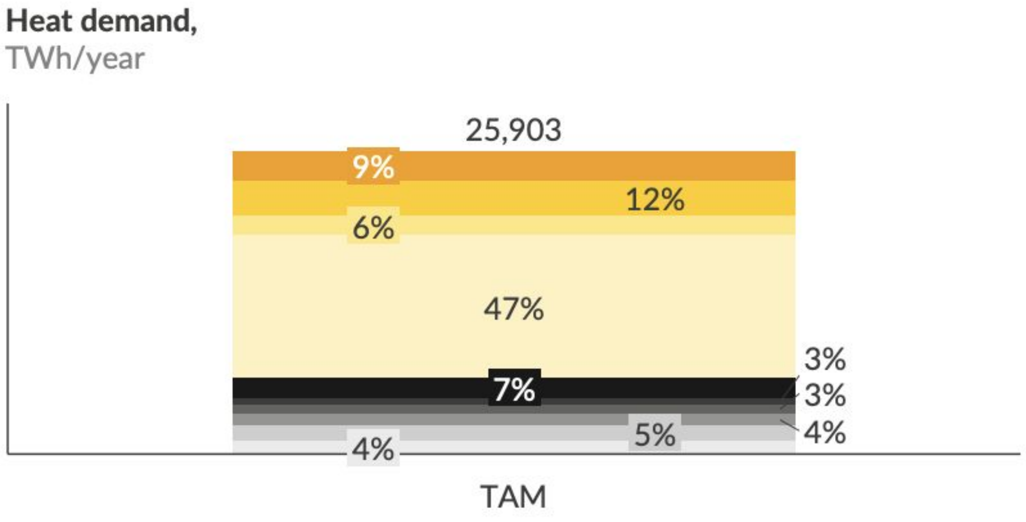
AURORA

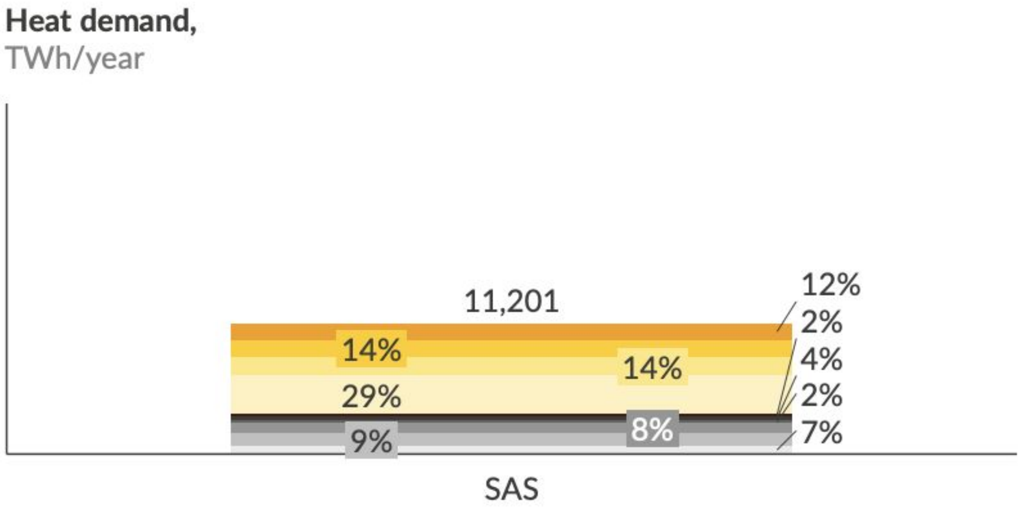
Total addressable heat market (TAM)

TAM =
Global heat demand ⊖ heat demand outside industry

Serviceable addressable segments (SAS)

SAS =
TAM ⊖ Heat demand outside relevant temperature range ⊖ existing low-carbon heat ⊕ heat demand for pre-heating





■ Chemical and petrochemical
■ Construction
■ Food and tobacco
■ Iron and steel
■ Machinery
■ Non-ferrous metals
■ Non-metallic minerals
■ Paper, pulp and print
■ Textile and leather
■ Not elsewhere specified

Source: Aurora Energy Research

Cumulative investment to electrify industrial heat using Heatcube is c.€1tn, with iron and steel representing about 29% of the total

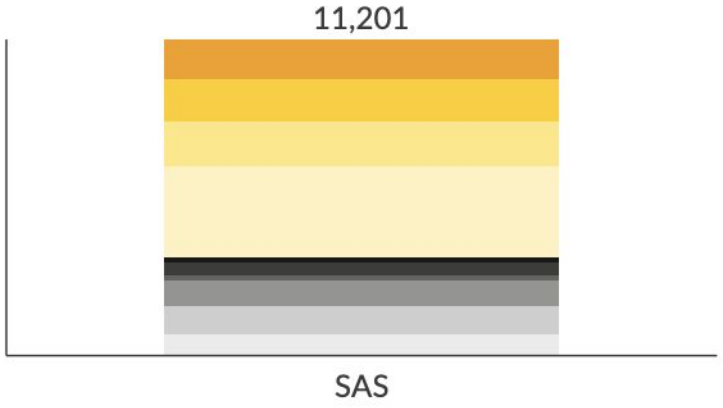
AURORA

Technology Assumptions

Unit capacity	12 MW charge; 5 MW discharge
Storage capacity	60 MWh
=> Annual heat output	**21.9 GWh**

