Whole-systems BECCS analysis

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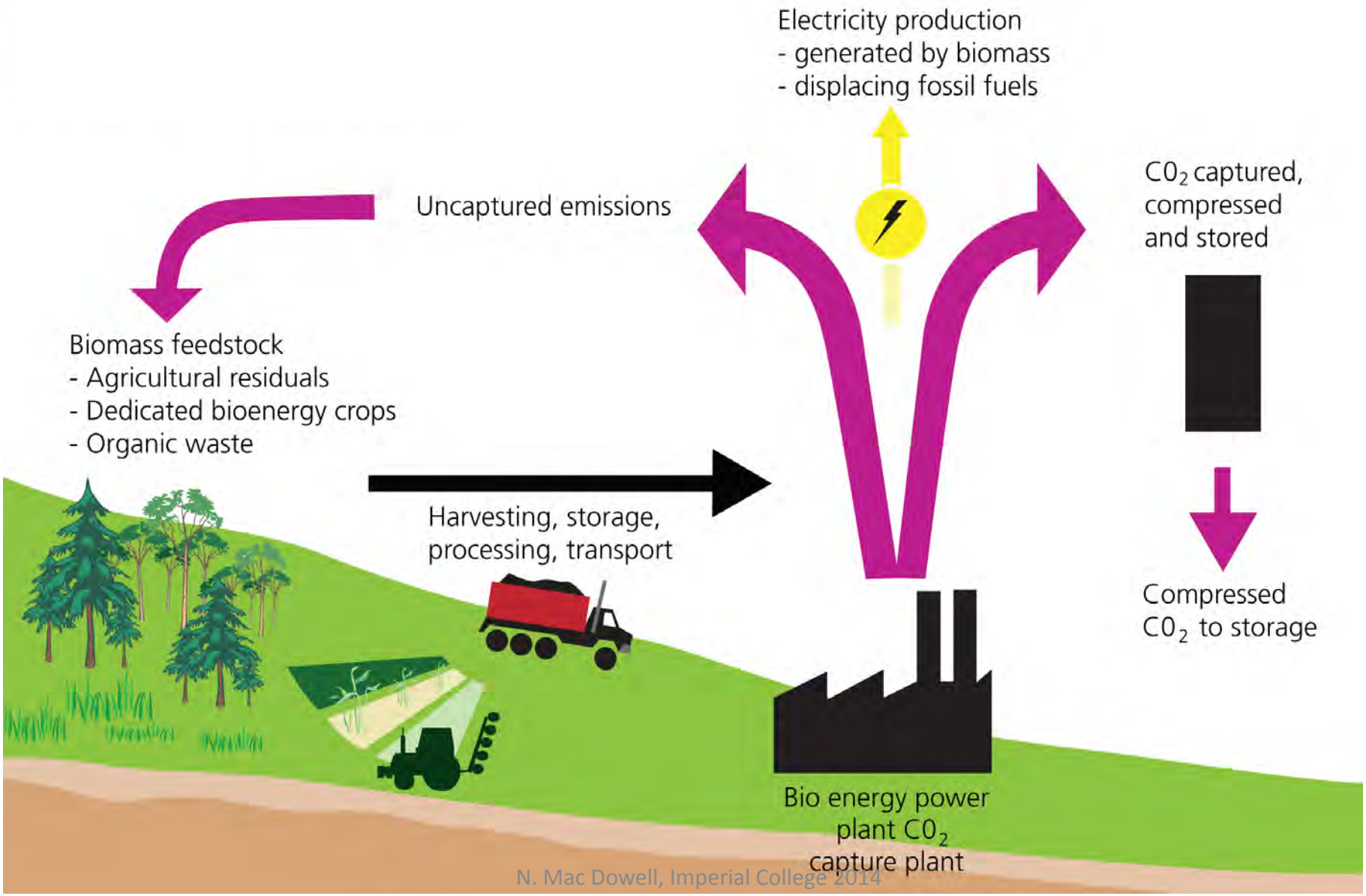
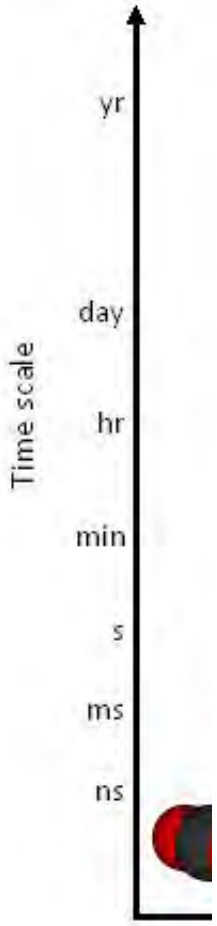
Outline

