Introducing the Bioenergy Value Chain Model: spatial optimisation, linkages and insights

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WholeSEM annual conference

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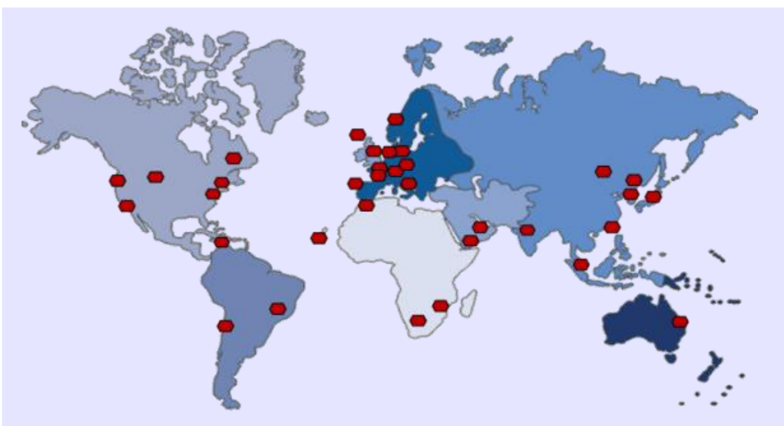
E4tech: Strategic thinking in sustainable energy

- International consulting firm, offices in UK and Switzerland
- Focus on sustainable energy
- Established 1997, always independent
- Deep expertise in technology, business and strategy, market assessment, techno-economic modelling, policy support…
- A spectrum of clients from start-ups to global corporations

RWE The energy to lead
IFC
Coca-Cola
iea International Energy Agency
IATA



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CLSA ASIA-PACIFIC MARKETS
e·on
Imperial College London
Unilever

Goldman Sachs
Shell
LONDON
Linde
TOYOTA
bp
DAIMLER
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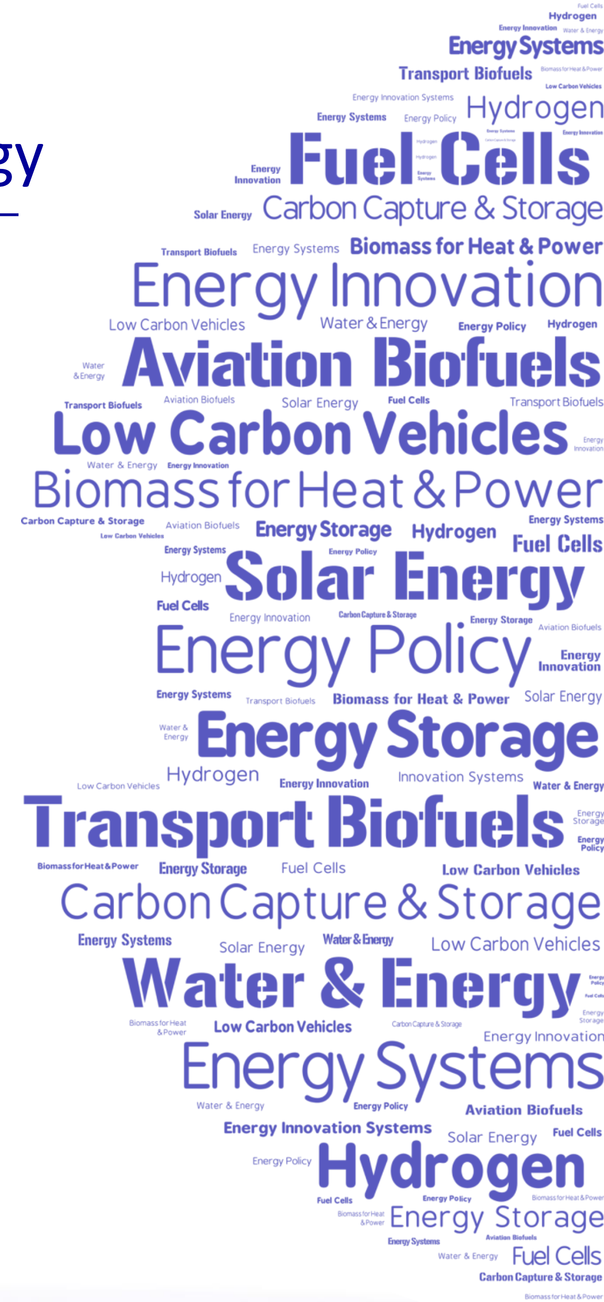

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Need for a detailed bioenergy system model in the UK

- Bioenergy selected by many whole energy systems models to 2050
- Typically only have a few different biomass types and conversion technologies, and no explicit consideration of physical **supply chains**
- In 2011, the Energy Technologies Institute (ETI) therefore commissioned a detailed **Bioenergy Value Chain Model** for the UK