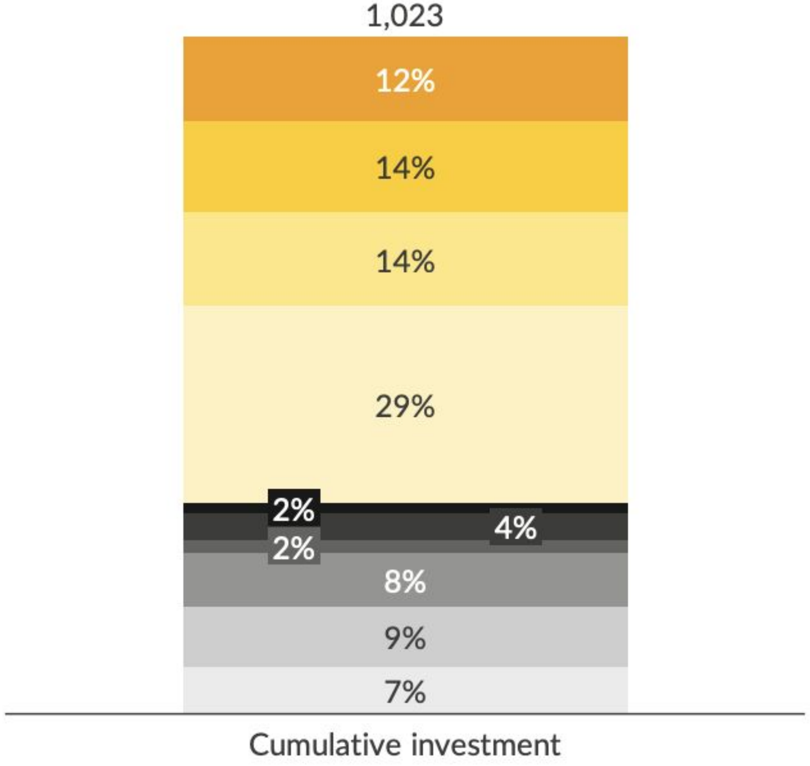
Global heat demand

TWh/year



Cumulative investment to electrify SAS

bn EUR

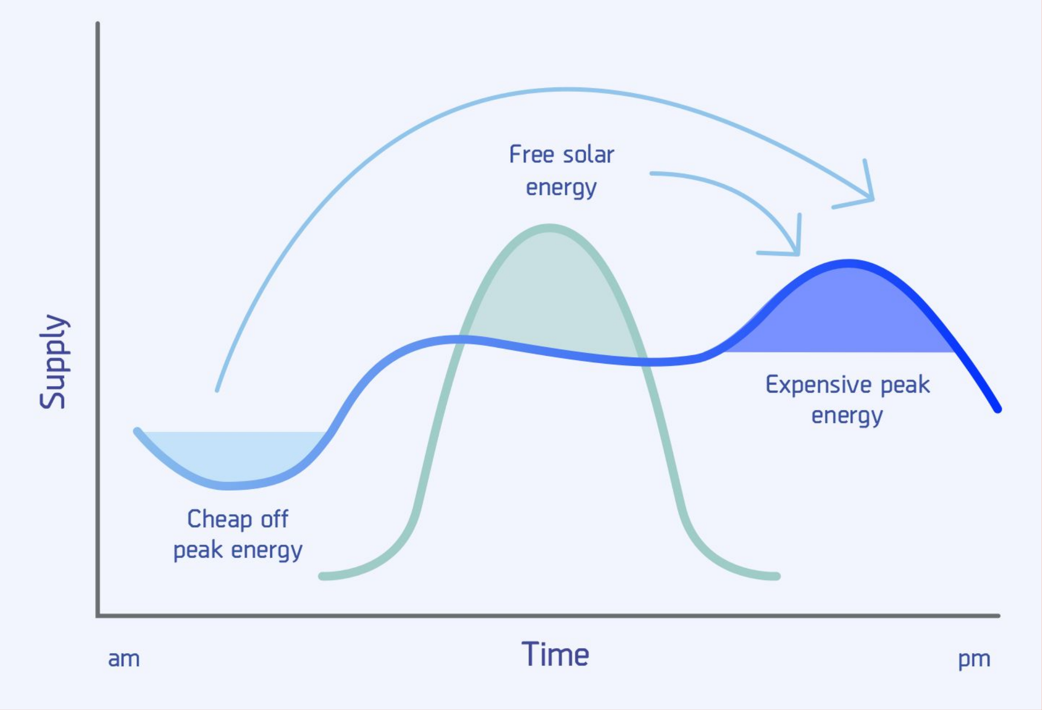


Comments

- We assume that Heatcube is cycled once per day – leading to a total of 21.9 GWh of heat output per 60 MWh unit
- CAPEX is assumed to be consistent over countries and industry applications
- Cumulative investment represents the market at saturation.

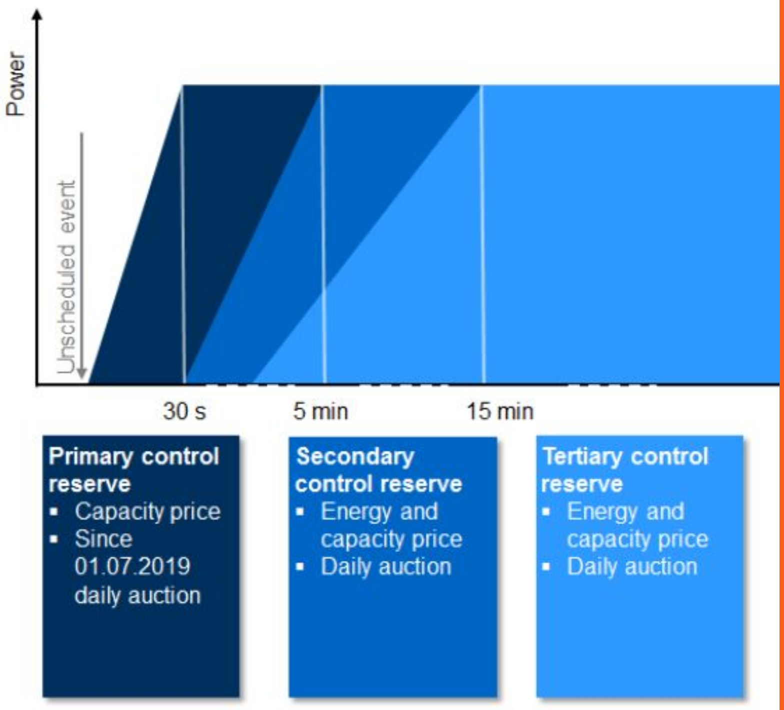
Kyoto's Heatcube enables industrial partners to benefit from off-peak electricity prices and from participating in the reserve market