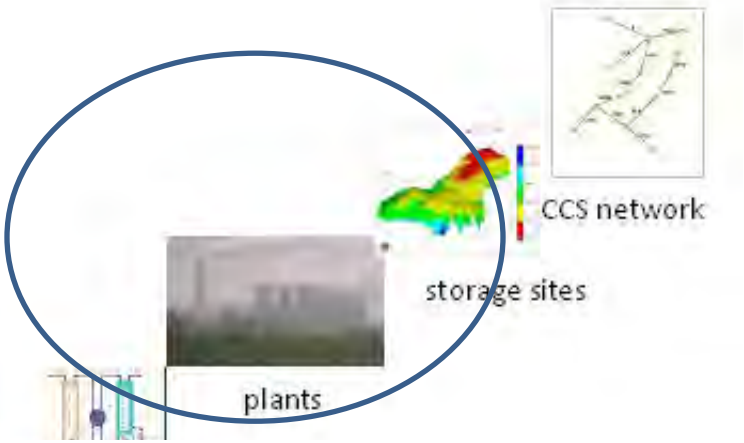
- What is BECCS?
- BECCS from the bottom up
- BECCS from the top down
- Conclusions

What is BECCS?



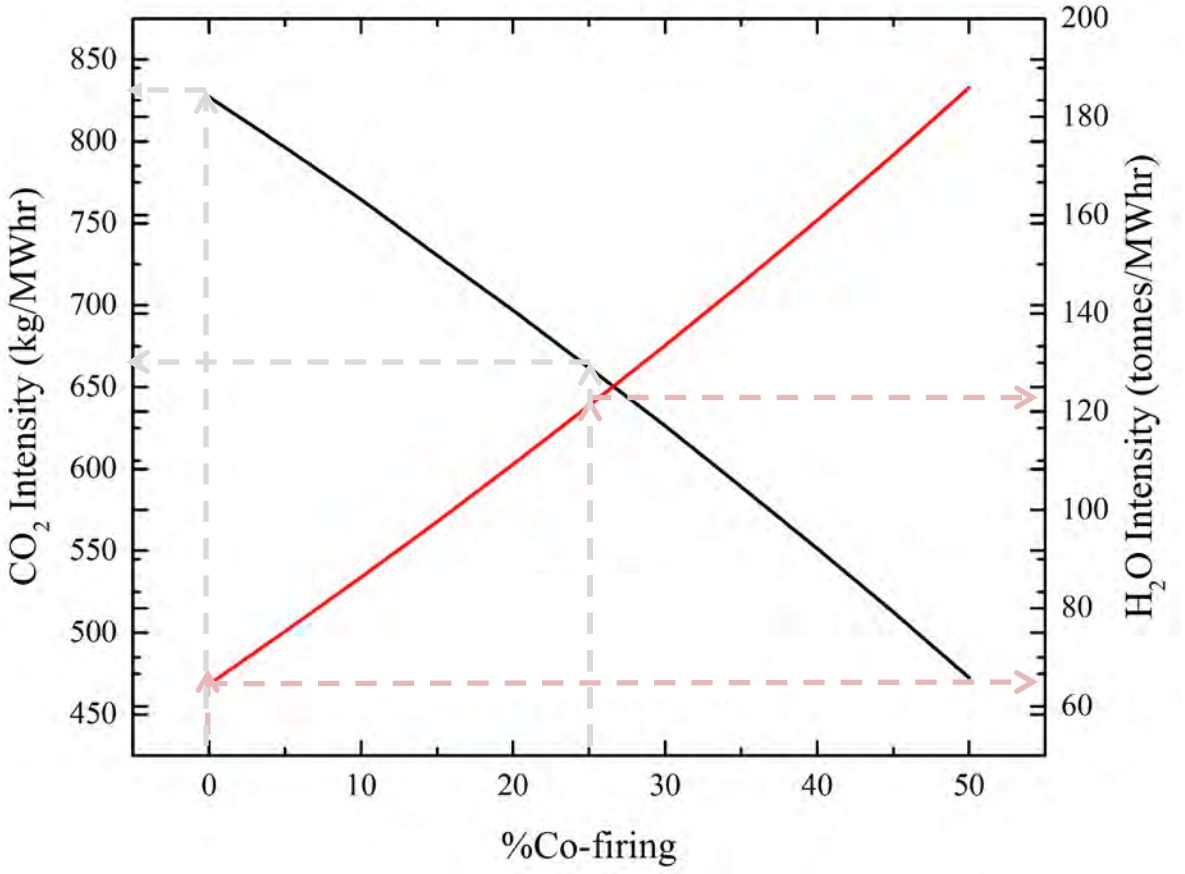
BECCS from the bottom up





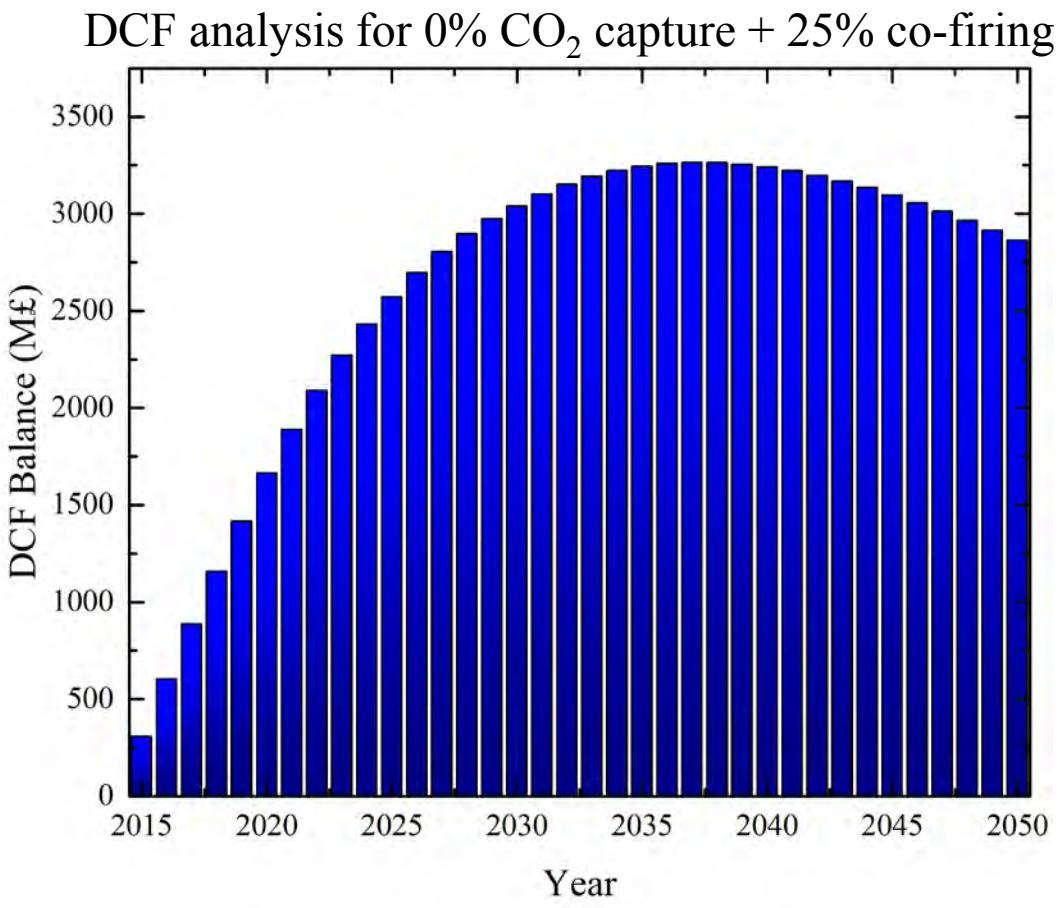
- Calculations using IECM software from CMU
- Investigated the water-carbon-biomass nexus
- Base scenario 500MW SC-PCPP, no CCS
- Separately consider the effect of co-firing and CO_2 capture on plant behaviour and economics
- Fuel/biomass/CO_2 compositions and costs as described in Akgul *et al.*, Int. J. GHG Con., 2014 (provided at the end of the presentation)

How far can co-firing go?



