Imperial College London

September Xth 2018

12th ECCRIA CONFERENCE

The Opening New Fuels for UK Generation Project

Paul Fennell

Department of Chemical Engineering, Imperial College London, South Kensington, SW7 2AZ, UK

Centre for the Environmental Policy, Imperial College London, South Kensington, SW7 2AZ, UK

Imperial College London

What is the Opening New Fuels for UK Generation Project?

£1.3 Million project, funded by EPSRC

Collaboration between Imperial, Sheffield, Leeds, and Edinburgh

Started 1st April 2015, just about wrapping up now

Complementary to Supergen Bio work, in particular at PACT

Imperial College London

Why waste woods?

Given the well-known concerns surrounding the sustainability of distributed global supply chains, it is imperative to exploit indigenous biomass resources to the greatest extent possible.

It has been shown that exploitation of secondary biomass resources such as reclaimed demolition wood provides a promising route towards increasing the indigenous biomass resource base.

This is without needing to overcome the many and varied challenges associated with the implications of land-use change arising from increasing UK biofuel production. Exploitation of such resources also prevents them from being landfilled.

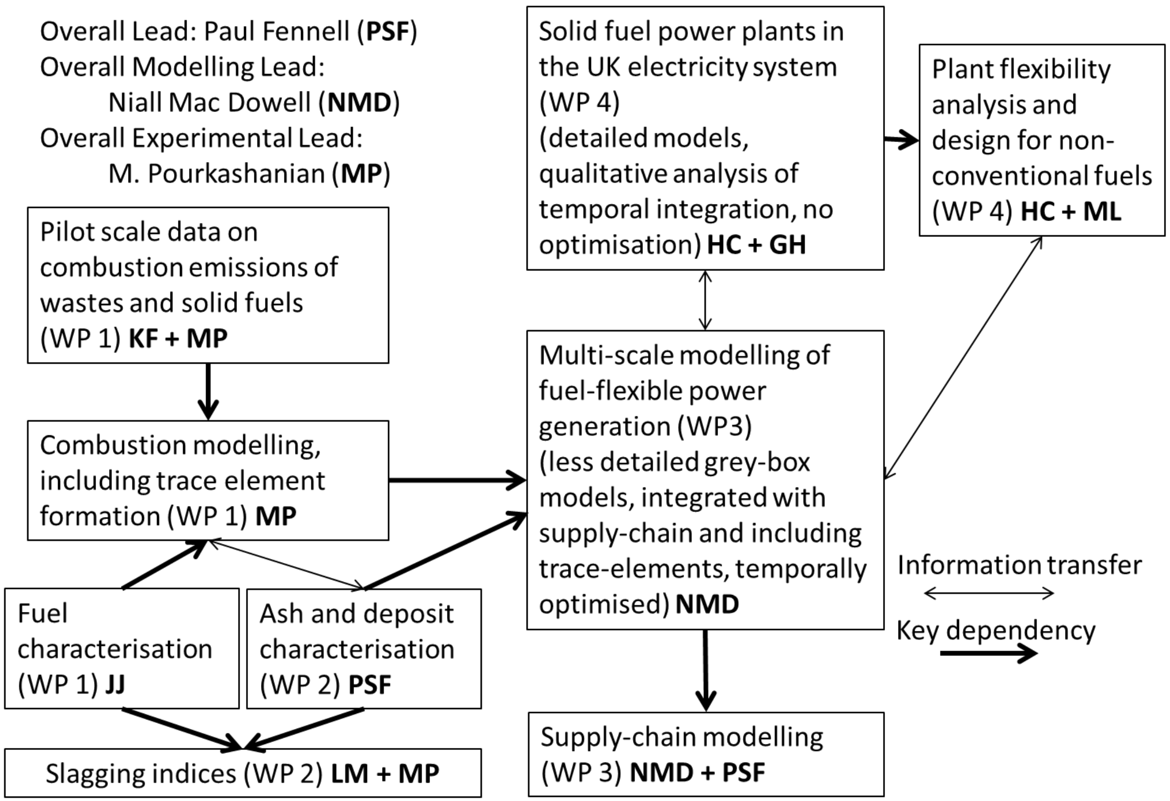
Imperial College London

Key Question: What amount of marginal fuels, of different types, can be *safely* burned in different types of UK power stations, and what proportion *should* be burned to maximise economic value

