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06/06/2022

Thomas Griffiths - PhD Student

Part 1: *The commercialisation of fusion for the energy market: A review of socio-economic studies*

Institute of Physics - *Progress in Energy*

Technical Meeting on Synergies in Technology Development between Nuclear Fission and Fusion for Energy Production - *Economic and market considerations on nuclear fusion power plants*.

Co-authors: Thomas Griffiths, Dr Michael Bluck, Dr Richard Pearson, Prof. Shutaro Takeda.

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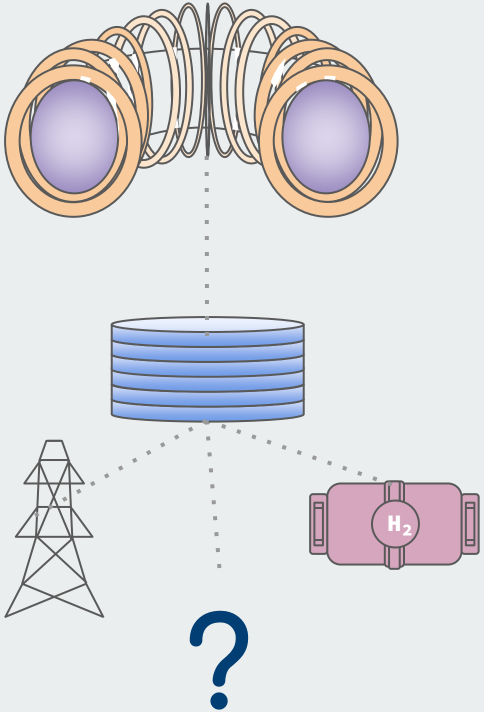
Introduction

PhD title: "The optimum role of fusion in carbon free future energy systems"

In other words - what will fusion be used for?



What will fusion be used for?

International Energy Agency (IEA) World Energy Outlook:

"*The social and economic benefits of accelerating clean energy transitions are huge, and the costs of inaction are immense.*" **- Fatih Birol, IEA Executive Director.**

Introduction

~~What will fusion be used for?~~

- **On commercialisation: What *should* we use fusion for (when it's ready)?**
- "*The social and economic benefits of accelerating clean energy transitions are huge, and the costs of inaction are immense.*"
    - **What are the socioeconomics of fusion**? - *Socioeconomics is the social science that studies how economic activity affects and is shaped by social processes*.

Introduction

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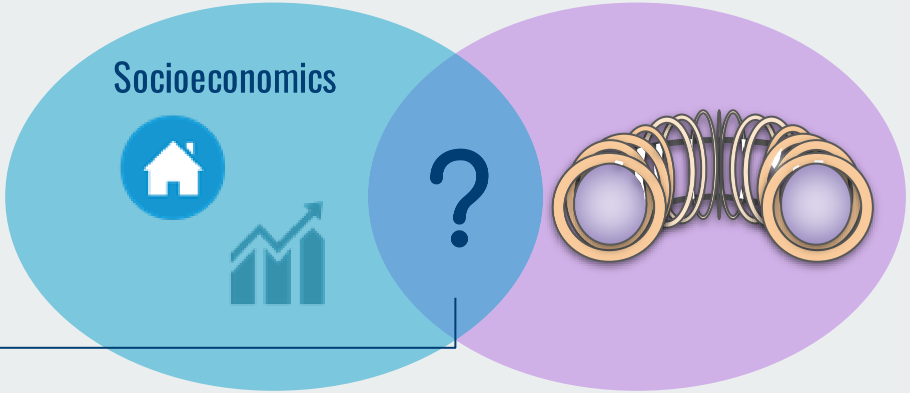
1. Role/Market - **What/where**
2. Cost - **How** much
3. Externalities - **Why**
4. Timescales - **When**



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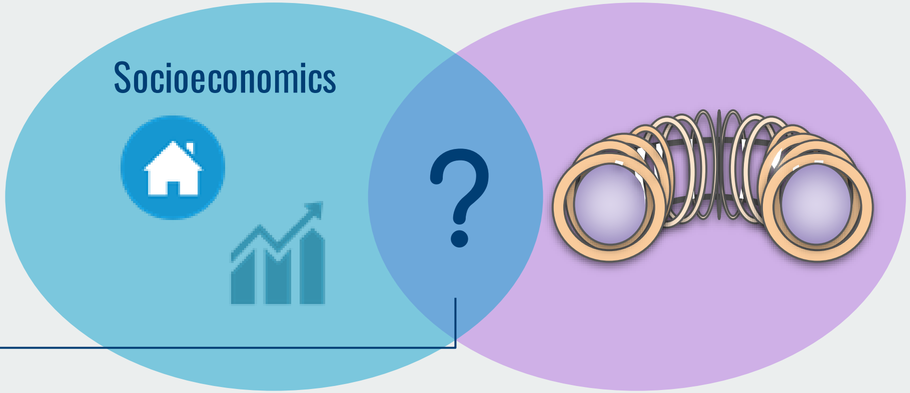

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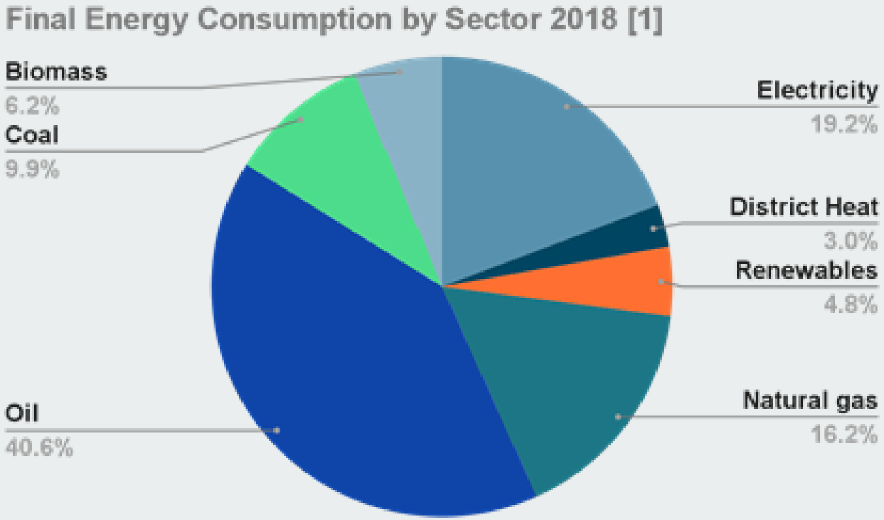
1. **The Role of fusion** - When commercialised, **what** form does it take? **Where** does it fit into the future energy system?