energy technologies institute

BVCM

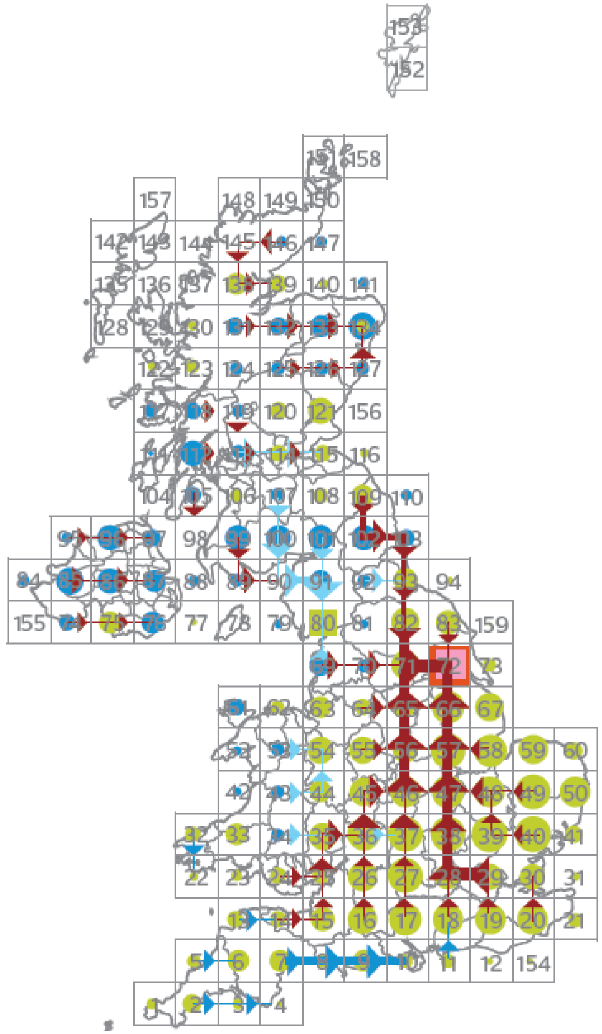
Bioenergy Value Chain Model
Optimising Bioenergy

Acknowledgments

- BVCM was commissioned and funded by the ETI
- E4tech led an original consortium of Imperial College Consultants, EIFER, Rothamsted Research, University of Southampton, Black & Veatch and Agra CEAS Consulting
- Improvement work since 2013 driven by ETI, E4tech and Imperial College Consultants – Nouri Samsatli, Sheila Samsatli, Nilay Shah
- Recent insights generated by ETI staff – Geraldine Newton-Cross, Hannah Evans

BVCM is a flexible, spatially explicit toolkit for whole system bioenergy value chain optimisation

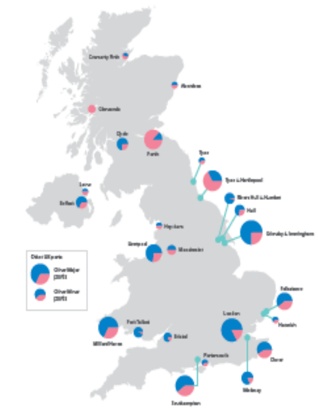
- First UK optimisation model that considers bioenergy system spatially at 50km resolution
- Balances resource flows in each of the 157 square cells and each decade (2010s - 2050s)
- Matching biomass resources with logistics and conversion technologies to show how **bioenergy pathways** can best be developed to meet user-defined **energy**, **economic** and/or **emissions** targets
- Implemented in the AIMMS modelling platform, with objectives minimised or maximised using the CPLEX MIP solver

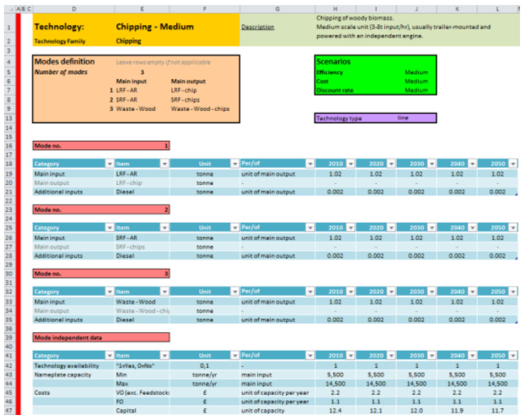


E4tech

Detailed underlying databases

- BVCM links a **large library** of data sourced from the original project partners, and subsequently from multiple ETI members and projects:
  - Maps of land types and availability
  - Yield, cost and GHG emission **maps** for arable & energy crops, forestry & wastes
  - 82 resources, with purchase/sale/disposal at system boundary, including imports at UK ports
  - CO_2 sequestered at **CCS hubs**
  - Road, rail, canal, ship and pipeline **networks** and impacts obey UK geography
  - Techno-economics for 61 distinct conversion technologies





Technology: Chipping - Medium
Technology Family: Chipping
Description: Chipping of woody biomass. Medium scale unit (3-8t input/hr), usually trailer-mounted and powered with an independent engine.

Modes definition (Leave rows empty if not applicable)
Number of modes: 3

	Main input	Main output
1	LRF - AR	LRF - chip
2	SRF - AR	SRF - chips
3	Waste - Wood	Waste - Wood - chips

Scenarios	
Efficiency	Medium
Cost	Medium
Discount rate	Medium

Technology type: line

Mode no. 1

Category	Item	Unit	Per/of	2010	2020	2030	2040	2050
Main input	LRF - AR	tonne	unit of main output	1.02	1.02	1.02	1.02	1.02
Main output	LRF - chip	tonne	-	-	-	-	-	-
Additional inputs	Diesel	tonne	unit of main output	0.002	0.002	0.002	0.002	0.002

Mode no. 2

Category	Item	Unit	Per/of	2010	2020	2030	2040	2050
Main input	SRF - AR	tonne	unit of main output	1.02	1.02	1.02	1.02	1.02
Main output	SRF - chips	tonne	-	-	-	-	-	-
Additional inputs	Diesel	tonne	unit of main output	0.002	0.002	0.002	0.002	0.002