Imperial College London

Work Packages

Work Package Dependencies



Imperial College London

Sheffield

1 Research work on ONF at Sheffield

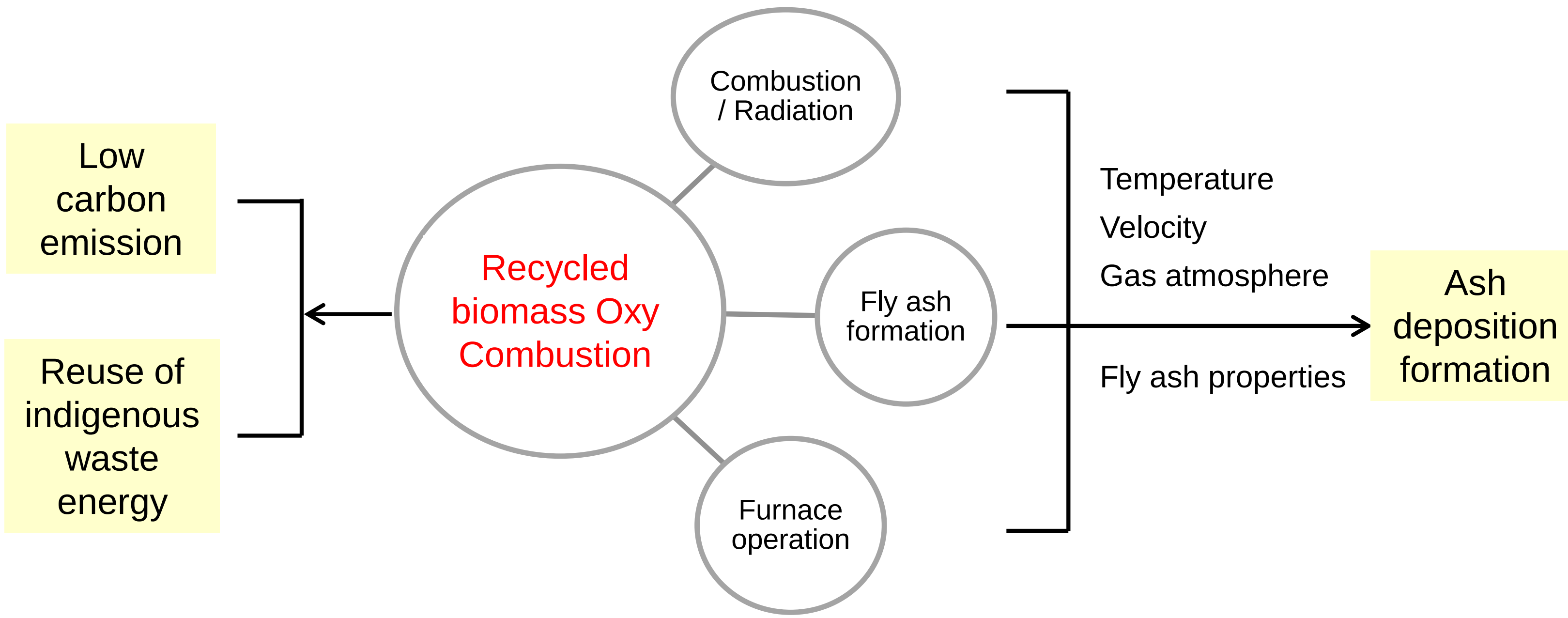
Ash deposition model development

- New multi-slagging indices for real boilers have been developed and validated. The indices have been attempted to be applied for EPRI .
- A new particle impaction revision model to minimize the numerical related errors in predicting the particle impaction efficiency without excessive meshing has been developed.
- An improved particle sticking model has been developed to take into account the particle properties-furnace operation conditions-deposit surface interaction for predict the particle sticking behaviour.
- A dynamic ash deposition model has been developed to predict the interaction of ash deposition formation and heat flux abatement.
- The above ash deposition models have been applied for the prediction of ash deposition behaviour for the contaminated wood oxyfuel combustion.

Ash deposition of contaminated wood oxyfuel combustion

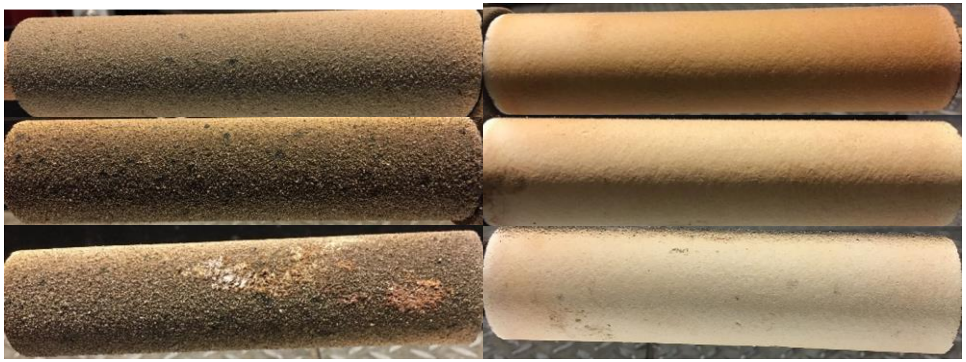
- Compared to the coal, Recycled wood has much higher deposition rate. The deposition rate under air combustion condition is slightly higher than Oxy27 condition.
- By using the ash deposition model developed and validated, coal ash has higher deposition efficiency than biomass ash with the same size. However, low velocity conditions favour coarse particle deposition. In addition, the recycled wood has much higher ash concentration. Both make the biomass has a higher deposition rate than coal.
- Oxy27 has slightly lower deposition rate than air which is mainly caused by the slight reduce in the velocity condition.
- Change the oxy condition can affect the velocity and temperature in the furnace, which have an effect on the deposition formation.
- The increase in the velocity to real boiler conditions could greatly change the deposition behaviour.