2018: Electricity made up **20%** of the World's energy demand, rising to 25% by 2040 [1].



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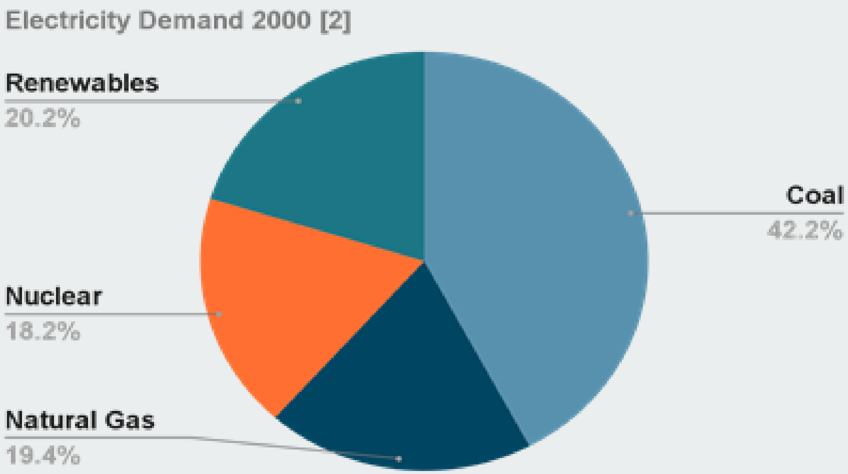
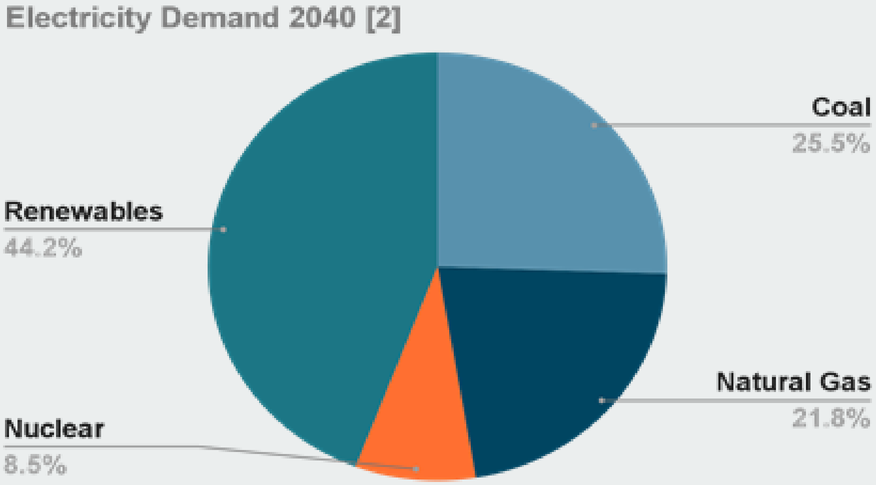
1. **The Role of fusion** - When commercialised, **<u>what</u>** form does it take? **<u>Where</u>** does it fit into the future energy system?

2040: Electricity market likely to be saturated with low-carbon technologies [2]





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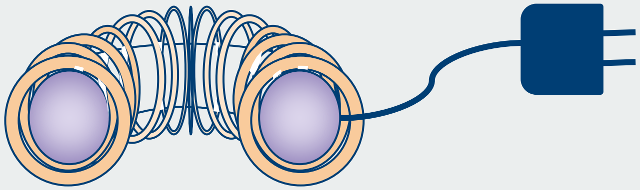
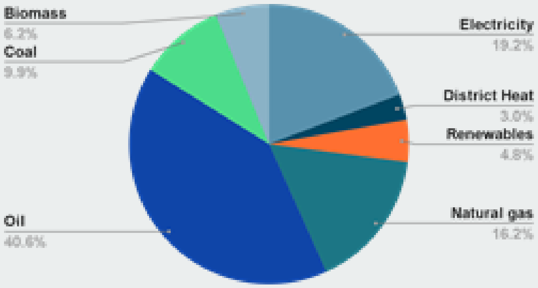
1. **The Role of fusion** - When commercialised, **<u>what</u>** form does it take? **<u>Where</u>** does it fit into the future energy system?

<u>Electricity</u> - 3 main findings:

A. When there are **no** climate change drivers**,** fusion is **not** an emergent technology
B. Fusion obtains a market share when climate change drivers are **in place**, with the inclusion of carbon taxes.
C. Cost has the **biggest** impact on fusion's emergence