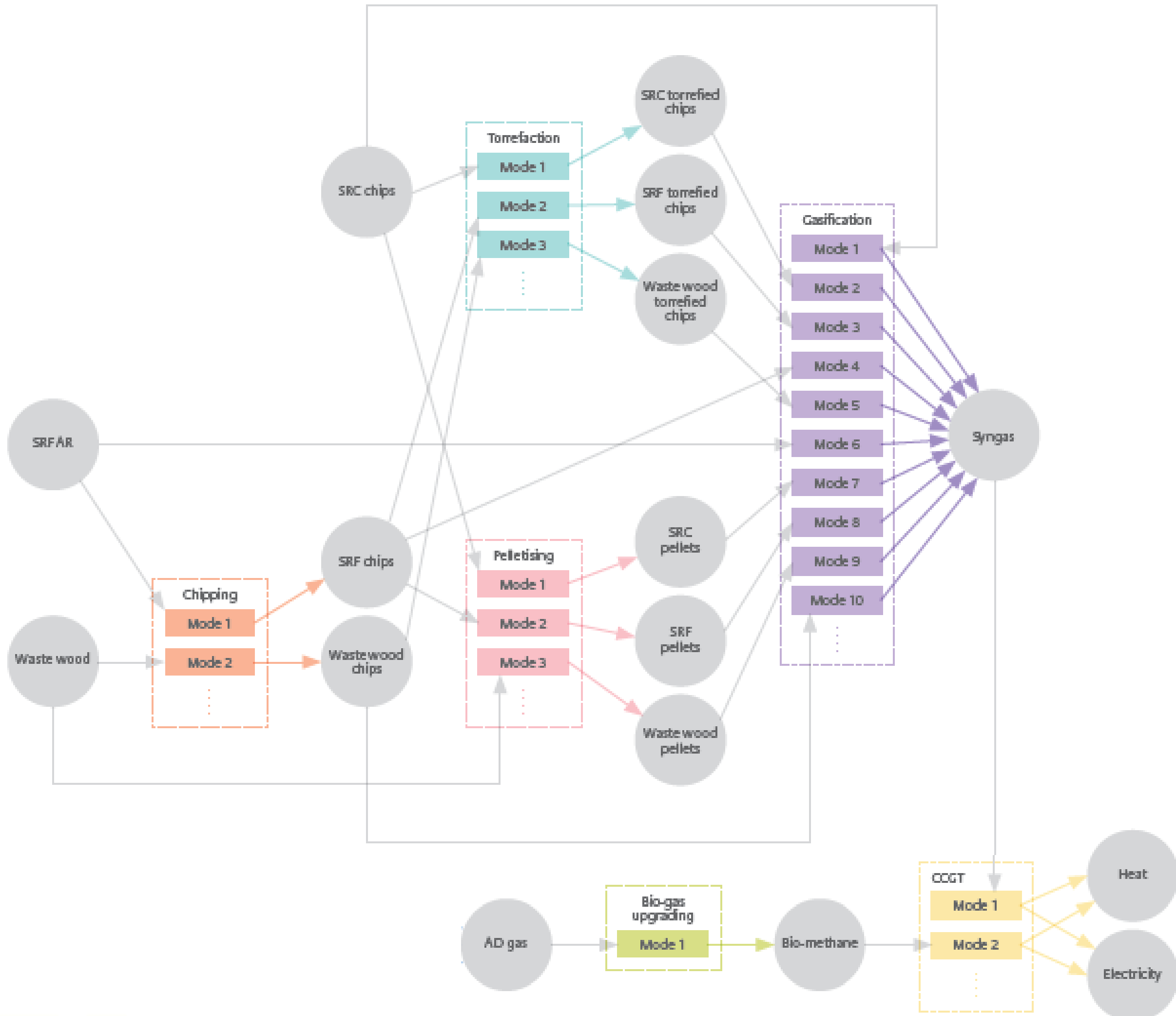
Mode no. 3

Category	Item	Unit	Per/of	2010	2020	2030	2040	2050
Main input	Waste - Wood	tonne	unit of main output	1.02	1.02	1.02	1.02	1.02
Main output	Waste - Wood - chi	tonne	-	-	-	-	-	-
Additional inputs	Diesel	tonne	unit of main output	0.002	0.002	0.002	0.002	0.002

