We have collated and categorised the questions posed by the attendees at our webinars. Many of the answers have been formed by the comments by those same attendees. We are thankful for their participation and contribution. We hope these questions and answers below can help to accelerate our broader understanding of how to deliver heat networks.

Design of Model- Software- Challenges to approach

Did we model smaller clusters and test whether a more granular phased roll-out might be better?	This hasn't been analysed yet but it is certainly a point of importance. We will progressively elaborate and further detail the plan as we moved ahead.
How did we approach trenching? Did we investigate the main underground infrastructure (tube, drainage system, river, etc). Have we tried modelling above ground piping as it is thermodynamically beneficial for Interseasonal energy transfer?	We have not gotten into that detail. What would be something we could model, in discussion with the client. Above ground pipes can be used for longer transport of heat from a remote source to a district for example but it is not really possible in a city centre. The pipes would take too much space.
Have we considered multiple energy sources? e.g. CHP; rooftop solar PV; existing heating sources and leverage them into the phased deployment; using heat pumps coupled with Interseasonal Energy Transfer and solar panels etc.	We have only considered taking heat from the river-source heat pumps. This is a starting point and it would make a lot of sense to work with the client to integrate other energy sources. In Glasgow, an obvious partner is the Energy from Waste plant at Polmadie, as well as the wind farms to the south of the city.
Have we looked at, and modelled other heat network technologies e.g. ambient loop, cooling networks,? Can we compare and contrast these technologies from a carbon, performance and financial return perspective?	We have not modelled any other heat network technologies but the software is more than capable of running multiple scenarios to determine where the balance lies.
Given our experience how close to reality have we found the heat load model using Hotmap benchmark datasets?	We have still to compare the Hotmaps datasets against the real thing. This is a next step and perhaps a client-led piece of work.

Building Efficiency & Hydraulics

Have we considered the sensitivity impacts of reductions in operating temperature of the buildings and networks? For example, how does each 5C of temperature	No, we have not developed scenarios as yet. These are great, next step questions. The software could apply these variable and compare the results to demonstrate the impact on IRR.

reduction impact on the cost per kWh of heat?	
Has any analysis been carried out on the fabric improvements required in the building stock, for the project to maximise system efficiencies?	Not as yet, we are interested in exploring those questions and could easily integrate into the model.
For wide and varied existing building stock. How do you reconcile a flow temperature? Is it the weakest link in terms of fabric/existing hydraulics?	This is a strategic question that needs to be discussed with the client. Do they want to make their buildings heat network ready first? This can all be modelled.
What assumptions are made about connecting the publicly owned building stock?	We have assumed all buildings are connected. Publicly owned are OK but not a big anchor load compared to hotels etc.
Looks like there is a lot of interconnection of the networks and complex opposing pumps - how does Comsof Heat software analyse the hydraulics within the pipe network?	The network design we presented for Glasgow consists of 4 non-interconnected networks, each getting its power from a river source heat pump. The networks are branched networks, there will be a pump handling an entire cluster. Additional pumps can be included in the network to overcome the terrain elevation towards the north of the city centre but that has not yet been taken into account in this study. To size the pipes, we calculate the pressure losses of paths and we dimension the networks respecting the network design constraints, we limit the max flow velocity and/or the max pressure gradient.
In the multiple Heat Pump scenario; is there sufficient flow within the River Clyde to avoid the cold water discharge of the heat pumps affecting the efficiency of a heat pump located downstream. I guess there are sufficient flow at the river for not to be an issue?	Yes, the River Clyde is able to provide 250MW of heat. This can be modelled to ensure that there is no chilling effect downstream.

Financial Modelling and business model

4% IRR is that incl indexation?	This rate is assumed to cover inflation.
Can the model compare different scenarios e.g. if standalone heat pumps were installed at each building, what would the cost to the electrical infrastructure be? And what would the capital cost of the additional generation need to be?	This is the counterfactual to budget of £90 million assigned to trenching and pipework. Yes, these comparisons can be produced very quickly once the model variable are set-up.
Did we tackle the maintenance and replacement costs of the heat pump compare to maintenance costs of gas boilers or gas CHP? £/mW? Were future gas prices modelled versus future electricity prices?	This can be modelled but was not included specifically at this stage.
How did we calculate the trenching cost per metre?	We consulted within our board and agreed that applying a standard cost of £2,000 per metre was a realistic starting point. This is regardless of the pipe diameter, as the costs are mainly absorbed in digging up and filling the road.