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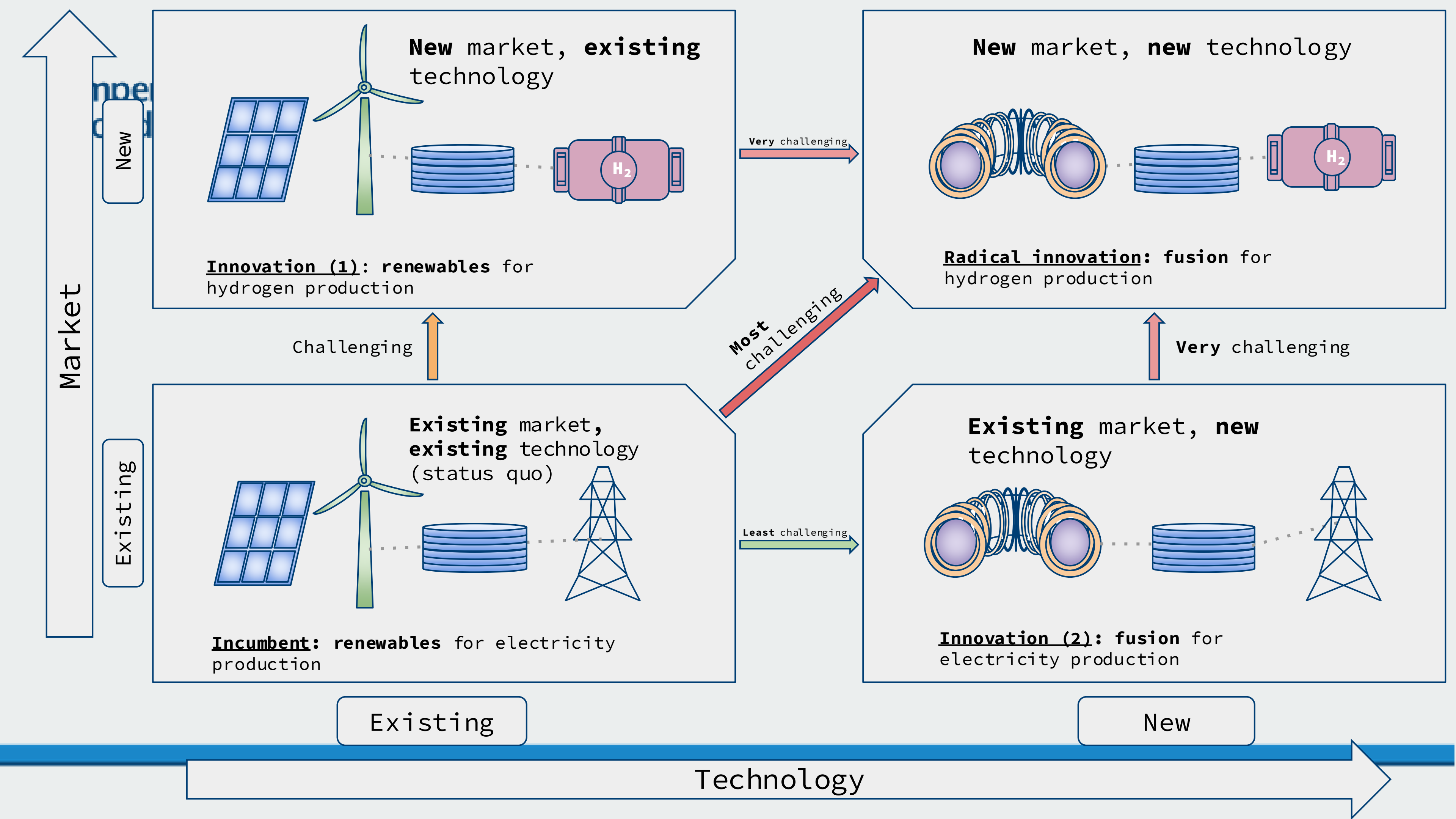
1. **The Role of fusion** - When commercialised, **what** form does it take? **Where** does it fit into the future energy system?

➔ If the electricity market is provided for, what non-electric applications could there be for fusion energy?
➔ Are these applications cost competitive (part 2)?
➔ Fusion energy is not likely to be used initially to establish a new sector, and is more likely to break into an existing one.
➔ What do I mean by this?

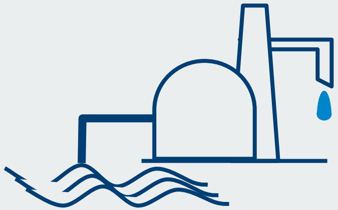


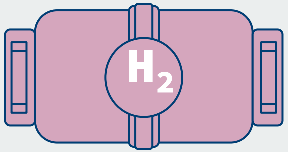
Market
New
Existing
New market, existing technology
Innovation (1): renewables for hydrogen production
Very challenging
New market, new technology
Radical innovation: fusion for hydrogen production
Challenging
Most challenging
Very challenging
Existing market, existing technology (status quo)
Incumbent: renewables for electricity production
Least challenging
Existing market, new technology
Innovation (2): fusion for electricity production
Existing
New
Technology

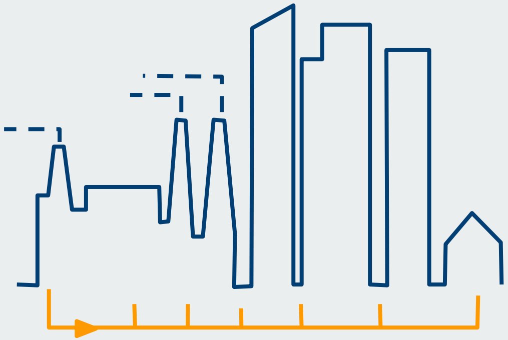
1. **The Role of fusion** - When commercialised, **<u>what</u>** form does it take? **<u>Where</u>** does it fit into the future energy system?

Other applications for fusion:

- ➔ Medical processes
- ➔ Transmutation of long lived radioisotopes in spent fuel
- ➔ Space propulsion
- ➔ Low temperature
    - ◆ Desalination
    - ◆ District heating
- ➔ High temperature
    - ◆ Hydrogen
    - ◆ Process heat







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Other applications for fusion:

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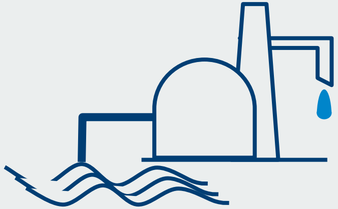

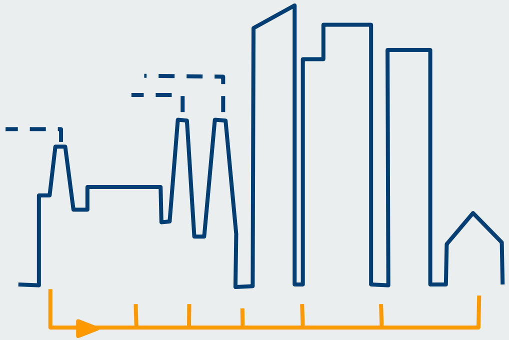

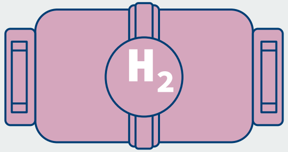

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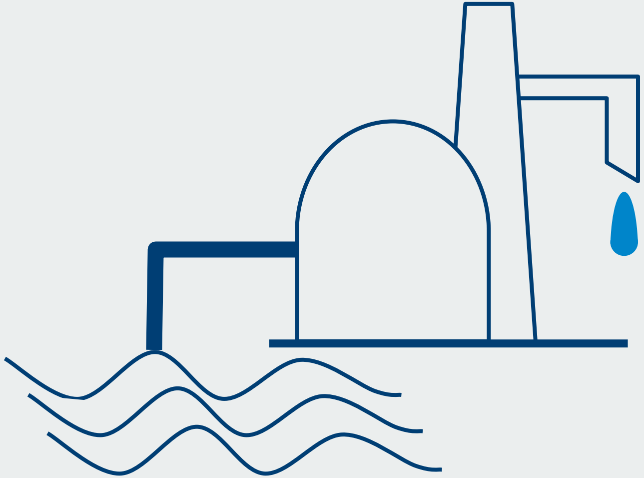
1. **The Role of fusion** - When commercialised, **what** form does it take? **Where** does it fit into the future energy system?