Mode independent data

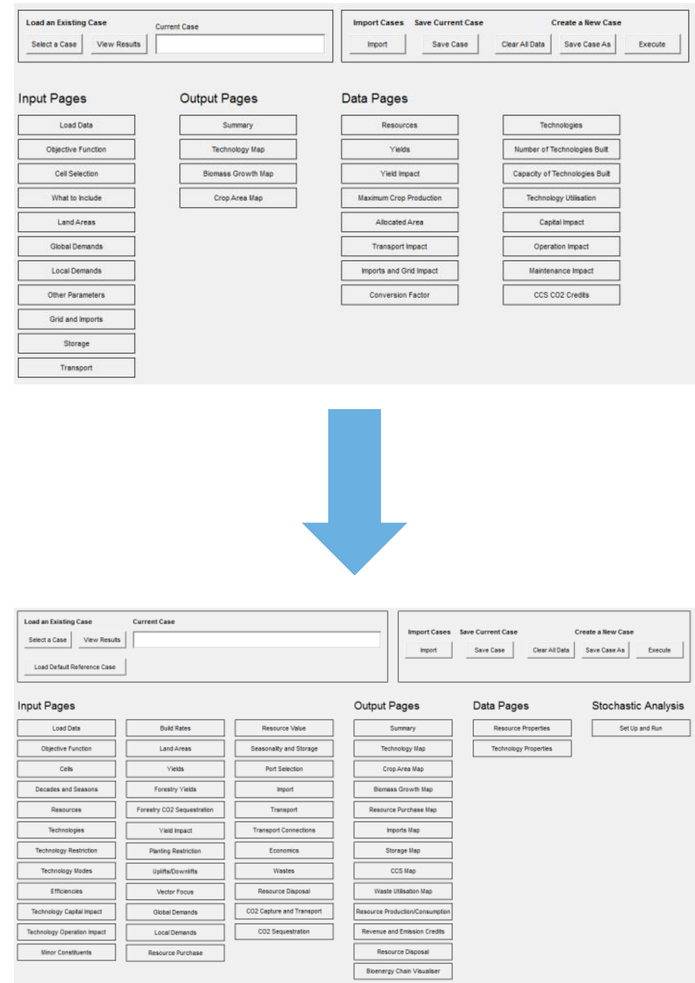
Category	Item	Unit	Per/of	2010	2020	2030	2040	2050
Technology availability	"1=Yes, 0=No"	0,1	-	1	1	1	1	1
Nameplate capacity	Min	tonne/yr	main input	5,500	5,500	5,500	5,500	5,500
	Max	tonne/yr	main input	14,500	14,500	14,500	14,500	14,500
Costs	VO (exc. Feedstock	£	unit of capacity per year	2.2	2.2	2.2	2.2	2.2
	FO	£	unit of capacity per year	1.1	1.1	1.1	1.1	1.1
	Capital	£	unit of capacity	12.4	12.1	12.0	11.9	11.7

Example of technology mode pathways



Development story

- **Started simple**: no imports, no wastes, no CCS, only cost minimising
- Added functionality: stochastics, vector objectives, non-GHG emissions, minor constituent limits, forestry sequestration, seasonality, energy crop ramp-ups, **land area masks**, CCS hub storage capacities
- Added technologies & starting assets: coal retrofits, CCGTs, biorefineries, waste conversion, **power & fuels with CCS**
- New visualisations with user interface, **supply chain maps**, Excel analysis tools
- Continuous **testing** over 4 years



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E4tech

Linkages to/from BVCM

ELUM
- UK biomass production pathways delivering genuine carbon savings with direct land use change

Characterisation of UK Feedstocks
- Linking properties to provenance; proximate and ultimate analysis

Techno-economic assessment of biomass pre-processing
- When does it 'pay' to pre-treat biomass

Refining estimates of land for biomass
- Conservative sense-check of BVCM land estimates via GIS and surveying

Enabling UK Biomass
- Benchmarking of energy crop competitiveness and identifying potential business models

Energy from Waste
- Waste arisings, composition and technology pathways

Waste Gasification
- Demonstration of integrated gasification gas clean-up and power systems

TESBiC
- Biomass to Power with CCS technology development: costs, barriers, opportunities

BVCM
Bioenergy Value Chain Model
Optimising Bioenergy

- Energy demands
- Specific vector demands
- Negative emission requirements
- CO_2 prices

- Available UK biomass
- Technology cost and performance trajectories

ESME
Energy System Modelling Environment

Cost of Preparedness
- Analysis of costs needed to reach required development points by 2030

Flexibility Project
- Ensuring future energy system meets needs and within GHG limits

SSH Programme
- Future UK district heating strategies; early biomass deployment vs. 2050

CCS Programme
- Offshore hub points and CO2 storage
- H_2 storage
- Costing bioenergy+CCS

ESD Programme
- Gas Vectors: costs and engineering issues to use/move CO_2, H_2, syngas and Bio-SNG; Heat Networks

Transport Programme
- Future requirements for alternative biofuels for LDVs and HDVs

Impact of linkages and system boundary

- Many linkages are library data only
- ESME determines several of BVCM's objectives – for example:
  - Negative 55 $MtCO_2e$/yr ⇒ CCS with power and H_2
  - High CO_2 prices ⇒ bio-CCS paid to sequester
  - 130 TWh/yr bioenergy ⇒ UK land utilised and balance of imports

- System boundary is conversion plant gate for **bio-electricity, bio-heat, bio-hydrogen, bio-methane** and **transport biofuels** (all counted equally)
- Fossil fuel & grid infrastructure, vehicles and industry are outside system
- Including new downstream technologies can have a big impact