1 Load Shifting



Load Shifting :
- Charging at cheapest hours
- Moving from gas / oil / coal to electricity

2 Reserve Market



Primary control reserve
- Capacity price
- Since 01.07.2019 daily auction

Secondary control reserve
- Energy and capacity price
- Daily auction

Tertiary control reserve
- Energy and capacity price
- Daily auction

Reserve Market:
- Offer storage to the grid provider and participate in the reserve market

Our Key Message

- Renewable energy needs storage to work.
- Heat is both the largest energy need, and biggest emitter of CO2.
- 2/3 of the industry needs heat, not electricity, so let's give it to them.
- Technology is ready. We must make it easy to choose.

Godart van Gendt

Senior expert at McKinsey & Company

McKinsey is a knowledge partner of the LDES Council, focused on energy system flexibility

LDES startups

Ambri
AZELIO
Breeze
BRENMILLER ENERGY
cellcube
ceres
ECHOGEN power systems
ENERGYDOME
EnergyNest The Thermal Battery company™
ENERGY VAULT
ENERVENUE
ENLIGHTEN
eos
ESS INC
e-zinc
LARGO
Form energy
HEATRIX
Highview Power®
HYDROSTOR
INVINITY ENERGY SYSTEMS
KRAFT BLOCK
KYOTO
MALTA
MAGALDI
Quidnet Energy
MGA THERMAL
PUMPED HYDRO STORAGE
redflow
RheEnergise
Rye Development
1414°
SaltX Technology
Stiesdal
STORWORKS POWER
TORC
VOLTSTORAGE

Anchors

Industry and services customers

COMPASS
EGA
RioTinto
Google
Microsoft
SOUTH32

Capital providers

Breakthrough Energy
Quinbrook Infrastructure Partners

Equipment manufacturers

Baker Hughes
ALFA LAVAL
INNIO
Sumitomo SHI FW
VOITH
SIEMENS energy

Low-carbon energy system integrators & developers

bp
corre energy
greenko
NEOM
Ørsted
Reliance Industries Limited
Shell
TotalEnergies

Membership overview as of July 13 2022

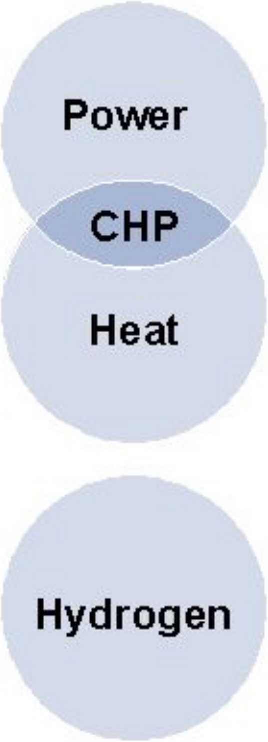
Key principles of the LDES Council

- Executive-led
- Global
- Fact-based
- For societal benefit
- All types of energy storage, not just electrochemical

The LDES Council is an independent body with its own governance structure, with the mission to accelerate energy decarbonization through the scale-up of LDES

A paradigm shift for power, heat and H2 is underway, moving from fossil-based, centralized and controllable to 24/7 renewable energy

From centralized, controlled power loads & local heat



Centralized, large scale generation with extensive T&D

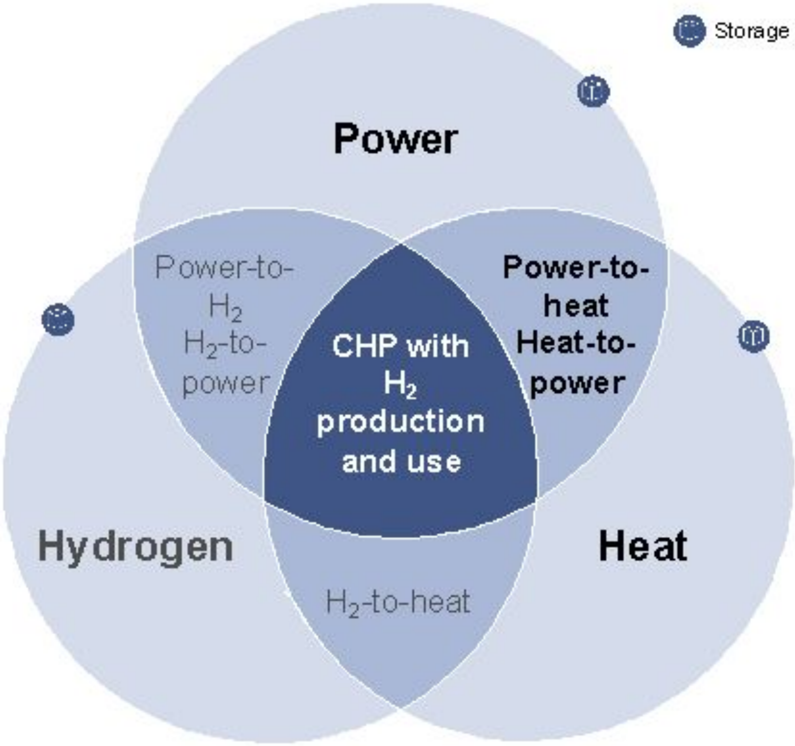
Smaller scale, localized CHP plants

Local-only gas or coal-based heating per boiler or otherwise

Storage as fossil-fuel commodities (e.g., coal pile, fuel depots) provide flexibility and resilience