Low temperature: **Desalination**



- ➔ World Energy Outlook: water sectors electricity consumption will increase **80%** by 2040. **20%** of this will come from desalination related demand [4].
- ➔ Estimated usage of facilities in **150 countries** and **300m people** [4].
- ➔ Possible to co-generate with electricity in SMRs during off peak periods when using reverse osmosis, electro dialysis, and membrane distillation.
- ➔ IAEA: **96** fission SMR-desalination projects in operation by **2030** [5].
- ➔ Thermal processes include multistage flash, multiple effect distillation [6].
- ➔ It may be possible to obtain **lithium from seawater** for fuel use in fusion plants.

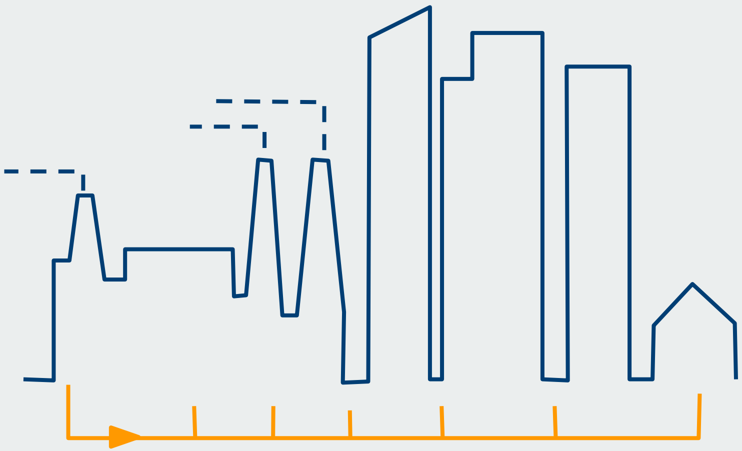
1. **The Role of fusion** - When commercialised, **what** form does it take? **Where** does it fit into the future energy system?

Low temperature: **District Heating**

- IEA: World energy consumption from heating homes, buildings and domestic water is 15% [7].
- 17% of UK carbon emissions from domestic heating [8].

Core characteristics of nuclear fission district heating systems [9, 10, 11]:

→ Size
→ Distance
→ Reliability
→ Load factors
→ Temperature



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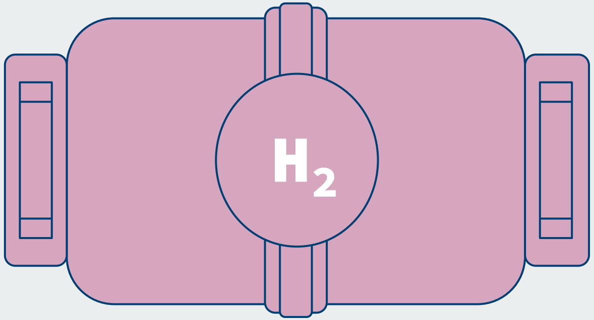
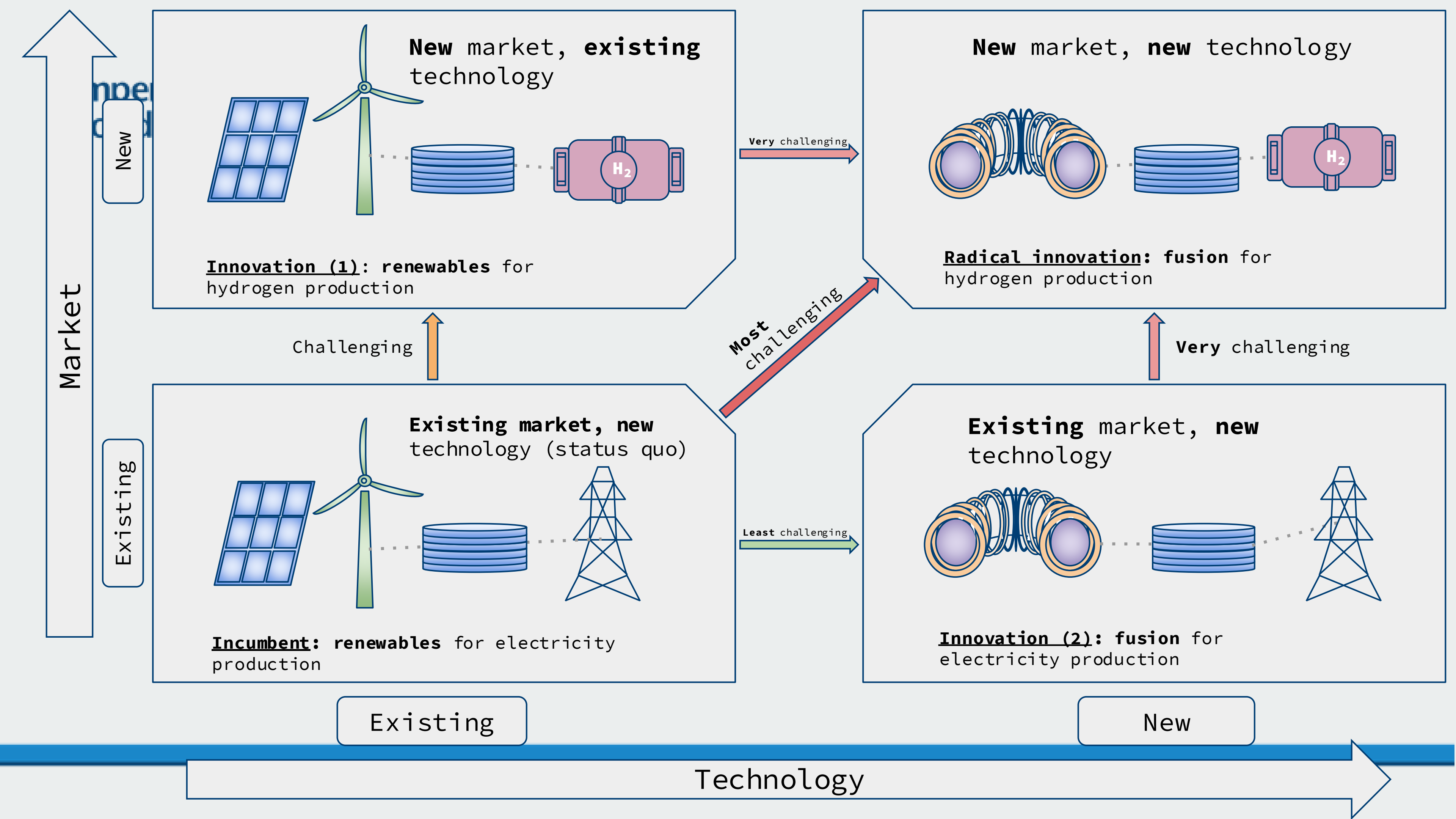
1. **The Role of fusion** - When commercialised, **<u>what</u>** form does it take? **<u>Where</u>** does it fit into the future energy system?