1 Introduction: Oxy → Ash deposition



How will this change affect the ash deposition formation?

Ash Deposition Studies



New burner designed and implemented
New sample probe manufactured and used

Direct measurements of trace elements during combustion

2 Achievements on ONF at Sheffield

2.1 Paper publication on high quality peer-reviewed journals:

- [1] Yang, Xin, et al. "Predicting ash deposition behaviour for co-combustion of palm kernel with coal based on CFD modelling of particle impaction and sticking." ***Fuel*** 165 (2016): 41-49.
- [2] Yang, Xin, et al. "Understanding the ash deposition formation in Zhundong lignite combustion through dynamic CFD modelling analysis." ***Fuel*** 194 (2017): 533-543.
- [3] Yang, Xin, et al. "Ash deposition propensity of coals/blends combustion in boilers: a modeling analysis based on multi-slagging routes." ***Proceedings of the Combustion Institute*** 36.3 (2017): 3341-3350.
- [4] Yang, Xin, et al. "Prediction of particle sticking efficiency for fly ash deposition at high temperatures." ***Proceedings of the Combustion Institute,*** 2018(Available online).

2.3 International collaboration:

- [1] Developed the slagging indice by collaborating with EPRI (US). In addition, EPRI is going to provide a new project to Sheffield University on developing slagging indice for Indian coals.
- [2] Developed the dynamic ash deposition model by collaborating with Zhejiang University (China).

2.2 Oral presentations at international conferences:

- [1] Yang X, et al. Prediction of particle sticking efficiency for ash deposition at high temperatures. Dublin, Ireland; 29 July-3 August 2018. ***The 37th International Symposium on Combustion***.
- [2] Yang X, et al. Ash deposition formation from biomass Oxyfuel combustion in a pilot-scale furnace. Cardiff, United Kingdom; 5-7 September 2018. (To be presented at ***the 12th European Conference on Fuel and Energy Research and its Applications***)
- [3] Yang X, et al. Predicting the ash deposition propensity of biomass combustion in a pilot-scale facility. ***International Bioenergy Conference***, Manchester, United Kingdom; 22 -23 March 2017.
- [4] Yang X, et al. Understanding the ash deposition formation in a pilot scale furnace: a dynamic CFD modelling analysis. ***The 11th European Conference on Coal Research and its Applications***, Sheffield, United Kingdom; 5-7 September 2016.
- [5] Yang X, et al. Ash deposition propensity of coals/blends combustion in boilers: a modelling analysis based on multi-slagging routes. ***The 36th International Symposium on Combustion***, Seoul, KOREA. 31 July-5 August 2016.

2.4 International Award:

- [1] Distinguished Paper Award from the Combustion Institute, 2017.

Imperial College

Imperial College London

Aim of work (Fennell Group)

Develop detailed model of pyrolysis, combustion and char burnout, link to experimental data from PACT facility.

Link the detailed model above to thermodynamic analysis of the trace element inventory and ash species present, including considerations of ash phases.

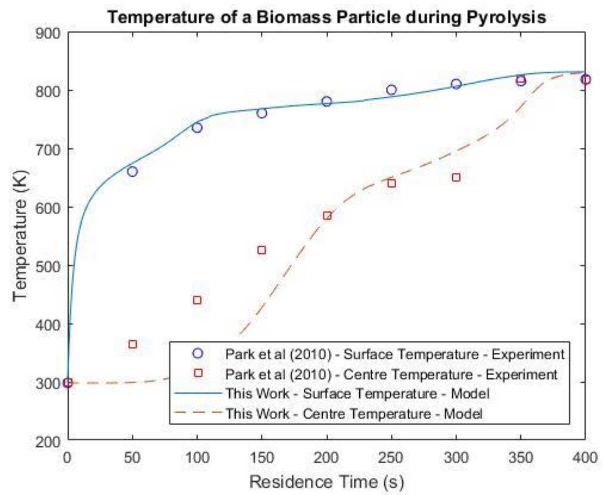
Particle model – nice, and validated

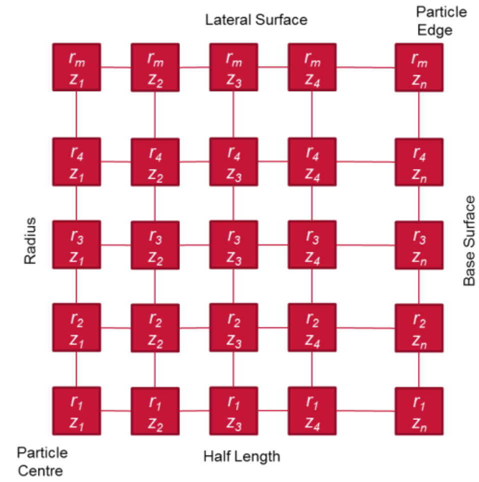
Thermodynamics – work in progress, but coming along nicely