SMR-based H2 production, for use as molecules in refining & ammonia production

To a distributed & integrated energy system, with variable generation

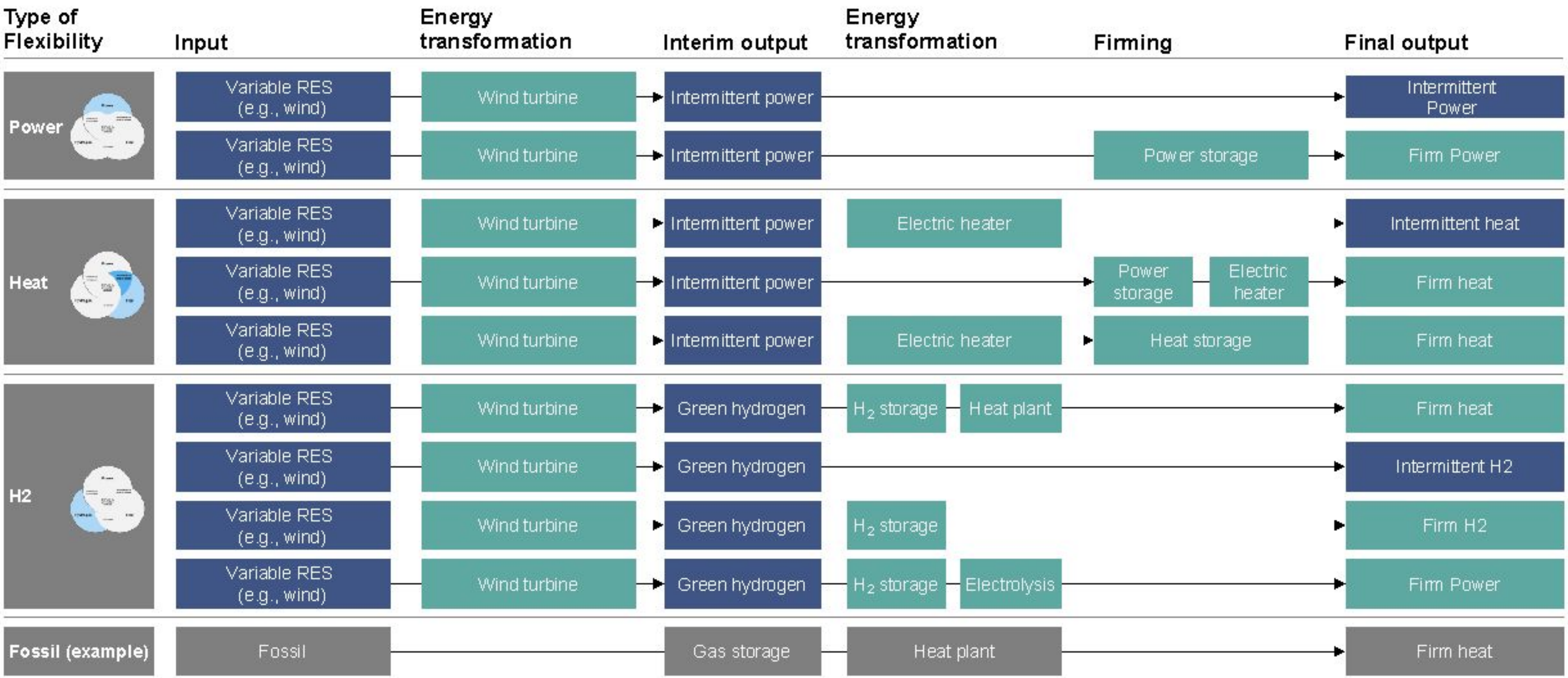


As we continue to electrify our world & build out renewables this integration will continue further