High temperature: **Hydrogen**

Challenges [12, 13, 14, 15]:

➔ Energy carrier, not a primary fuel.
➔ Battery technology improvements.
➔ Energy storage per unit volume < fossil fuels.
➔ Suffers from leakage.
➔ Requires high pressure storage.

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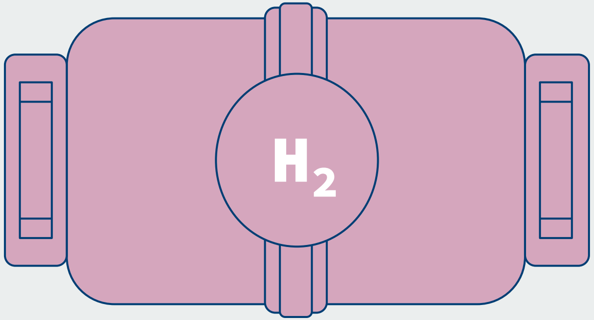
1. **The Role of fusion** - When commercialised, **what** form does it take? **Where** does it fit into the future energy system?

High temperature: **Hydrogen**

- ➔ **Water electrolysis**
- ➔ **Steam electrolysis (600-1000°C)**
- ➔ **Thermochemical processes (600-900°C) -** sulphur iodine cycle
- ➔ **Reformation of fossil fuels (700-1100°C) -** *blue* hydrogen



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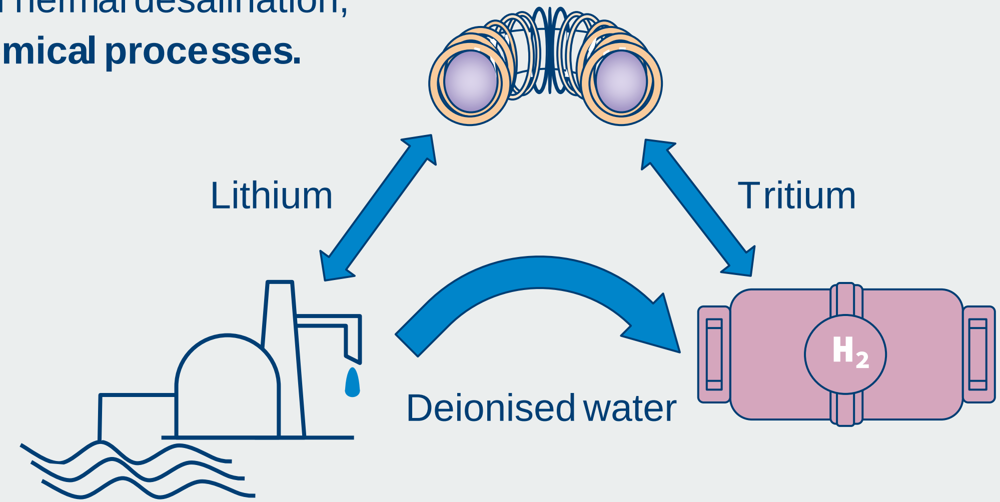
Three-way cogeneration: Thermal desalination, **hydrogen via thermochemical processes.**



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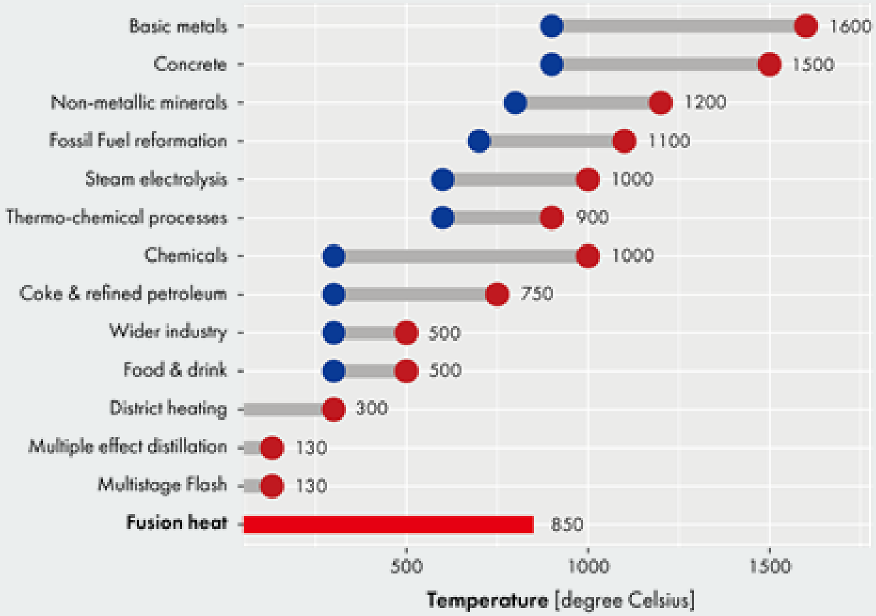
1. **The Role of fusion** - When commercialised, **what** form does it take? **Where** does it fit into the future energy system?

High temperature: **Process heat**

- ➔ IEA: **Industrial sector** responsible for **37%** of total final energy use in 2018, accounting for **24%** of emissions - 8.6GtCO_2 [17].
- ➔ To meet Sustainable Development Scenario, industrial sector needs to decarbonise to **7.4GtCO_2** [17].
- ➔ EU: >400°C heat accounts for 26% of demand [18].
- ➔ UK emissions: heating sectors account for 14% [19].