Given electricity input is the single largest 'operational' cost, what was the input electricity (p/kWh) used and to what extent can this be reduced via more intelligent purchasing, heat storage, sleeving, PPAs or co-locating renewables etc.?	We ran through two pricing scenarios, buying at 10p and at 4.5p/ kWh. We determined that buying locally, e.g. a local EfW or from local wind farms we could get a better price. For example 40GW of wind farms are south and south east of Glasgow, looking for a market.
Does the current model recycle profits to pay for the expansion of the heat network? If so, it may cause customers bills to increase heavily, quickly causing issues of fuel poverty.	The current business model is based on a target IRR of 4%. This was selected as an acceptable long-term IRR. The conclusion is that this is loss-making based on this fairly standard model. Or we have to increase tariffs, which will have a detrimental impact on fuel affordability. We accept and are interested in different businesses models to prevent the risk of fuel poverty.
Are there subsets of the network that provide a higher IRR, which could be used to get it going? By covering a wide area are you tackling hard bits which bring down returns?	This will no doubt be the case. The objective is to reach zero carbon emissions- which means we have to cover the whole area.
What assumptions are made about connection fees (domestic / non-domestic)?	We have not included connections fees in this scenario.
Did we model a reduced temperature flow to see how would that impact the efficiency of the heat pumps and overall IRR etc.?	We based our modelling on a 50 degrees Celsius return temperature, yielding a COP of 3. There are better return temperatures to target, and better COPs to achieve, that would improve the IRR.
Did any of the iterations look at the interplay of building level efficiency improvements and heat network?	We included an investment to improve building efficiency to enable it to accept our assumed flow and return temperatures. There is plenty of scope within the software to apply scenarios that increase CAPEX, but lower OPEX, that may lead to a lower heat demand, but maybe a higher heat cost per kWh. The result could be that the total cost of heating remains the same or lower (or higher). This can all be modelled.

Policy, Planning & Engagement

How can we promote connection?	We believe that connection should be mandatory. We recognise that connection fees make sense for new builds, however there may be delayed to connect existing buildings, while we wait until the gas boilers reach end of life.
Should policy restrict choice on how to heat homes, to improve efficiencies, drive economies of scale, reduce demand risk?	Business as usual should no longer be an option. The positive change and benefits derived from this should be explained.
Do policy makers understand that the scale of application might be worth dedicated policy changes?	We do not think this is the case at the moment. Policy must be fit for purpose and basing it on small, fragmented, low hanging fruit projects will never deliver the scale necessary to go zero carbon.
Can a carbon price support mechanism could be used as a legislative tool (stick) for inflating cheap gas in urban environments?	Our analysis for Glasgow demonstrates that it costs about £150 per tonne of carbon emission avoided, over the total 60-year lifetime. The social cost of doing nothing is estimated at £350 per tonne emitted (Nature, September 2018).

Can policy be put in place to provide government funding of heat networks? Should gas bills to have a component to fund the underground infrastructure for DHNs? What do we think about the idea of campaigning for a gas fuel "carbon tax" to push people towards heat networks instead?	Our example demonstrates that it is difficult to get these large-scale networks off the ground whilst conventional gas solutions remain the cheaper solution. Looking at the example of the power, the capital cost of installing the electricity grid was paid for by means of the standing charge. It was a government funded initiative because it was seen as a national imperative. If we all believe that reaching zero cabon is a national imperative then finding a private sector-only funding model is going to be difficult
How can we mitigate the overwhelming cost of trenchwork and coordinate the installation of pipework across the city?	We clearly need a joined-up, publicly-led approach that unites all utility players, where we strategically plan and share costs. The overwhelming cost of new DHN networks is the underground pipe. And of this, the trenching costs are the main component.
What role can anchor loads play?	Anchor loads provide a demonstrator approach. People are motivated by what they see. It may help a project become more deliverable in the short term. Investors looking at the scheme will have more confidence with key anchors established.
How can the modelling be improved through policy?	Local authorities should have the power to mandate that all building owners within a heat network zone provide the heat usage data. Also, for those zones that are designated for heat networks, there should be an imperative on the building owners to become 'heat network' ready.
How can buildings be made heat network ready? How can we get the data on heat demand, support potential connections to improve their efficiency and achieve the needed delta-T?	What we should be saying is, “heat networks are coming, you need to start gathering data on your heat demand now, and you need to make improvements to your building heating systems now so that you are ready for the change”. If the message gets out and local authorities/commercial properties clearly understand the changes that they need to and can easily make (let’s be honest they should be doing this anyway), then there is a much better chance that heat networks will progress.
How have we engaged with Glasgow City council and what has been the result?	We continue to keep the local politicians and executives up to speed with our work. As this is a pro bono project, we want our analysis to help all local authorities and governments to strengthen their resolve and their policies.
Are we in touch with any other projects or organisations where our work can add value, or even better, accelerate heat networks?	Yes, we think this is major opportunity to reduce costs and integrate multiple long-terms solutions for environmental sustainability. We are in contact with the (Y)Our City Centre project, and the Zero Carbon Innovation District projects, both in Glasgow precisely to exchange ideas and approaches.