Flexibility to create firm power, heat and hydrogen from renewables

ILLUSTRATIVE **NON-EXHAUSTIVE**

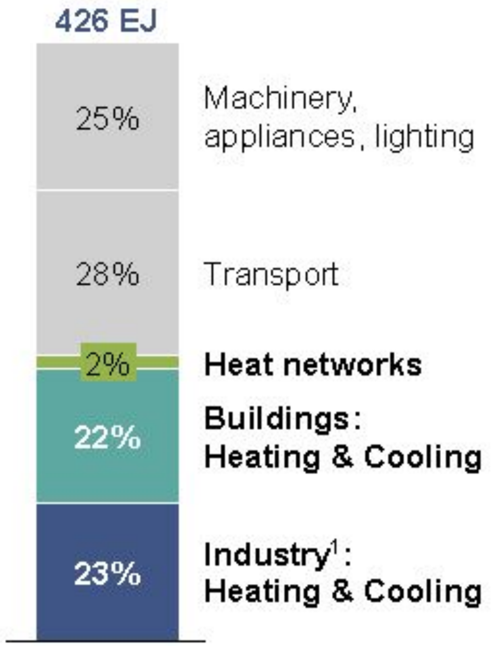
🟦 Intermittent 🟩 Firm



Type of Flexibility	Input	Energy transformation	Interim output	Energy transformation	Firming	Final output
Power	Variable RES (e.g., wind)	Wind turbine	Intermittent power			Intermittent Power
	Variable RES (e.g., wind)	Wind turbine	Intermittent power		Power storage	Firm Power
Heat	Variable RES (e.g., wind)	Wind turbine	Intermittent power	Electric heater		Intermittent heat
	Variable RES (e.g., wind)	Wind turbine	Intermittent power		Power storage Electric heater	Firm heat
	Variable RES (e.g., wind)	Wind turbine	Intermittent power	Electric heater	Heat storage	Firm heat
H2	Variable RES (e.g., wind)	Wind turbine	Green hydrogen	H_2 storage Heat plant		Firm heat
	Variable RES (e.g., wind)	Wind turbine	Green hydrogen			Intermittent H2
	Variable RES (e.g., wind)	Wind turbine	Green hydrogen	H_2 storage		Firm H2
	Variable RES (e.g., wind)	Wind turbine	Green hydrogen	H_2 storage Electrolysis		Firm Power
Fossil (example)	Fossil		Gas storage	Heat plant		Firm heat

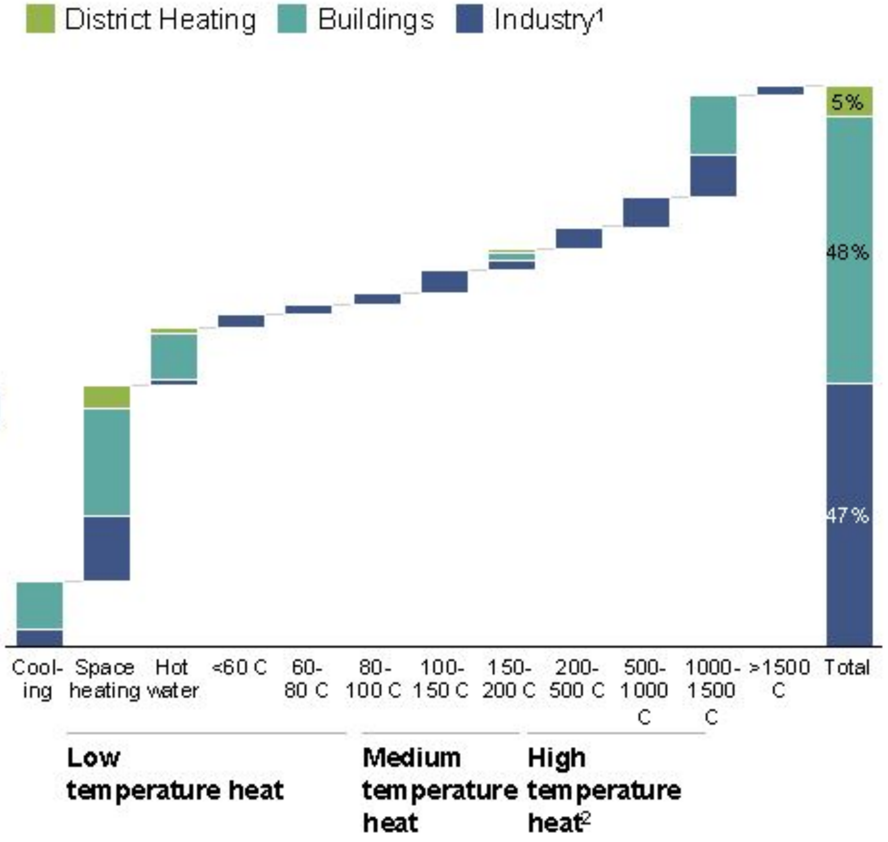
DEEP-DIVE: Heat accounts for ~50% of global energy demand and still relies on fossil fuels for 70% of heat