Contents

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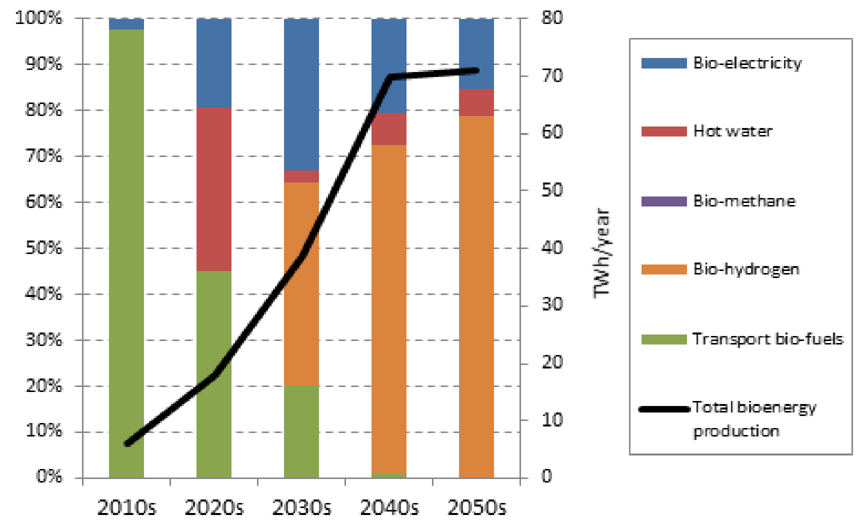
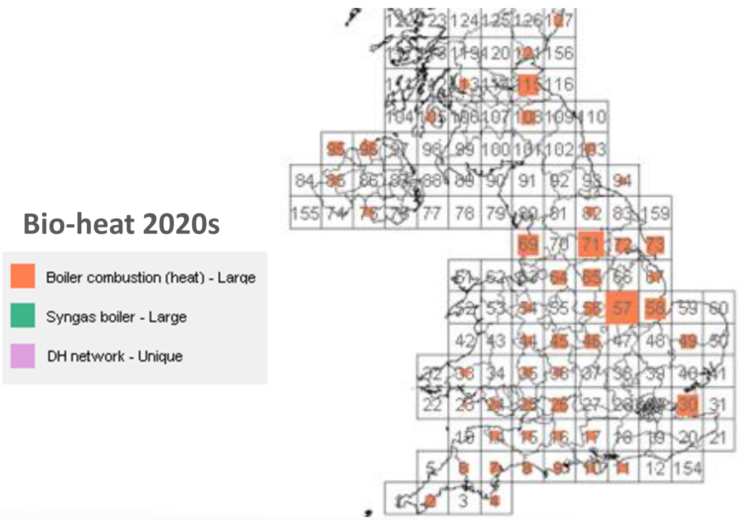
Hundreds of scenarios used to generate insights

- Preferred bioenergy vectors
- Key technologies
- Key locations for resource production
- CCS system changes with and without imports
- Impacts of land optimisation

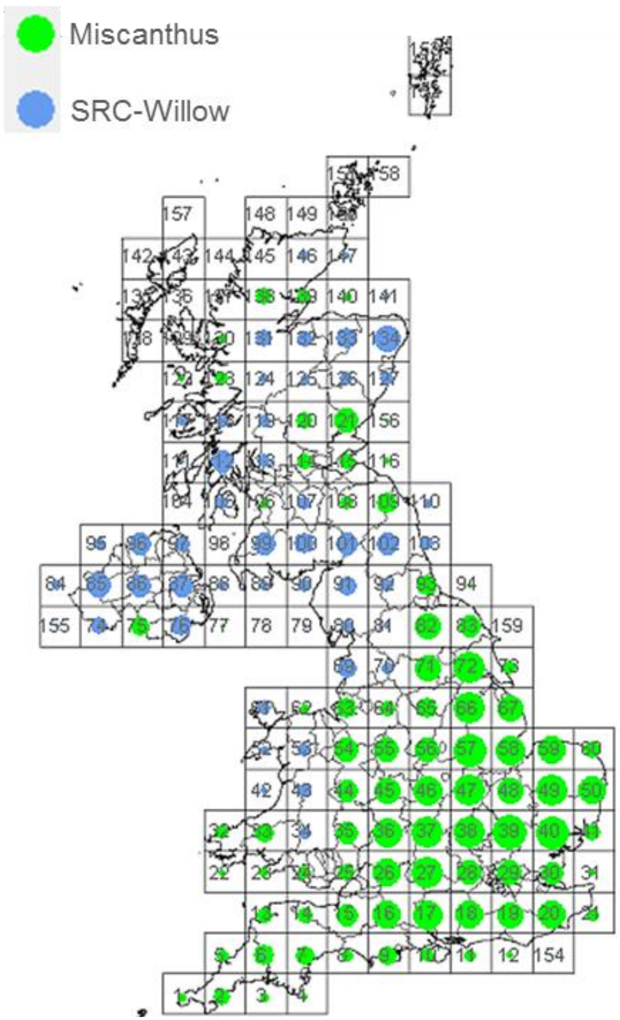
Choice of vectors and technologies favours gasification and CCS

- **H_2 with CCS and power with CCS** preferred over biofuels or biomethane, as can deliver significant negative emissions
- **Gasification** is a key enabler, resilient to scenario assumptions
- H_2 vs. power choice due to biomass availability, grid intensity, and demand/GHG objectives
- **Bio-heat** often chosen early as high efficiency kick-start to a domestic biomass market. District heating from CCS can happen later