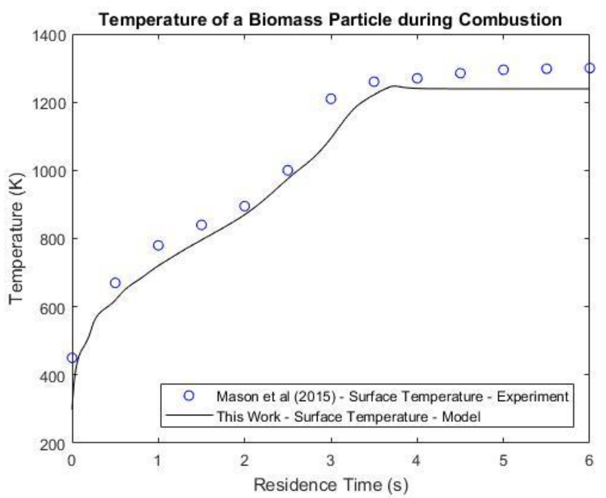
Imperial College London

Model

Single Particle Model





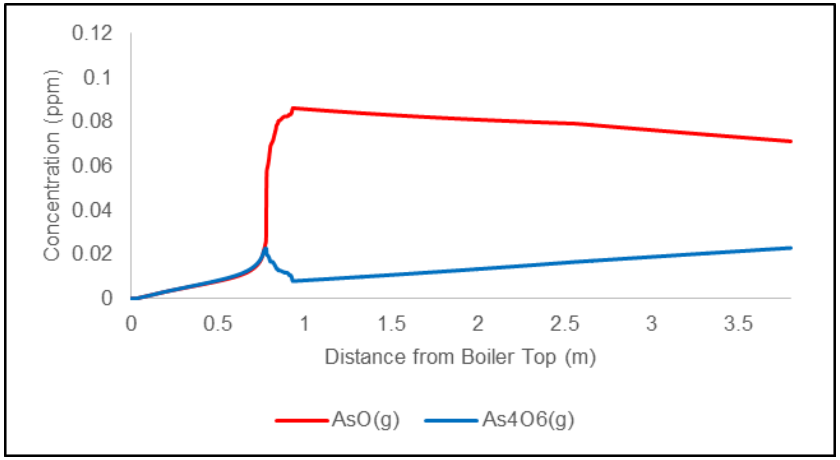


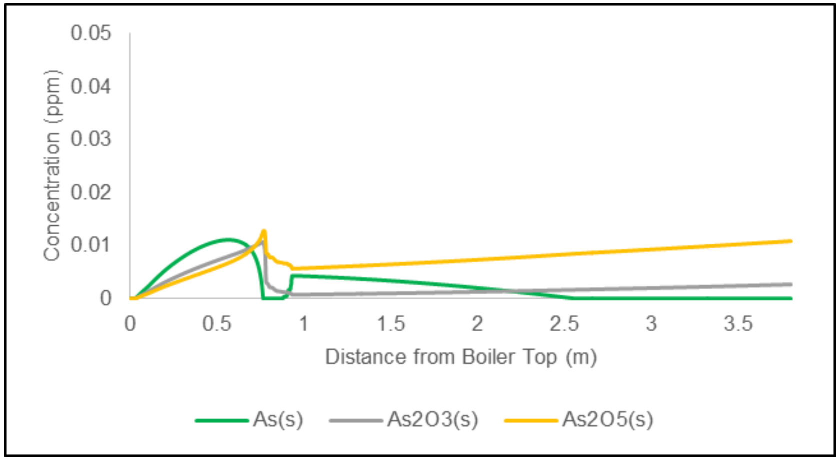
- Interior Mass Transfer Rate
  - $$\frac{\partial[X]}{\partial t} = \frac{D_{eff}}{r}\frac{\partial}{\partial r}\left(r\frac{\partial[X]}{\partial r}\right) + D_{eff}\frac{\partial^2[X]}{\partial z^2} + \frac{1}{r}\frac{\eta}{\mu}\frac{\partial}{\partial r}\left(r[X]\frac{\partial p}{\partial r}\right) + \frac{\eta}{\mu}\frac{\partial}{\partial z}\left([X]\frac{\partial p}{\partial z}\right)$$
- Interior Heat Transfer Rate
  - $$\frac{\partial T}{\partial t} = \frac{\alpha}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \alpha\frac{\partial^2 T}{\partial z^2}$$
- Surface Boundary Mass and Heat Transfer Rate
  - $$\frac{\partial[X]}{\partial r}_{r=D,z=z} = \frac{h_m}{D_{eff}}\left([X]_{Boundary} - [X]_{r=D,z=z}\right)$$
  - $$\frac{\partial[X]}{\partial z}_{r=r,z=L} = \frac{h_m}{D_{eff}}\left([X]_{Boundary} - [X]_{r=r,z=L}\right)$$
  - $$\frac{\partial T}{\partial r}_{r=D,z=z} = \frac{h_c}{k_{eff}}\left(T_{Boundary} - T_{r=D,z=z}\right) + \sigma\epsilon\left({T_{Wall}}^4 - {T_{r=D,z=z}}^4\right)$$
  - $$\frac{\partial T}{\partial z}_{r=r,z=L} = \frac{h_c}{k_{eff}}\left(T_{Boundary} - T_{r=r,z=L}\right) + \sigma\epsilon\left({T_{Wall}}^4 - {T_{r=r,z=L}}^4\right)$$
  - $$\frac{\partial[X]}{\partial r}_{r=0,z=z} = 0; \frac{\partial T}{\partial r}_{r=0,z=z} = 0$$
  - $$\frac{\partial[X]}{\partial z}_{r=r,z=0} = 0; \frac{\partial T}{\partial z}_{r=r,z=0} = 0$$