2019 global fuel consumption, EJ % of total

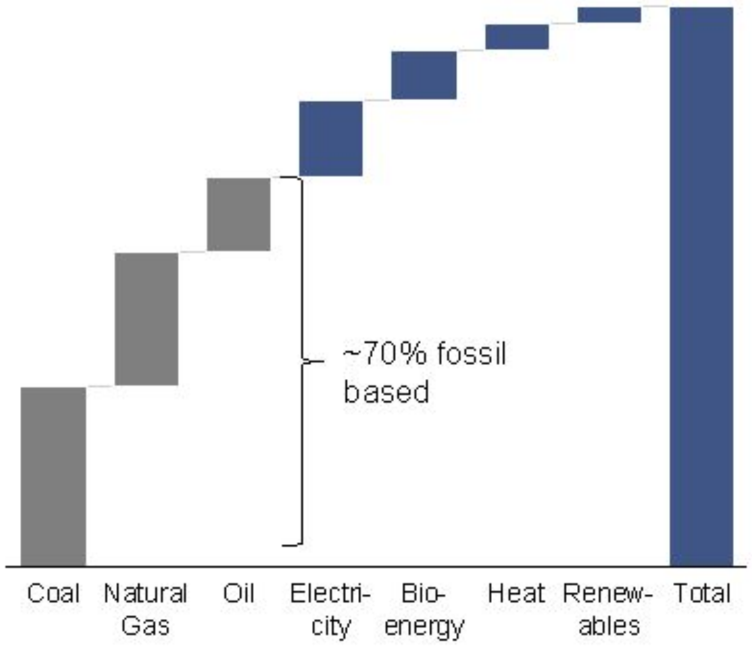


~50% of global fuels is consumed to produce heat

End-use demand by heat grade, %



Global fuel consumption for heating & cooling by fuel source, EJ



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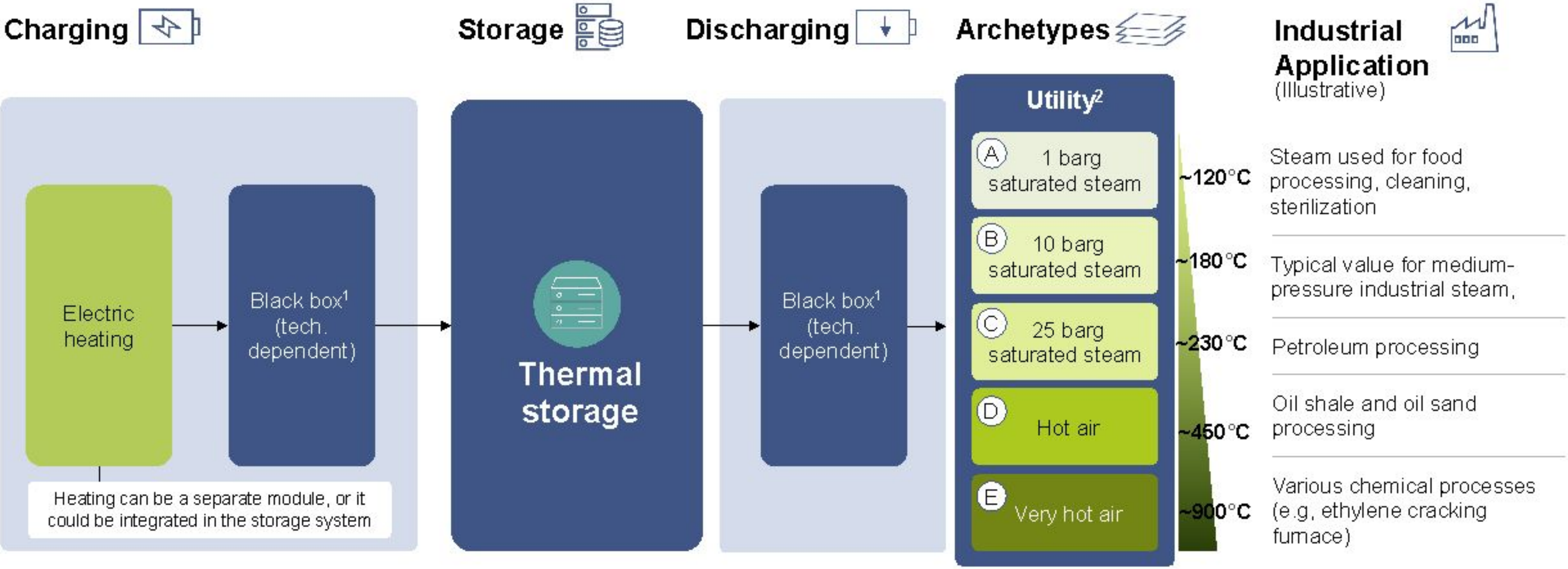
1. Includes Refining
2. High temperature heat in buildings is used for cooking (e.g., Gas flame is ~1000C)

Source: McKinsey Global Energy Perspective

What do we mean with ‘firm heat’ and ‘thermal storage’?

Technological setup defintion for cost data collection



Charging

Electric heating

Black box[1] (tech. dependent)

Heating can be a separate module, or it could be integrated in the storage system

Storage

Thermal storage

Discharging

Black box[1] (tech. dependent)

Archetypes

Utility[2]

Ⓐ	1 barg saturated steam	~120°C	Steam used for food processing, cleaning, sterilization
Ⓑ	10 barg saturated steam	~180°C	Typical value for medium-pressure industrial steam,
Ⓒ	25 barg saturated steam	~230°C	Petroleum processing
Ⓓ	Hot air	~450°C	Oil shale and oil sand processing
Ⓔ	Very hot air	~900°C	Various chemical processes (e.g, ethylene cracking furnace)

Industrial Application
(Illustrative)

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1. Technology provider-dependent pathway of charging or discharging. Required for like-for-like comparison of costs
2. Five types of specific outputs should cover majority of industrial heat demand use cases making benchmark relevant for all industry players

There are numerous thermal energy storage (TES) technologies

TECHNOLOGY LANDSCAPE

Category	Subcategories	Examples	Example players
Sensible heat storage (SHS) Thermal energy storage via temperature change of material	**Solids**	▯ Ceramics, sand, silica, rocks ▯ Concrete ▯ Metals and carbon-based materials	ALUMINA ENERGY SIEMENS energy MAGALDI KRAFT BLOCK EnergyNest ECHOGEN power systems MALTA
	Liquids	▯ Water (water tank TES) ▯ Molten salts, metals (e.g., aluminum), or inorganic materials (e.g., silicon)	MALTA KYOTO
Latent heat storage (LHS) Thermal energy storage through phase change materials (PCM)	**Solid-liquid**	▯ Organic (paraffin wax, fatty acids) ▯ Inorganic (salts, metals) ▯ Composite	AZELIO TORC SUNAMP
	Liquid-gas	▯ Liquid air energy storage	
	Solid-solid (change in crystalline structure or encapsulated micro-particles)	▯ Salt hydrates ▯ Micro-encapsulated materials (e.g., paraffins, metals) or macro-encapsulated materials	MGA THERMAL
Thermochemical storage (TCS) Use of reversible chemical reactions to store thermal energy	**Thermochemical**	▯ Metal carbonites & oxides ▯ Zeolites (e.g., hydrated alkalis) ▯ Absorption systems	SaltX

234 GWh

of thermal storage used in 2019[1]

<1%

of global storage in 2019 was thermal storage[1]