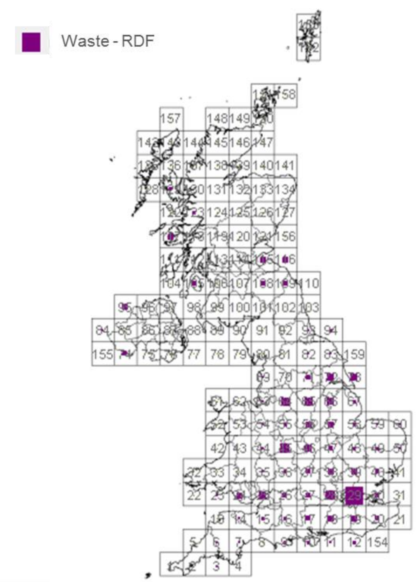


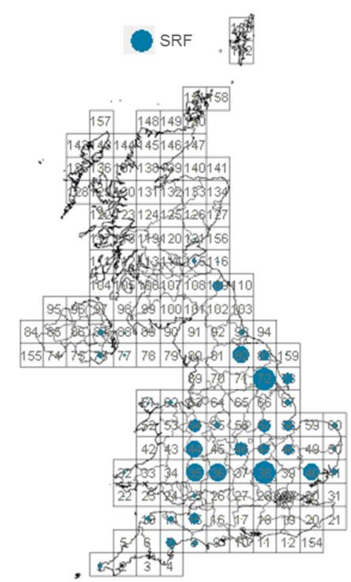


Resource locations show clear split, following yield maps



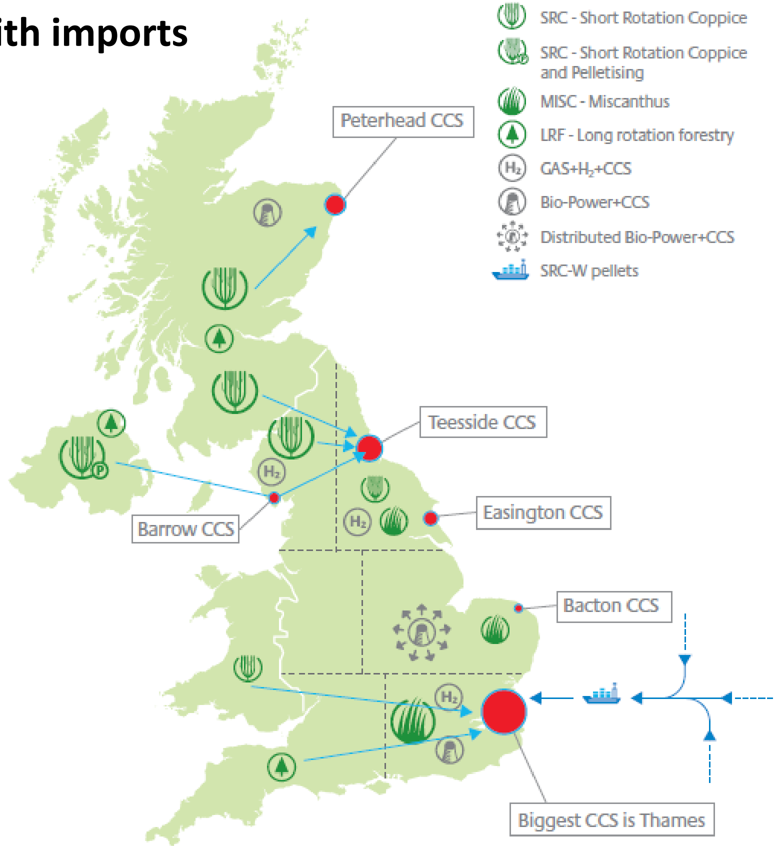
- **Miscanthus** preferred in South and East, SRC willow in West and North
- **Waste** arisings and RDF centred around cities, heavily utilised due to negative cost
- Short rotation forestry infrequently grown, due to low yields