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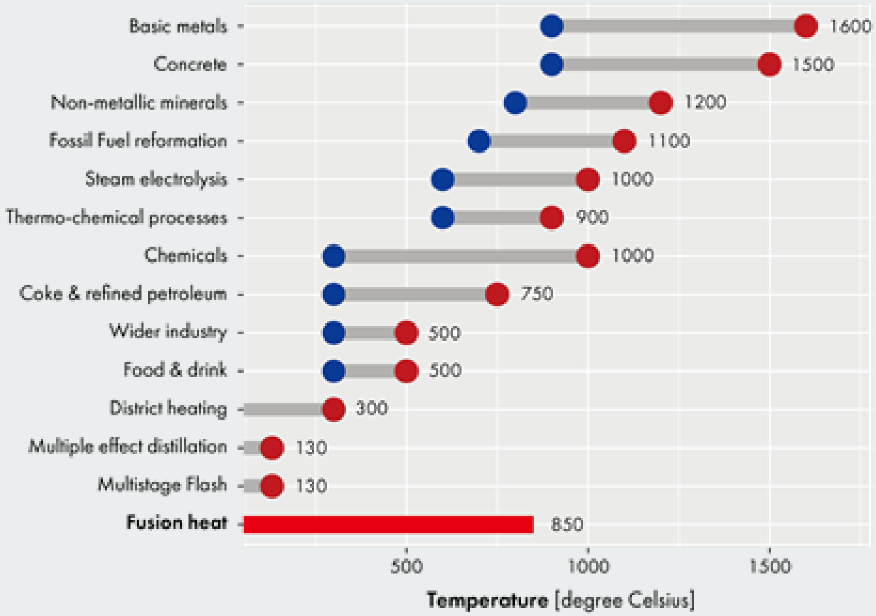
1. **The Role of fusion** - When commercialised, **what** form does it take? **Where** does it fit into the future energy system?

High temperature: **Process heat**

➔ Cement industry: **5-6%** of total anthropogenic CO_2, **4%** of warming [20]

➔ UK: **50%** of total process heat consumption from food and drink, iron and steel, transport fuels, and other process industries [8].



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Part 1 finished - Short break and questions

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Part 2: *The commercialisation of fusion for the energy market: A review of socio-economic studies*

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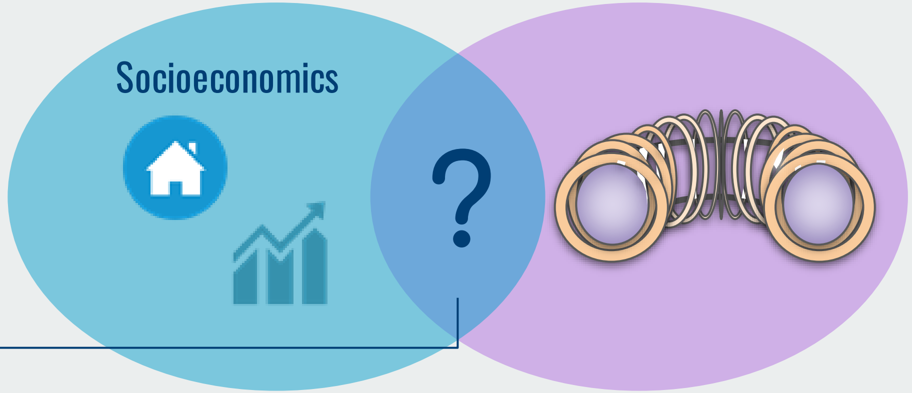
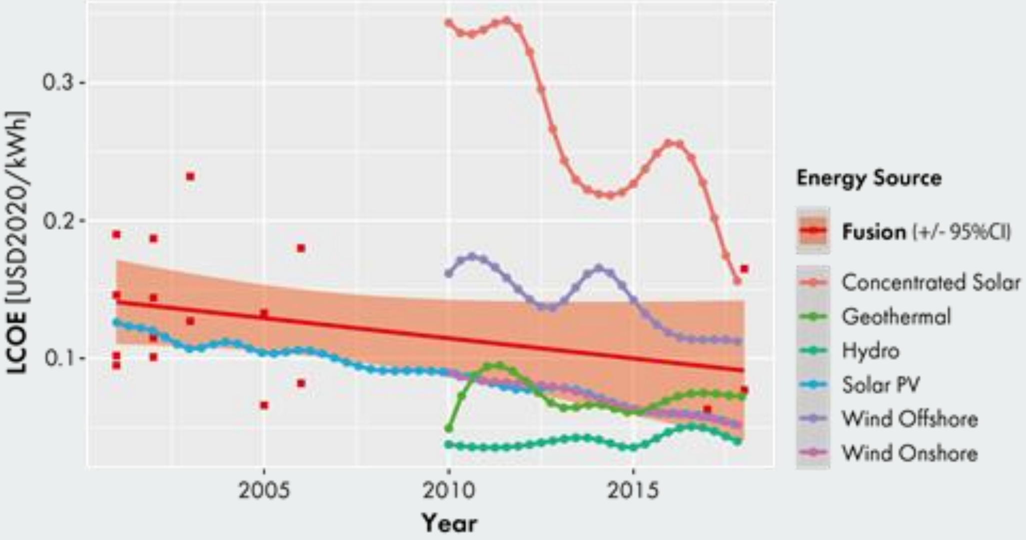


2. **Cost of fusion**: compared to other technologies, how much will fusion cost?

- An illustration of the apparent decline in the estimated cost of fusion electricity in the last two decades.
- This is not to be confused decline with the learning factor after FOAK.
- There are **many** uncertainties contained within costing calculations.



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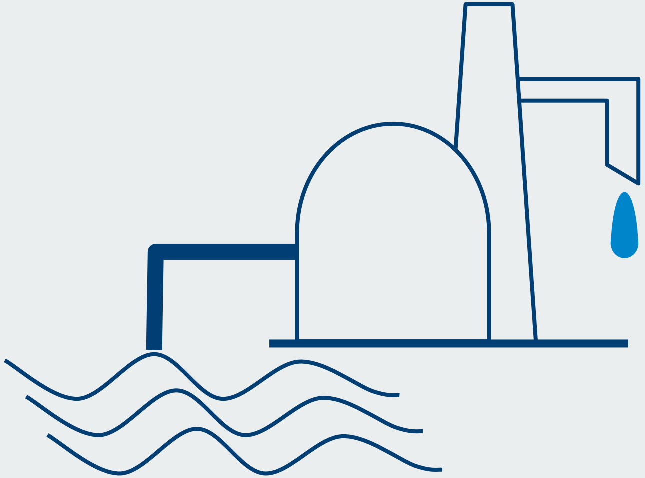
Low temperature applications: **Desalination**

➔ 2021 market valued at **US$14.5 billion**, growing to US$35.5 billion [21].

