CHALLENGE 1: DECARBONISATION OF HEAT

The aim of the Challenge is to develop and apply a system-architectural perspective to explore technological and operational problems & opportunities associated with Decarbonisation of Heat.

Terminology: This proposal distinguishes between individual energy technologies (electric heating, hydrogen (CCS or electrolytic), biomass, solar and geo-thermal, and demand reduction), energy and decarbonisation strategies (typically characterised by a selection of multiple technologies against a background of a long term plan to achieve overarching goals such as affordability, emissions reduction and resilience) and energy system architectures (the spatial, topological and functional organisation of energy generation, conversion, transmission, distribution and storage systems within the whole energy system).

Background: The energy technologies that are available to support a strategy of decarbonising heat supply have been rehearsed in numerous publications, but much of what has been published to date implicitly views heat supply technologies as being in competition (CCC 2017), with comparatively little consideration of questions of whole energy system architecture, integration and inter-vector synergies, or of the potential impacts of technological uncertainty and evolution (IET & ESC, 2017). Key technologies exhibit significant economies of scale with respect to capital and operational costs, and there is the potential for powerful synergies between electricity and heat, in principle allowing their complete decarbonisation, together with much of terrestrial transport. At the same time, the interplay of smart systems, transmission and storage – much of it delivered outside the electricity system - offers the promise of the flexibility needed to accommodate very large inputs from variable renewables and relatively inflexible nuclear. But the extent to which economies of scale, synergies, and system-wide flexibility are realisable in practice is heavily dependent on energy system architecture. It is likely that different system architectures will perform differently under the impact of unexpected technical and cost evolution that affects the relative ranking of individual technologies. Thus, it may become possible to partially de-risk decarbonisation strategy by selection of particular energy system architectures – for example those that support interchangeability at the level of individual technologies, while preserving the key features of the overall structure. Energy system architecture and associated issues are not well represented by the UK’s two main whole energy system models, UKTM and ESME, which currently support policy analysis and development in BEIS, CCC, ESC, ERP and academia, and strategy development in industry. Moreover, while markets are relatively effective at selecting technologies within a given energy system architecture, they are not generally capable of selecting architectures.

Methodologically and computationally, the above questions constitute an extremely demanding, intrinsically whole-system problem, which has only recently become the focus of research initiatives – examples include: the Energy Systems Catapult & IET work under the Smart Systems and Heat programme, which approaches the problem from the perspective of market organisation and governance; the IEA Draft Annex TS3 - Hybrid Energy Networks, which plans to approach the problem from a predominantly engineering perspective, focusing on the interconnection of electricity, gas and heat networks. The task of this Challenge is to illuminate key aspects of the problem sufficiently to give key actors the confidence to begin, and to continue to move forward.

The Challenge will in the main, focus on heat in buildings, and will be organised around three Work Packages (WPs), which will be undertaken in parallel. Challenge management, cross-theme integration, liaison, integration and communication of findings, will be handled in a 4th WP.

- WP1 Systematic review of existing proposals for heat decarbonisation
- WP2 Analysis and development of proposals to improve performance of energy system models with respect to treatment of energy system architecture
- WP3 Evaluation of social, regulatory and governance implications of findings
- WP4 Challenge management, cross-theme integration, liaison, integration and communication of findings

Strategic Partners for this Challenge will include: BEIS, CCC, Energy Systems Catapult, National Grid, and energy supply companies (e.g. EDF). This Challenge will link strongly to UKCRED Theme 1 (‘Transforming Building Energy and Power Demand’), 4 (‘Flexibility’) and 6 (‘Governance and Policy’). It will also forge links to other research activities both in the UK and internationally, including BEIS’ Heat Strategic Options Programme (HSOP), Mission Innovation Affordable Heating and Cooling of Buildings Innovation Challenge, IEA Draft Annex TS3 and the work of the International
Institute for Energy Systems Integration (IIESI).

**WP1 Systematic review of existing proposals for heat decarbonisation**
The aim of this Work Package will be to undertake a multi-disciplinary systematic review, in partnership with stakeholders, of the available research and scenarios on Heat Decarbonisation in the UK and elsewhere. This review will be designed to facilitate conversations across the groupings associated with particular technologies or strategies in order to achieve a consensus on comparative advantages/disadvantages and to facilitate the characterisation and quantification of synergies, based on technical performance, costs and deployment rates, at the level of individual technologies and the whole system, together with stability of technology choices and system architectures across a wide range of outcomes for individual technologies. The work will build both on existing energy systems optimisation and spatio-temporal models, and work that has been undertaken on individual heat supply and storage technologies undertaken through the EUED interdisciplinary centre for Storage, Transformation and Upgrading of Thermal Energy (I-STUTE). The overall intention would be to move to a richer and more subtle conceptualisation of technological opportunities for policymakers and research funding organisations. The programme, in outline and subject to harmonisation with other major research and policy publications and initiatives (including the Clean Growth Strategy and a possible Heat & Energy White Paper), will be:

**WP1.1 Agreement and publication of common format for strategies and criteria for evaluation, developed through a series of facilitated workshops and working papers.**

**WP1.2 Publication of heat decarbonisation strategies in common format.**

**WP1.3 Review of current/future heat loads and sources in the UK.**

**WP1.4 Peer review exercise in which strategy teams undertake and publish in-depth reviews of each other’s work.**

**WP1.5 Independent whole system economic and spatio-temporal engineering analyses of heat decarbonisation strategies by UCL’s UKTM team and by an independent energy system modelling organisation working with oversight of strategy teams, and with input from UCL Energy’s Energy Space & Time group.**

**WP1.6 Identification of social, regulatory and governance issues emerging from published heat decarbonisation strategies.**

**WP1.7 Identification of potential synergies, research, development, demonstration and deployment opportunities/requirements not covered by individual strategies.**

**WP1.8 Publication of draft and final reports, with recommendations for stakeholders, and closing conference.**

Methods: Engineering-economic analysis; cross-Theme and cross-Work Package meetings.

Research outputs: Draft and final reports, journal papers (Nature Energy, Energy Policy)

Outcomes: Improved understanding of uncertainties and opportunities around heat decarbonisation

Start date: April 2018. End date: March 2021. Resource: The work will be undertaken by a team led by Dr Steve Pye and Prof Mark Barrett of the UCL Energy Institute. Connection to the most recent work on technology costs will be ensured by the inclusion of Prof Phil Eames as CoI. Total commitment, 48 person months.

**WP2 Analysis and development of proposals to improve performance of energy system models with respect to treatment of energy system architecture**
The UK’s two key whole energy system optimisation models are UKTM and ESME. These two models represent many person-decades of work and funding, and have been central to the analysis of energy policy options since the early years of this Century. It is not the intention of this Challenge to replace them - funding alone precludes this – rather to understand and document their strengths and limitations with respect energy systems architecture and attendant issues. Then, to generate proposals to address or circumvent such problems as are found, either by developing the spatio-temporal capability of these models, or by making use of models in which spatio-temporal capability is already well developed, or by developing a set of work-arounds outside the whole energy system models. The research question is whether and to what extent energy systems, and particularly heat
systems architectures are an output of whole system optimisation, or are implicit in data structures and computational architecture of these two whole system models. It is currently not possible to say which of these avenues is likely to be most fruitful, hence the exploratory and participatory nature of this Work Package. Nevertheless, there are fundamental reasons for believing that improved representation of energy systems architecture and spatio-temporal interactions will reveal a richer landscape of technological niches than current whole system optimisation modelling. The potential for highly novel research outcomes is provided by the inclusion in the team of engineers, building scientists and energy systems modellers with experience in data analytics and machine learning. Interdisciplinary learning will be supported through regular cross-package workshops linking WP2 & WP3.

At the same time, the review of energy system models will offer an opportunity to develop explicit metrics for two emergent properties of current and future energy systems: flexibility, and potential for impacts on equity and fuel poverty. The case for the latter emerges from the likelihood that the balance of whole system costs will shift from running costs that are avoidable by consuming less energy in any given year, to sunk costs that are unavoidable on a year-by-year basis. On the assumption that retail tariffs will, in the long run, reflect the energy supply system’s underlying cost structure, this shift in cost structure would, among other things, make it harder for people to avoid expenditure by foregoing comfort. It appears likely that it would be straightforward to quantify such an effect. The value of such metrics will be heavily dependent on the extent to which policy analysts and policy makers find them useful. The work will therefore be conducted in consultation with colleagues from BEIS and elsewhere.

WP2.1 Review of existing whole system energy models to identify factors and properties relating to sub-system and whole system costs and performance that are not dealt with explicitly or at all.

WP2.2 Development of metrics for energy system flexibility and impact of heat decarbonisation on equity and fuel poverty.

WP2.3 Development of proposals and strategies drawn from full range of available computational technologies and approaches (AI, genetic algorithms, ABM, neural networks…), for implementing energy system architectural concepts and metrics into existing model structures.

WP2.4 Development of strategies, tools and heuristics for addressing weaknesses outside existing model structures, to support more effective policy making.