Chemical Equilibrium

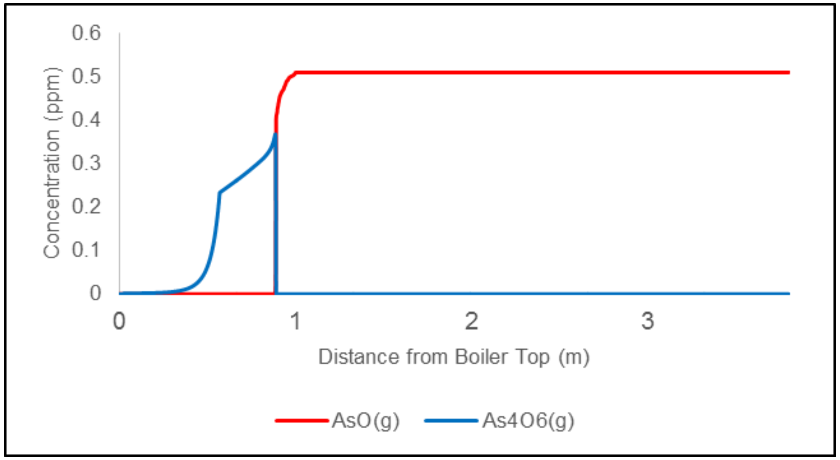
FactSage-MoDS and ChemApp Result Comparison

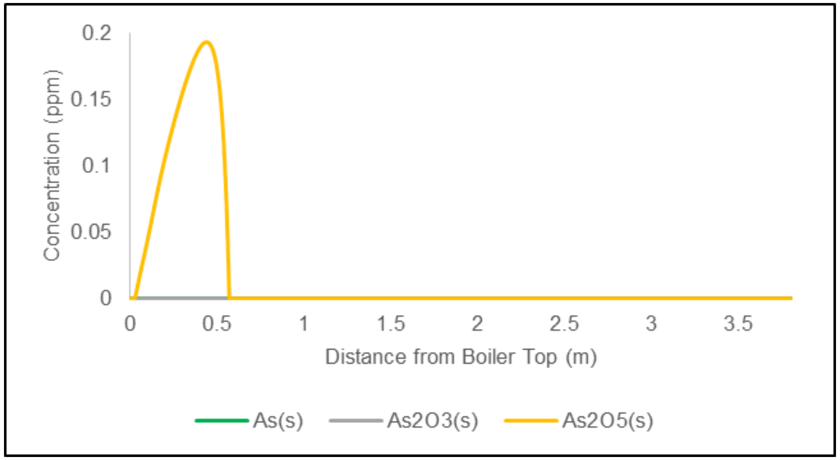
FactSage-MoDS – C-H-O-N-Si-As





ChemApp – C-H-O-N-Si-As





Imperial College London

Mac Dowell Group

UK BECCS supply chain model

Inputs

Geographical data

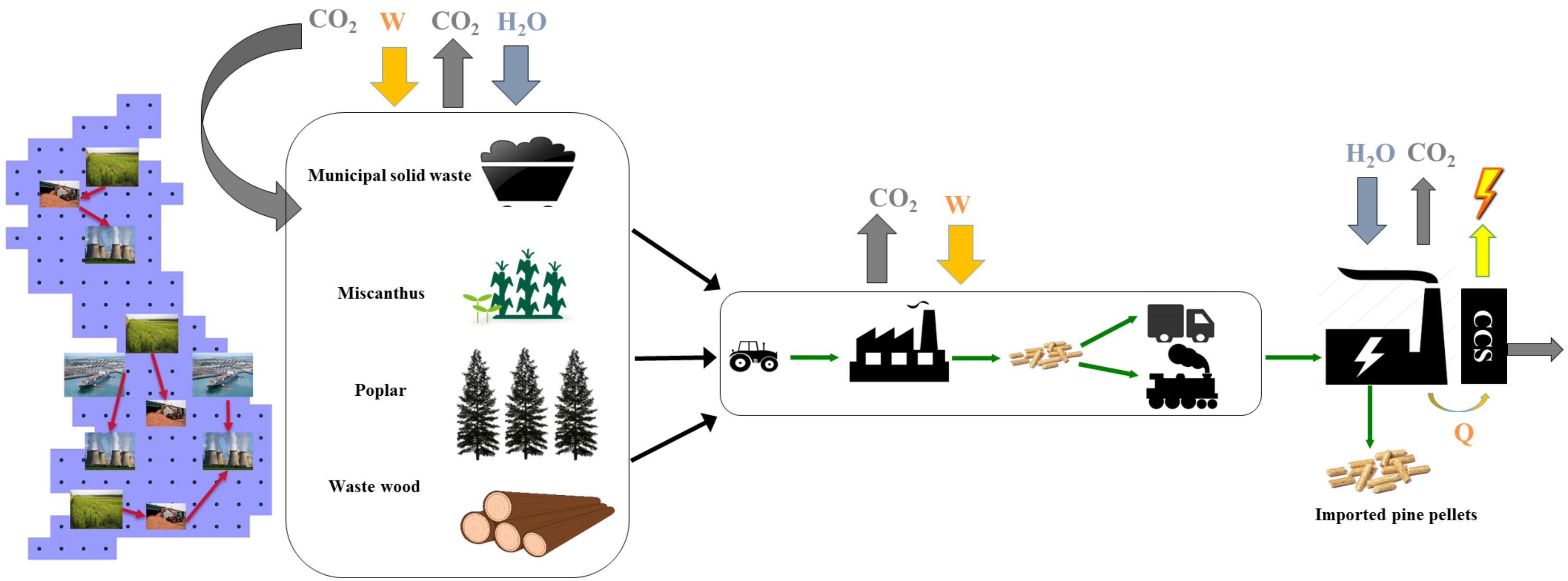
- available sites for power plants, pellet plants
- available locations and unloading capacities of ports for imported pellets
- availability of different raw material types for pellet production
- virgin biomass land availabilities of each region,
- total biomass land availabilities for each time period with the time domain