➔ Cost depends on:
  - degree of salinity;
  - desalination method;
  - energy source for desalination;
  - capacity of the plant [22].



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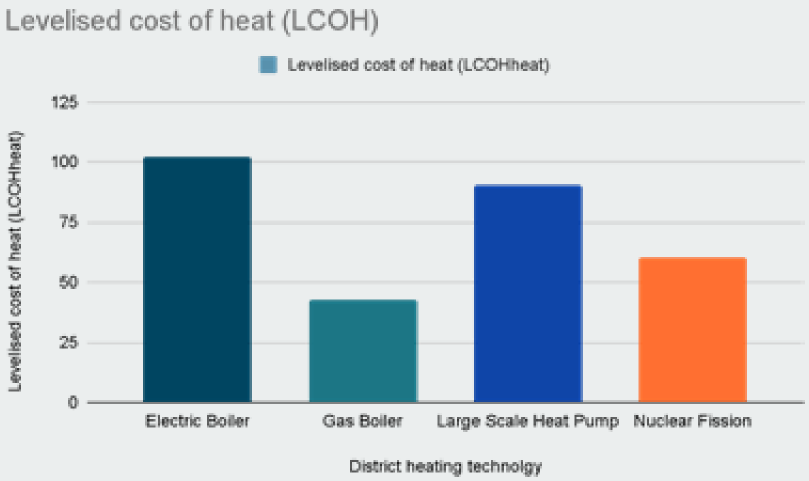
Low temperature applications: **District heating**

- ➔ No fusion studies to date.
- ➔ Levelised cost of heat (LCOHheat) was **60.3US$/MWh$_{th}$** for a Nuclear district heating system [23]:
  - ◆ Electric boiler: **102.45US$/MWh$_{th}$**;
  - ◆ large scale heat pumps **90.40US$/MWh$_{th}$**;
  - ◆ gas boilers **42.95US$/MWh$_{th}$**[23].



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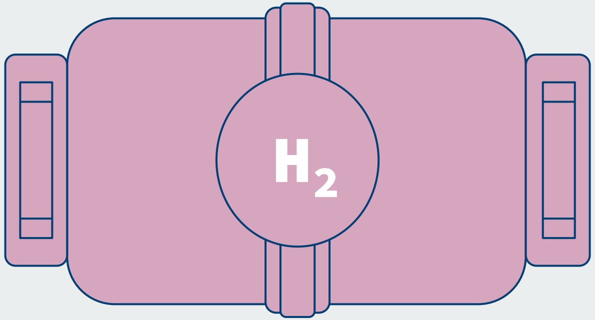
High temperature applications: **Hydrogen**

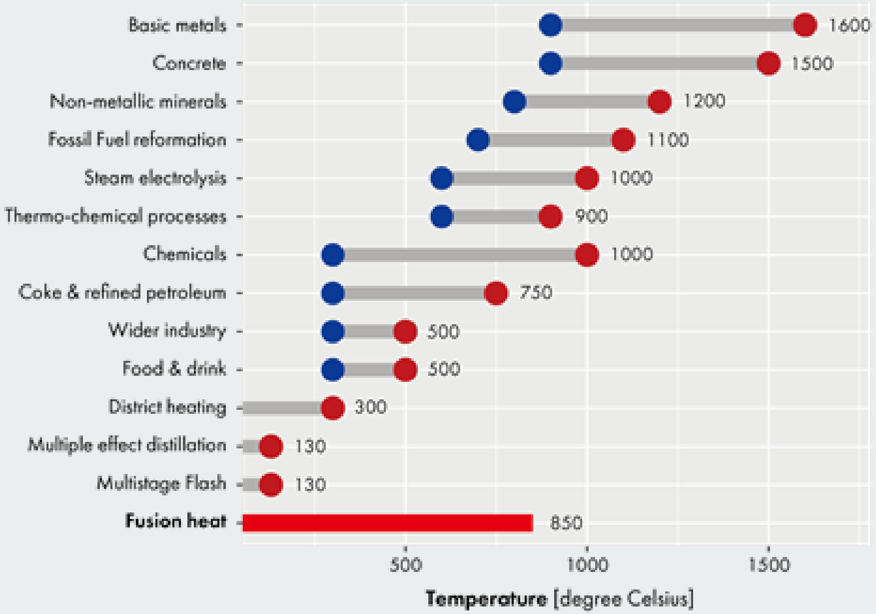
- ➔ Bloomberg: $150bn needed to implement hydrogen economy by 2030 [24].
- ➔ The IAEA's Hydrogen Economic Evaluation Program (HEEP) software estimates hydrogen production costs 1.58 - 3.66$/kg (£0.04 to £0.09/kWh) using nuclear fission energy in four nuclear reactor/hydrogen concepts [25].



2. **Cost of fusion**: compared to other technologies, how much will fusion cost?

High temperature applications: **Process heat**

- ➔ No fusion costing studies to date.
- ➔ Fission: PWR with 35% efficiency produces electricity at 78–120$/MWh will harbour a thermal energy cost of **7.42–11.42$/GJ** (natural gas 3.5-8$/GJ) [26].
- ➔ Nuclear heat costing US$3.00/kg for steel making increases the cost of production by **12.8%** [27].