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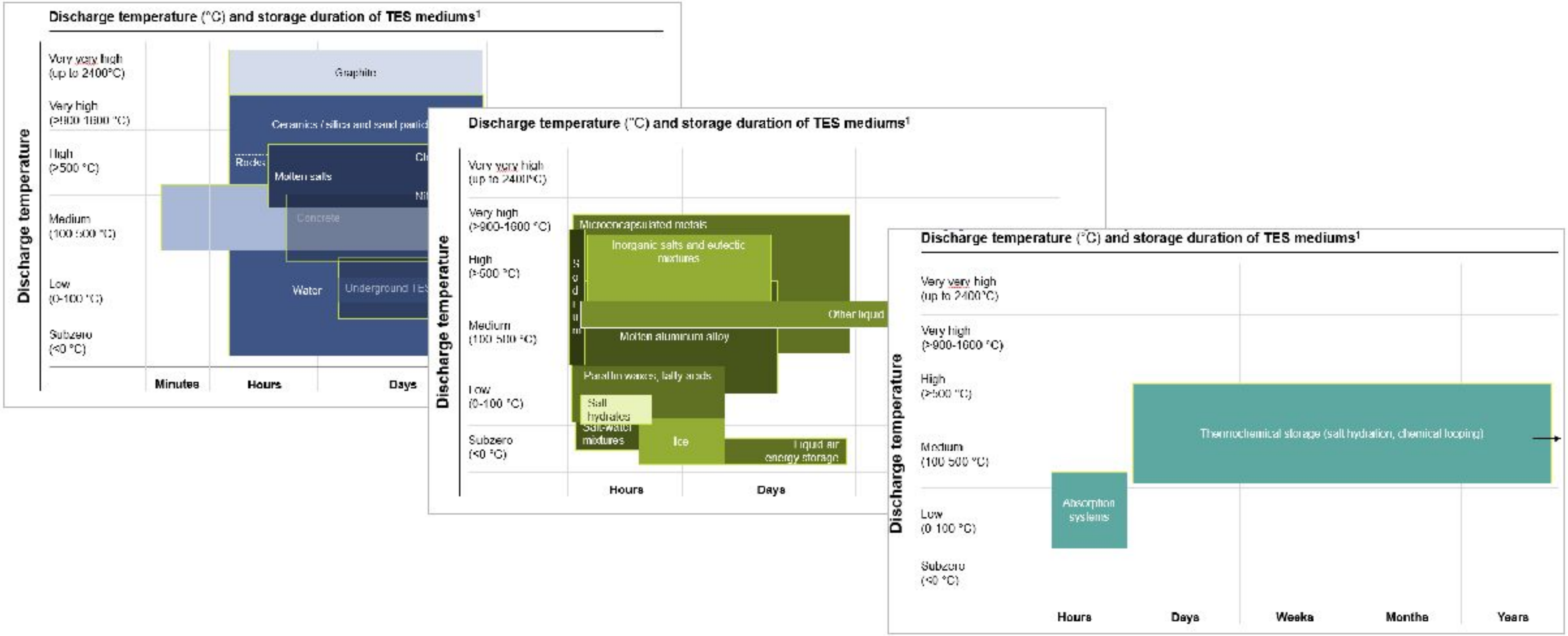
1. IEA data (assuming 3.3 GW of storage in 2019 was used 100% of the time for 29,908 GWh in 2019)

Source: IEA, press search, Council members

Thermal storage solutions can already provide temperatures of >1,000°C and store heat for multiple years, depending on the solution