Transportation data

- modes
- costs
- transportation emissions

Pellet plant & Power plant data

- unit raw material supply, pellet production and electricity generation costs
- embodied emissions of different pellets
- captial investment cost for pellet production facilities and BECCS power plants
- CO_2 removal target of each time period



Geographical results

- optimal locations of the biomass farms, ports, the pellet production facilities and the BECCS power plants
- areas of virgin biomass farm in each region
- raw material supply rates

Transportation results

- flows of raw material and pellets between cells
- modes of transport of delivery for raw material and pellets

Pellet plant & Power plant results

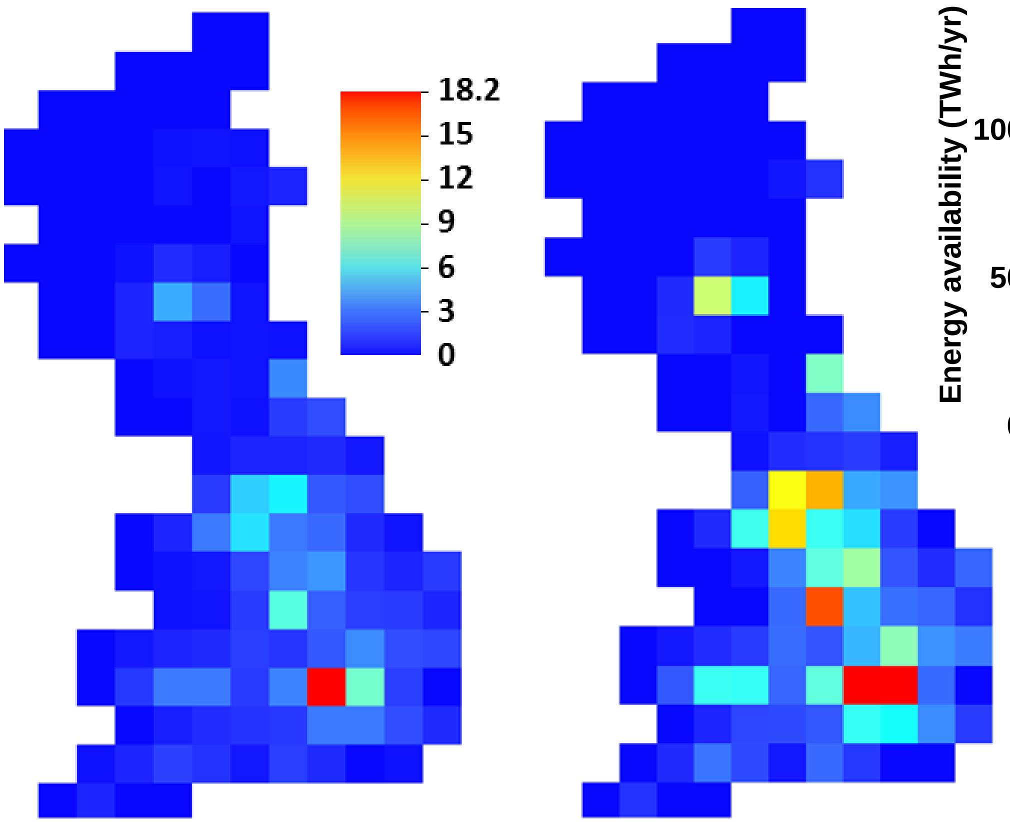
- Pellet production rates
- electricity generation rates
- Fuel burn rates