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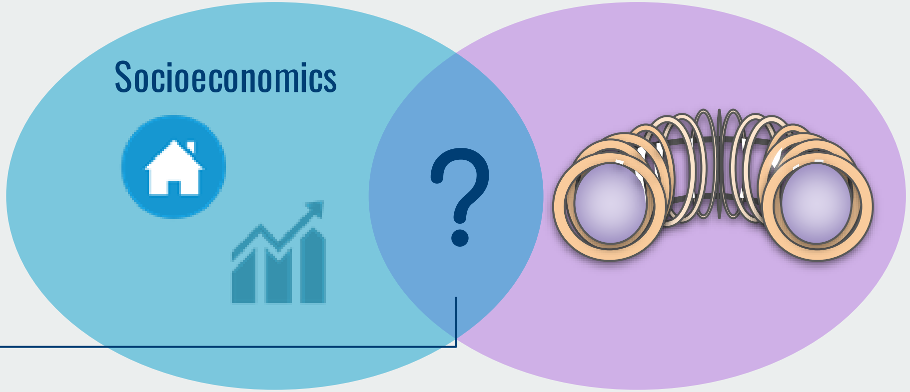

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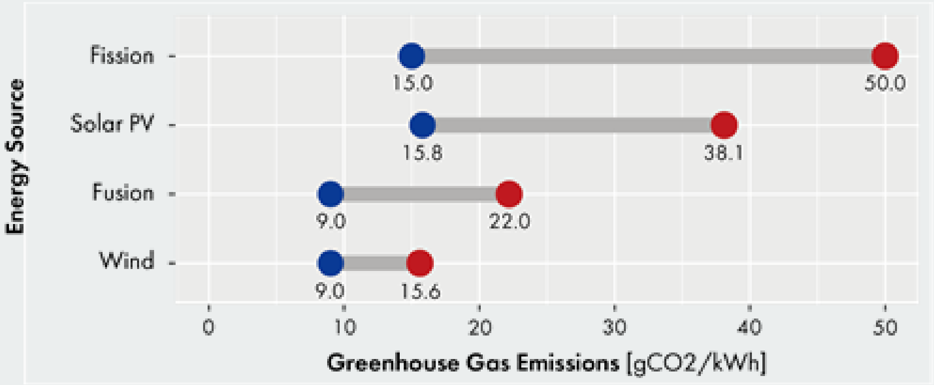
3. **The externalities of fusion -** Why do it.

Topic areas for attention:

- ➔ Sustainability
- ➔ Carbon footprint
- ➔ Job creation
- ➔ Regional benefits
- ➔ GDP: 183,000 FTE jobs, equating to 133.6 FTE/MW (Banacloche 2021) [28].



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3. **The externalities of fusion -** Why do it.

External review of fusion: Carayannis et al [29] categorise defined as

- ➔ Geo-economic,
- ➔ Geopolitical,
- ➔ Geo-sociocultural,
- ➔ Geo-technological

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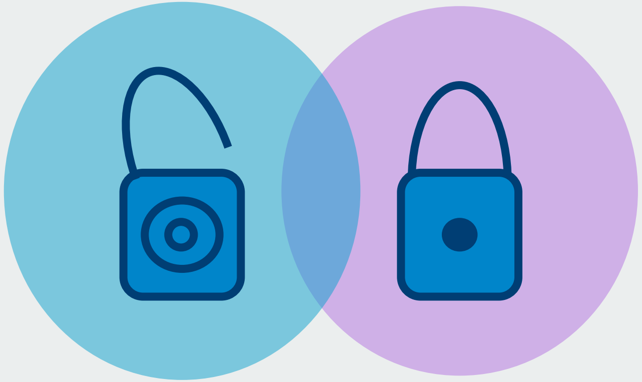
3. **The externalities of fusion -** Why do it.

Public vs Private?



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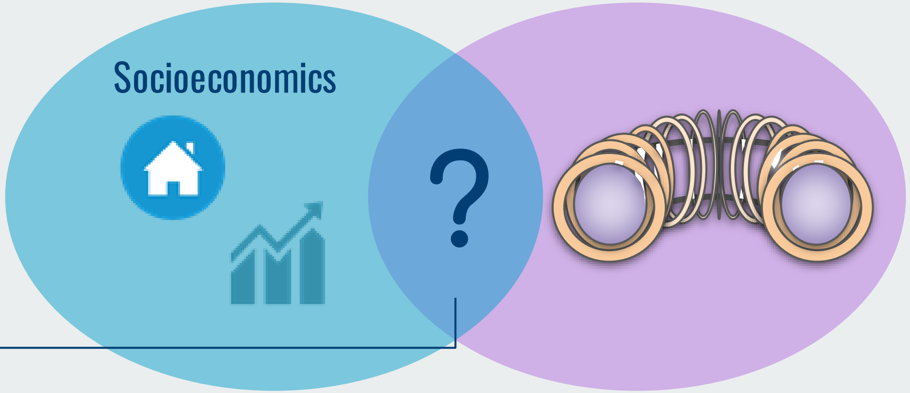

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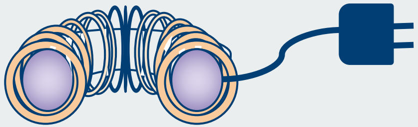
4. **The timescales of fusion -** When is it likely that fusion reaches commercialisation?

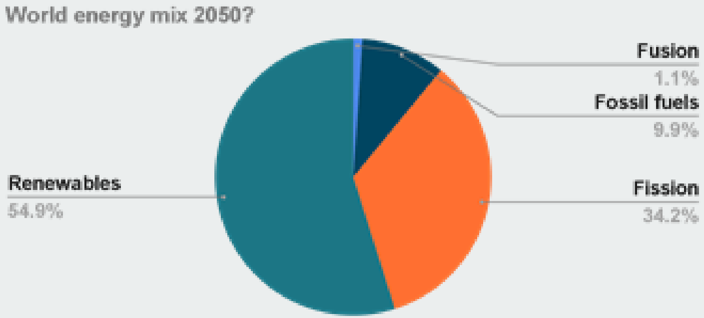
How can we define *when*?

- Q>1?
- Fusion provides electricity?
- 1% of global energy mix? [30]?



➔ Roadmaps, both public and private, are not credible sources.

➔ Assumptions, such as construction are overlooked.



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Conclusions (i):

1. **The role of fusion - What**:
    a. Many potential pathways for techno-economic investigations outside of electricity generation exist, especially for reactor designs within the private sphere.
    b. The fusion community should not rely on climate change mitigation policies for commercialisation, nor any unrealised sectors, such as hydrogen.
    c. Thermodynamic cycles in fusion reactors.
2. **The cost of fusion - How much**:
    a. To be cost competitive, fusion relies on carbon taxing.
    b. Uncertainties are a major issue.
    c. Costing studies focussing on confinement methods are needed.
    d. Costing studies focussing on fuel cycle are needed.

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Conclusions (ii):

3. **The externalities of fusion - Why**:
   a. How can investment potential be improved through financial instruments and partnerships?
   b. Further sociological impact studies of fusion, and its impact on job creation and GDP are needed.
4. **The timescales of fusion - When**:
   a. Quoted construction times are optimistic.
   b. Supply chains must be ready in order to scale up for commercialisation.

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Questions?

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