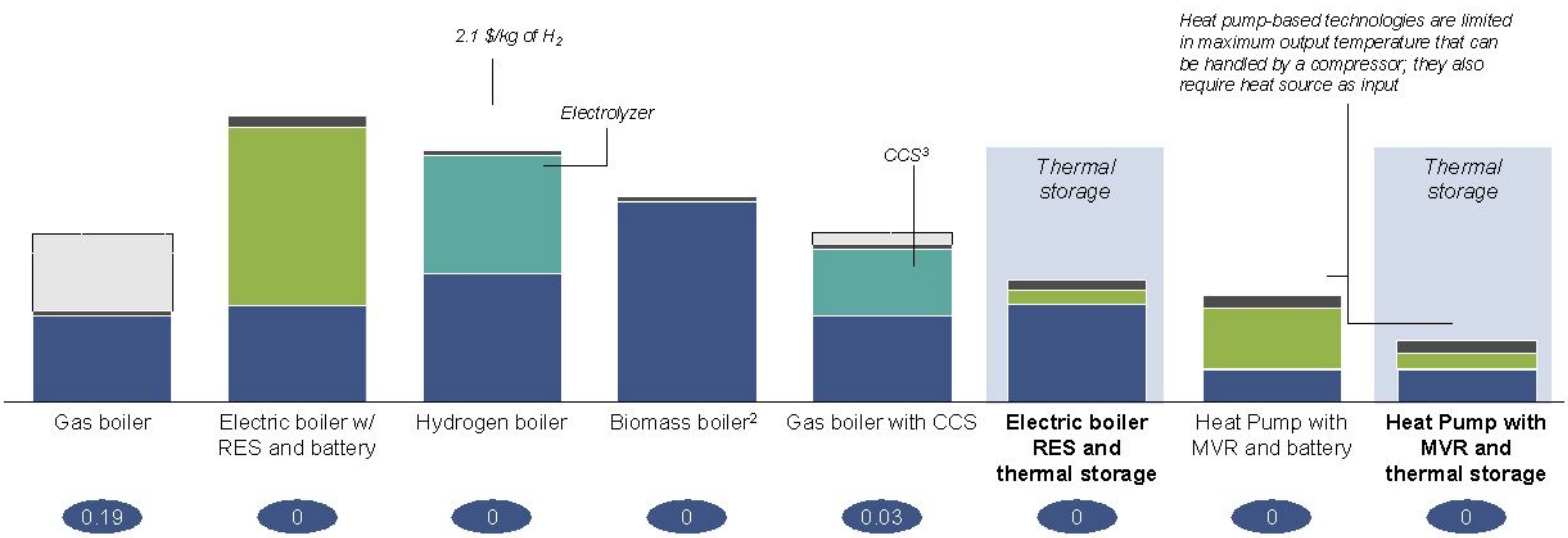
🟦 SHS 🟩 LHS 🟩 Thermochemical



Source: Council members

Thermal storage can be cost-competitive with fossil heat when including carbon tax or at low electricity costs

Levelized cost of heat for selected technologies[1], $/MWh



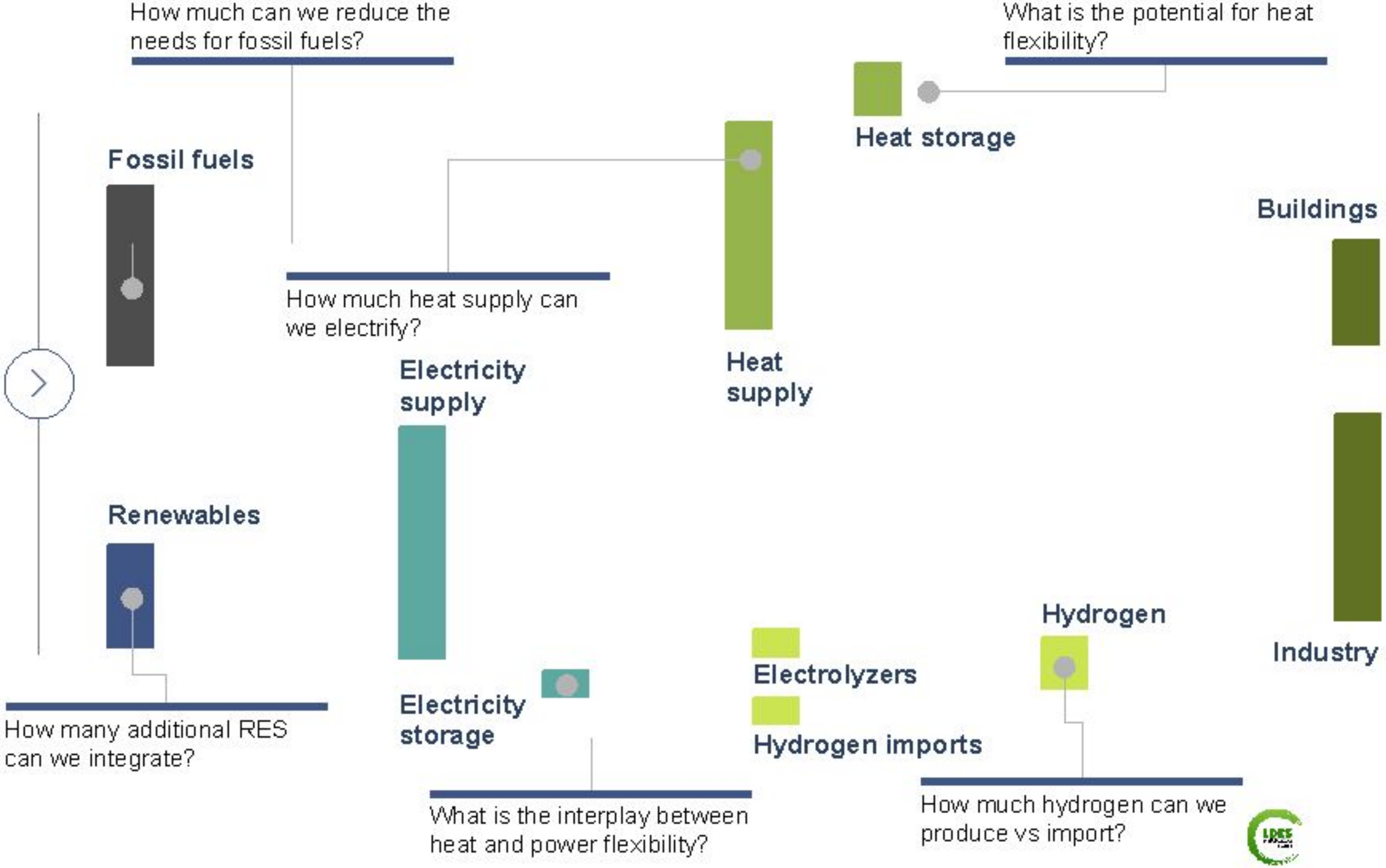
1. Steam production
2. Biofuels cost vary regionally and can have a very broad range
3. CCS @ 108 USD / tCO2

Source: Net Zero Heat storage business case calculation, LDES Council Net Zero Heat storage industry benchmark 2022

Integrated energy system modelling includes all forms of flexibility

The integrated LDES pathway model can co-optimize the supply of the main energy commodities such as electricity, heat and hydrogen

By running multiple scenarios with different assumptions, such modelling can help in understanding the interlinked dynamics between energy flexibility and supply, as well as related costs and savings



How much can we reduce the needs for fossil fuels?

What is the potential for heat flexibility?

How much heat supply can we electrify?

How many additional RES can we integrate?

What is the interplay between heat and power flexibility?

How much hydrogen can we produce vs import?

Source: LDES Pathway modeling