Outputs

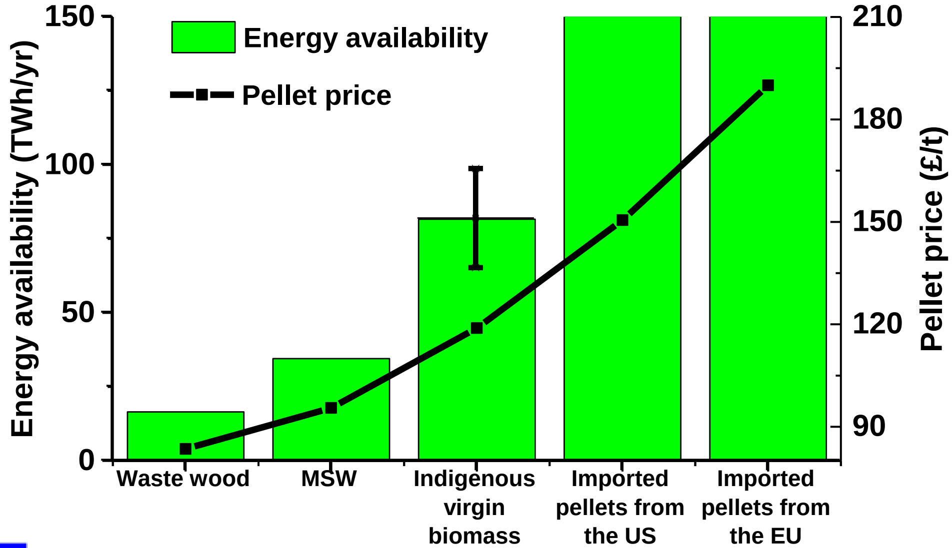
Imperial College London

Demonstrating the value of waste wood & MSW

Waste wood and MSW availability (t/ha/year)



Biomass pellets and energy availability



The availability of waste biomass correlated with population density.

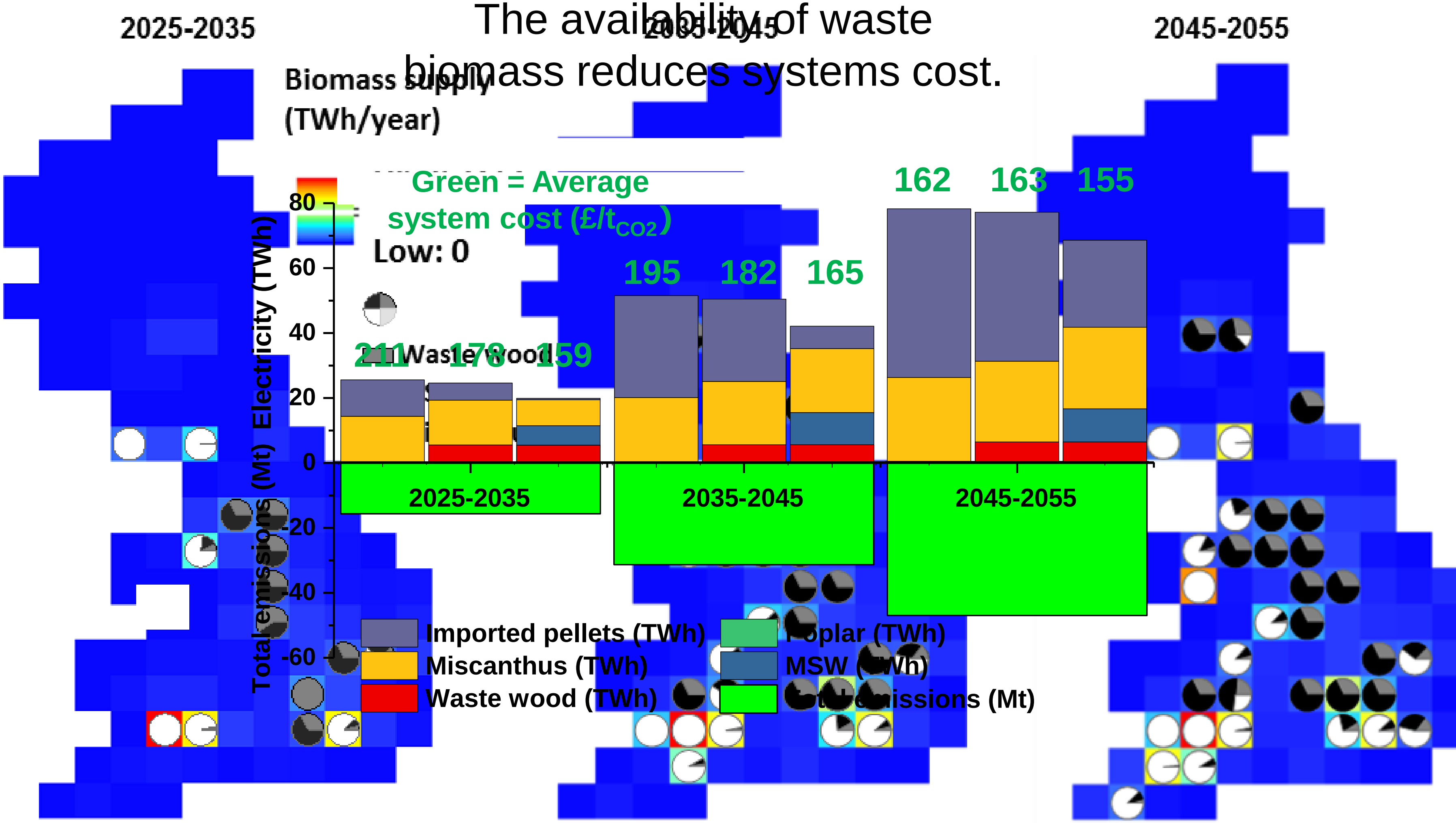
Waste wood and MSW pellet costs are significantly lower than the price of virgin and imported pellets.

