Seasonal thermal energy storage in smart energy systems to provide flexibility services

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New system flexibility is needed

- Level of wind curtailment is increasing due to network constraints and demand/supply mismatch
- This will increase further (CCC) with estimates low-carbon generation needs to quadruple from 2019 levels
- Peak daily and hourly gas demand up to four times the electricity demand
- 1 hour difference in demand over 7 times larger for gas compared to electricity
- Seasonal thermal energy storage could provide flexibility at low cost
Seasonal thermal energy storage (STES)

- Four main types: Tank, Pit, Borehole, and Aquifer
- Used in solar district heating, but potential for using multiple energy sources in smart energy systems

Presentation content:
1. Smart applications
2. Energy system modelling
District-level smart energy systems

Energy system integration
- Local electricity distribution network
- Heat network
- Cool network
- Local hydrogen pipe network
  - Wider grid connection*
  - Grid services
  - Tariffs
  - Wider heat network
  - Waste heat
  - Wider cooling network
  - Waste cool
  - Wider hydrogen network
  - Electrolyser
  - Hydrogen tanks

Conversion
- Fuel cell/CCST
- Solar collector*
- CHP
- Heat pump*
- Natural sources
- Absorption chillers
- Mechanical chillers
- Fuel boiler
- Wind turbine*

Storage
- Short-response storage
- Large-scale storage
- V2G batteries
- Stationary batteries
- Seasonal Storage: BTES, ATES, PTES, TTES
- PCM
- Hot water tanks
- Cold tanks

Demands
- Transport
- Electrical demand
- Space heating
- Hot water demand
- Cooling demand

* At transmission level or distribution network plus connection to transmission network
*These convert solar, wind, and upgrade low-grade heat sources
Utilisation of renewable energy sources

- Coupling of electricity and heat sectors using heat pumps and CHP
- Seasonal and short-term electrical and thermal storage have a role to play
- STES has been installed to increase utilisation of solar collectors, but can be a role to increase utilisation of wind and PV generation
- District-scale energy systems should be integrated with the wider energy system
Waste heat and cool

- Waste heat is possible from industry and commercial sectors, as well as power generation
- Huge waste heat potential in UK – estimates vary between 10-40 TWh
- Potential for geographical and temporal mismatch to heat demands
- STES can contribute to decoupling supply and demand
- Waste heat can be used to meet cooling demands
Electrical network balancing

- Electrical heat production units can provide distribution and transmission electrical network services if they operate flexibly.
- STES slow charge/discharge but can still allow increased flexibility of other fast-response tech.
- Potential mechanisms: frequency response, demand/supply matching, responding to time-of-use price signals.
- Received little attention in literature.
Seasonal thermal energy storage in energy system modelling tools

- Reviews exist of modelling approaches, but focus on integration with solar energy and typically single sector focus.
- Underrepresented in planning tools, typically treated as energy flow without considering temperature and mass flows.
- TRNSYS dominates the state-of-the-art studies for borehole thermal energy storage.
- More detailed physics tools can represent underground STES more accurately, and power system modelling tools can capture wider energy system.

Source: Arefeh Hesaraki, Sture Holmberg, Fariborz Haghighat, Seasonal thermal energy storage with heat pumps and low temperatures in building projects—a comparative review, Renewable and Sustainable Energy Reviews, Volume 43, 2015.
Co-simulation methods

Co-simulation process diagram of multiphysics storage model and energy system model

Extend this co-simulation platform to include a power system tool?

Source: Abdulrahman Dahash, Fabian Ochs, Michele Bianchi Janetti, Wolfgang Streicher, Advances in seasonal thermal energy storage for solar district heating applications: A critical review on large-scale hot-water tank and pit thermal energy storage systems, Applied Energy, Volume 239, 2019
PyPSA-GB: An open source dispatch model of the GB transmission network
Analysing the integration of seasonal thermal energy storage

How do we design and control a seasonal thermal energy storage system at one of these buses?
1. Directly in PyPSA-GB (limited to high-level control)
2. Co-simulation with TRNSYS (implement real optimal control)
Conclusions

**Smart applications**
- Seasonal thermal energy storage can be useful beyond solar. Multiple energy sources can be used, e.g., wind, waste.
- Utilisation of renewable energy sources both locally and part of wider energy system
- Waste heat and cool integration to take advantage of huge potentials
- Contribute to electrical network balancing which has increasing importance towards net zero

**Energy system modelling**
- Limited in planning tools and TRNSYS dominates detailed studies
- Co-simulation of energy system tool with seasonal thermal energy using detailed physics tools and power system tools
- Transmission network model of GB (PyPSA-GB) to be used to analyse integration of seasonal thermal energy storage
  - Co-simulation with TRNSYS
  - Direct implementation in PyPSA-GB