Methods: Analysis of model structures and databases, qualitative and quantitative comparison with fundamental concepts in engineering-economic analysis (economies/diseconomies of scale, time domain diversity, exergy efficiency), system architecture, and control theory (including relationship between dumb and smart components and systems). Cross-Theme and cross-Work Package meetings.

Research outputs: Draft and final reports, journal papers (Energy Policy, Nature Energy)

Outcomes:
- Improved understanding of strengths and weaknesses of the main energy system models available to support policymakers in the UK.
- Concrete proposals for extending existing energy system models to improve treatment of energy system architecture.
- Tools and heuristics to support development of economically efficient strategies for decarbonisation of heat in the absence of whole energy system models capable of a comprehensive treatment of energy system architecture.

Start date: April 2018. End date: March 2021. Resource: The work will be undertaken by a team led by Dr Steve Pye and Prof Mark Barrett of the UCL Energy Institute. Total commitment, 48 person months.

WP3 Evaluation of social, regulatory and governance implications of findings

The aim of this Work Package is to provide earliest possible feedback on potential social, regulatory and implications of proposals for heat from socio-technical and political-economic perspectives. This will require significant involvement of staff associated with WP3 – primarily Chiu (a social scientist) and Grubb (a political scientist) - with other teams responsible for the other Work Packages. The Work Package will build on existing work, in particular, the Energy Systems Architecture work of the
ESC, providing a powerful and innovative connection between the infrastructure-led conceptualisation of energy systems architecture that informs this proposal, and the “system of systems” conceptualisation that informs the ESC work. The work will link to and inform UKCRED’s Governance Theme, led by Prof Nick Eyre.

**WP3.1 Review of metrics, and evaluation of potential social implications of different proposals for heat decarbonisation, in collaboration with WP2.**

**WP3.2 Evaluation of implications for market structures, governance, policy implications and support for innovation of different proposals for heat decarbonisation.**

Methods: Interdisciplinary review of activities of and outputs from WP1 and WP2. A Learning Platform will be established between Work Packages to facilitate cross-disciplinary learning for evaluation. [Socio-technical case studies](#) will be undertaken to contextualize, validate and evaluate outputs from WP1 & 2.


Outcomes: Improved understanding of risk pathways for vulnerable groups and potential mitigation strategies.  
- Improved understanding of political economic drivers of and risks to potential mitigation strategies.

Start date: April 2018. End date: March 2021. Resource: The work will be led by Prof Michael Grubb and Dr Lai Fong Chiu of the UCL Energy Institute. Total commitment: 8 person months.

**WP4 Challenge management, cross-theme integration, liaison, integration and communication of findings**

The purpose of this Work Package is to integrate findings within the Challenge as a whole, and across the rest of UKCRED, and to provide the vehicle for stakeholder liaison and consultation and external communications. The necessity for such a Work Package arises from the concurrent nature of the first three Work Packages, and synergies with other UKCRED themes – particularly Theme 1 – Transforming Building Energy and Power Demand, Theme 4 – Flexibility, and Theme 6 – Governance and Policy. Mechanisms for integration across UKCRED will be set out elsewhere, underpinned by core support for Impact. Cross-theme integration will be ensured by monthly cross-theme meetings (in workshop format where appropriate). These will be written up and, together with records of meetings of the Challenge Advisory Board (CAB) and working papers, will provide a cumulative record of the progress of the Challenge. To the extent that the Challenge and this Work Package prove successful, they will represent a model that could be continued beyond the end of UKCRED.

WP4 will be organised around the following sub-packages:

**WP4.1 Heat Challenge management, led by the PI supported by a Challenge Manager.**

**WP4.2 Cross-theme integration and integration across UKCRED.**

**WP4.3 Cross-Work Package integration and learning, led by the PI.**

**WP4.4 Stakeholder liaison, led by the PI supported by a Challenge Manager.**

**WP4.5 Integration and communication of findings, led by the PI supported by a Challenge Manager with support from UCL Energy Institute administrator and UKCRED Impact Coordinator.**

Methods:
- Monthly cross-theme meetings.
- Cross-work package interdisciplinary Learning Platform, based on cross-package meetings, with approximately monthly frequency
- Peer reviewed publications.
- Quarterly Challenge Advisory Board meetings.

Research outputs: As above, plus summary of the whole Challenge in a single, final report

Outcomes:
- Development and communication of overview of the Challenge and its findings from multiple
disciplinary and stakeholder perspectives.

- Establishment of a continuing 'Commission on Decarbonisation of Heat'.
  Start date: April 2018. End date: March 2021. Resource: the Work Package will be led by the PI and Challenge Manager. Total commitment: 35 person months.