Imperial College London

Demonstrating the value of waste wood & MSW

Evolution of biomass supply network

The availability of waste biomass reduces systems cost.



IC Publications

- Bui, M., C.S. Adjiman, A. Bardow, E.J. Anthony, A. Boston, S. Brown, P.S. Fennell, S. Fuss, A. Galindo, L.A. Hackett, J.P. Hallett, H.J. Herzog, G. Jackson, J. Kemper, S. Krevor, G.C. Maitland, M. Matuszewski, I.S. Metcalfe, C. Petit, G. Puxty, J. Reimer, D.M. Reiner, E.S. Rubin, S.A. Scott, N. Shah, B. Smit, J.P.M. Trusler, P. Webley, J. Wilcox, N. Mac Dowell, Carbon capture and storage (CCS): The way forward. Energy & Environmental Science, 2018. 11(5): 1062-1176.

- Bui, M., M. Fajardy, N.M. Dowell, Thermodynamic Evaluation of Carbon Negative Power Generation: Bio-energy CCS (BECCS). Energy Procedia, 2017. 114(Supplement C): 6010-6020.

- Bui, M., M. Fajardy, N. Mac Dowell, Bio-Energy with CCS (BECCS) performance evaluation: Efficiency enhancement and emissions reduction. Applied Energy, 2017. 195: 289–302.

- Bui, M., M. Fajardy, N. Mac Dowell, Bio-energy with carbon capture and storage (BECCS): Opportunities for performance improvement. Fuel, 2018. 213: 164-175.

THE UNIVERSITY of EDINBURGH
School of Engineering

Institute for Energy Systems

WP4 overview

GB Electricity System

Plausible GB system including
- 30 GW wind
- 20 GW solar

Power Plant Options

- Co-firing Pulverised Fuel
- Dedicated Pulverised Biomass
- Circulating Fluidised Bed
- Bubbling Fluidised Bed
- Packed Bed – Grater

UCED (Unit Commitment Economic Dispatch) with challenging biomass

Opportunities in GB

- Preliminary results suggest packed bed-grater has best performance
- Challenging fuels unlikely to play a significant role in UK electricity mix unless there is appropriate support

Regulations, Policy incentives & support mechanisms

Options being explored include
- Capacity Market
- 'Traditional' financial support (e.g. ROCs, Feed-in-Tariff)
- Additional measures to support investment

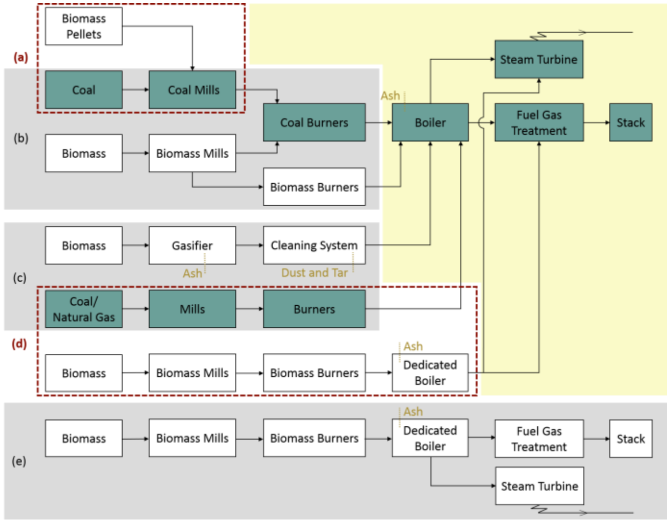
WP4 outcomes (so far) and next steps

Technology selection and operating parameters for challenging biomass based on

- Review of biomass and waste fuels previous experience and future opportunities in the UK
- Qualitative assessment and comparison of combustion technologies for biomass and challenging fuels based on key indicators
- Identification of policy incentives and support mechanisms for power plants and CHP plants

UCED model using robust technical and economic parameters will be used to support

- Sensitivity analyses, with particular focus on fuel price and power-plant average efficiency
- Assessment of a variety of support mechanisms for challenging biomass plants



Imperial College London

Conclusions

Interesting and exciting project

Is leading to excellent modelling and experimental crossover, with nice links between IC and Sheffield.

Supply chain work has novel theoretical methodology and underpins the project's underlying assumptions of growth in waste wood availability.

Underpinning work on how power stations burning waste biomass fit into the UK energy grid.

Imperial College London

The EPSRC are warmly thanked for funding under grant reference **EP/M015351/1**

All members past and present of the Clean Fossil and Bioenergy group are thanked for their hard work and determination.

Imperial College London

Would you like to know more?

p.fennell@imperial.ac.uk

http://imperial.ac.uk/energy-futures-lab/new-fuels