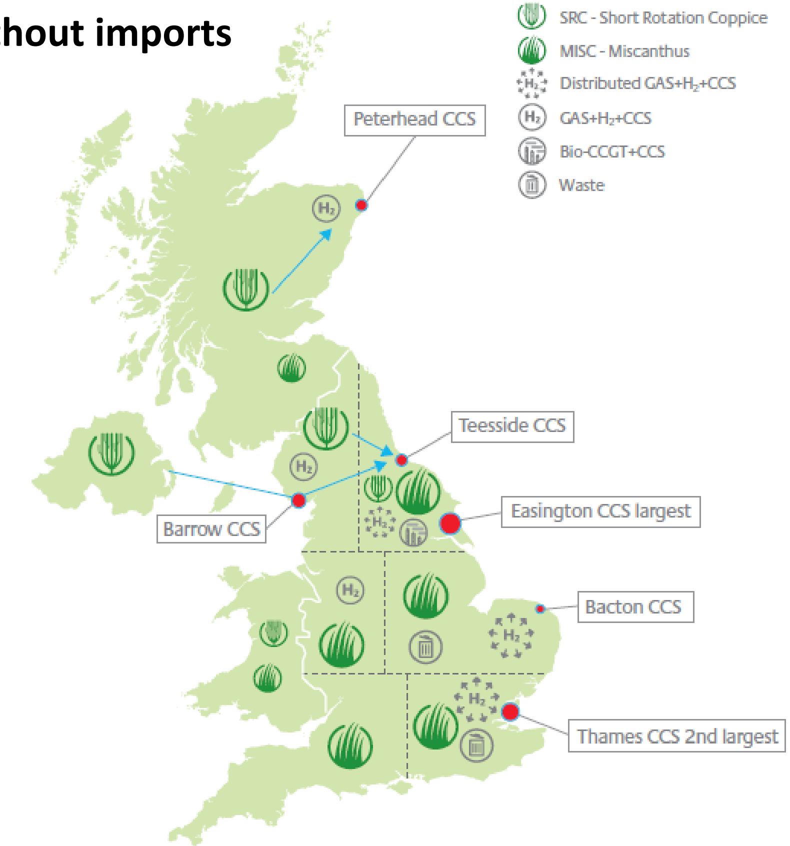


Choice of technology and CCS locations dependent on feedstocks and ports

With imports

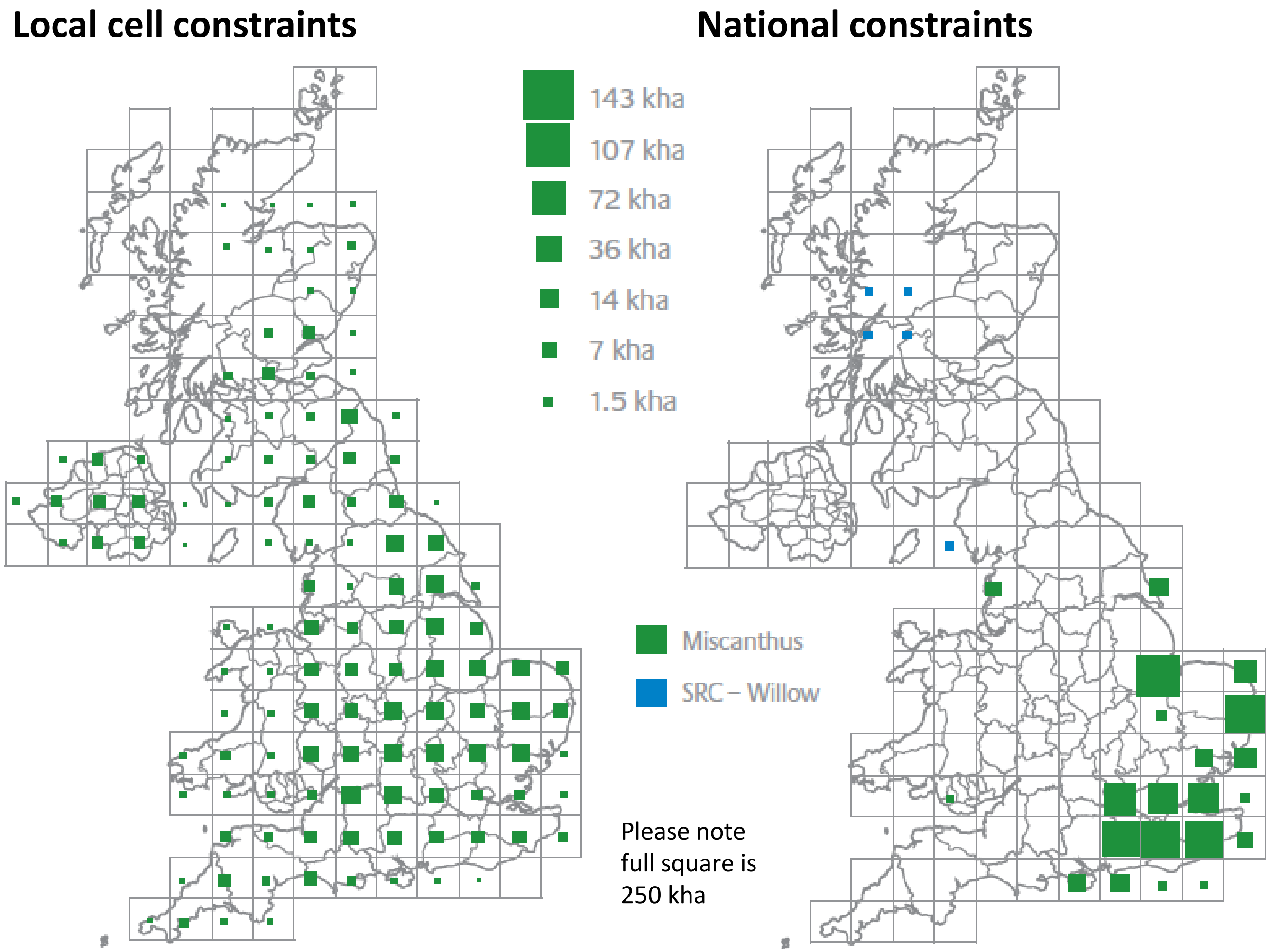


Without imports



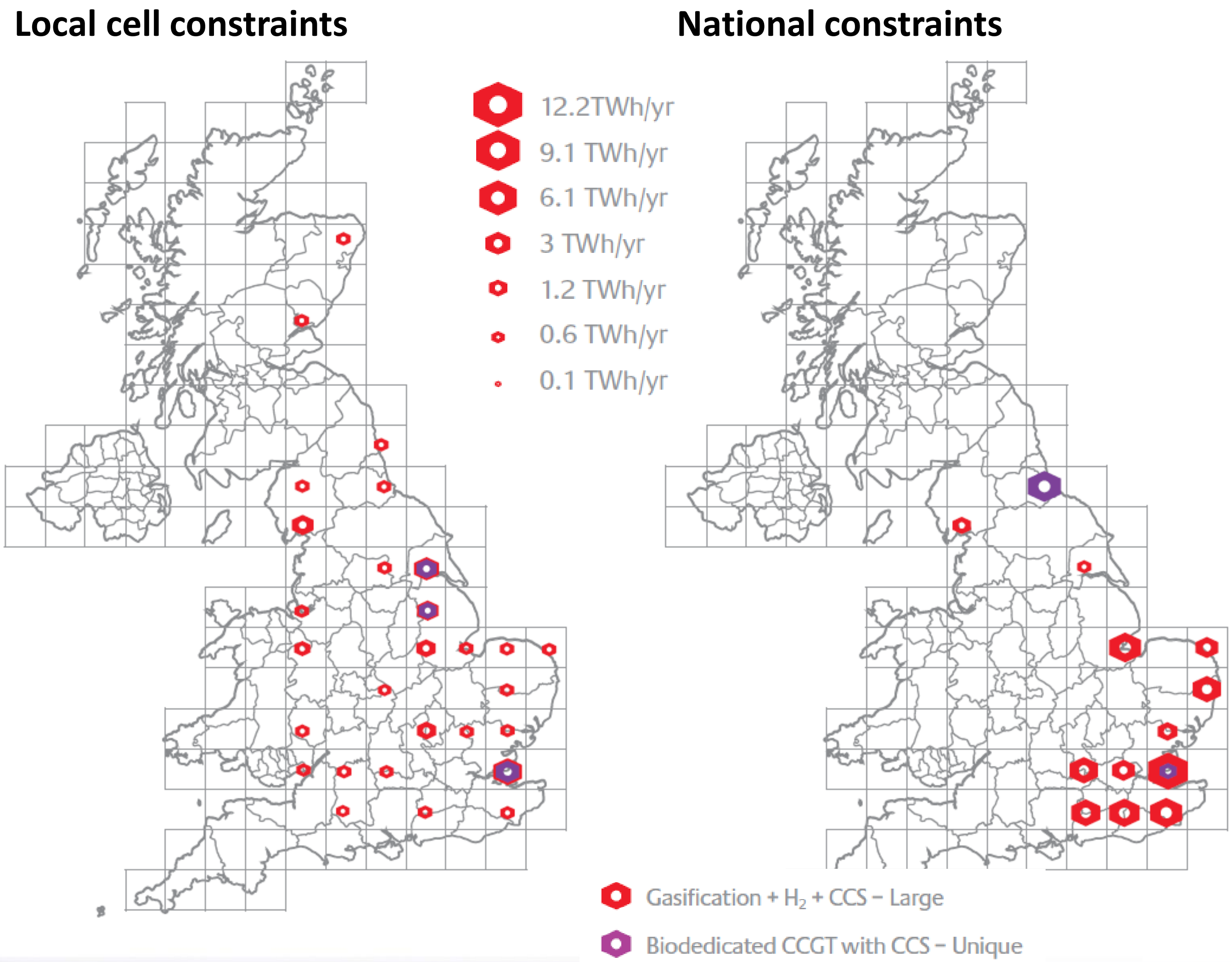
- Large plants built at high capacity ports that have CCS **hubs** (Thames and NE England)
- System more **decentralised**, with more CO_2 and syngas piping

UK land use can be optimised – with dramatic impacts on feedstock locations…



- Local constraints mean **2.3 Mha** of land needed to produce ~135 TWh/yr of UK biomass, as no option but to use lower yielding cells
- Maximising planting in best yielding cells under national constraints only needs **1.28 Mha**

… technologies and system costs



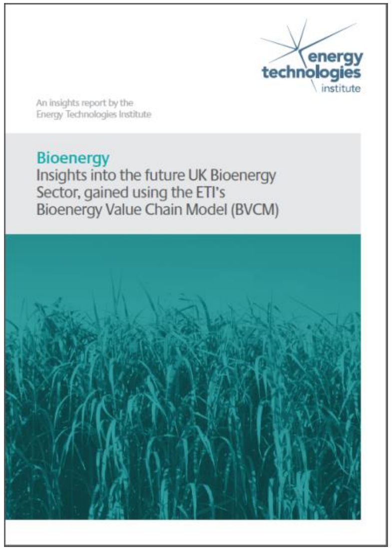
- **Disperse** feedstocks mean technologies are smaller, transport distances are longer and system costs are higher
- **Concentrated** feedstocks allow larger more efficient plants, shorter transport distances and lower system costs

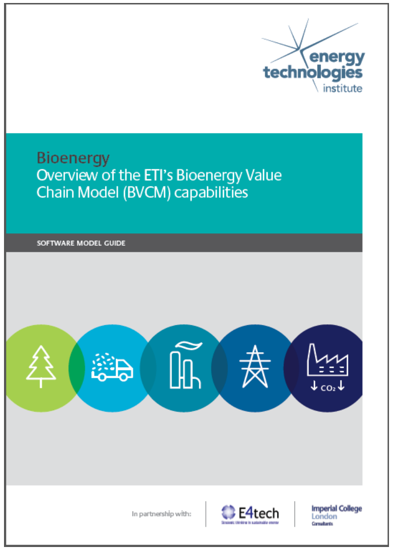
Key insights gained from BVCM

- **Bioenergy with CCS** seen as the only credible, cost-effective route to deliver the negative emissions required to help the UK meet 2050 emission reduction targets
- The lowest emission pathways convert biomass to **hydrogen** and **power**, in preference to biomethane and biofuels; but local-scale biomass heating could also be important in the near-term
- **Gasification** is a key technology for developing the bioenergy sector
- Optimal locations for UK biomass production have been identified, based on **trade-offs** between energy crop yields, land availability, conversion plant locations, CCS infrastructure and import capacities

BVCM publications

www.eti.co.uk/bioenergy-insights-into-the-future-uk-bioenergy-sector-gained-using-the-etis-bioenergy-value-chain-model-bvcm





Samsatli, S., Samsatli, N.J. & N. Shah (2015) “BVCM: A comprehensive and flexible toolkit for whole system biomass value chain analysis and optimisation – Mathematical formulation” Applied Energy 147, pp. 131-160

Looking forwards

- BVCM is a powerful **analysis tool** for supporting decision-making around optimal land use, biomass utilisation and the impact of different technology improvements
- The ETI have already used the results of BVCM to help **commission further research** and field-work on pre-treatment technologies and biomass characterisation
- E4tech and Imperial are **continuing** with improvement work, adding functionality and new data impacts
- The ETI will continue using BVCM to identify bioenergy technologies with system-wide importance, and hence **opportunities for acceleration**

Thank you for your attention!

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