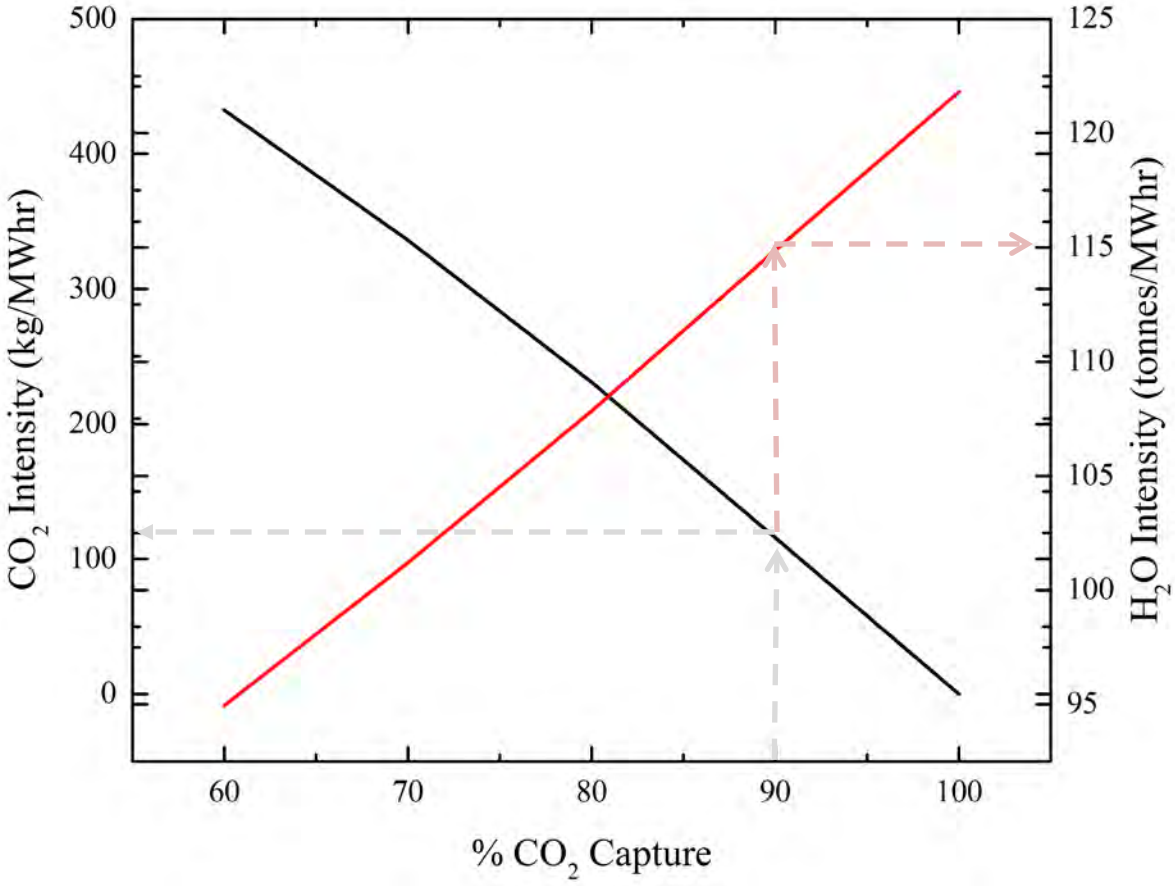
- Base-case SC-PCPP
  - $\eta \approx 39\%$ efficient
  - CI $\approx 837\ kg_{CO2}/MWh$
  - WI $\approx 64.5 Te_{H2O}/MWh$
- 25% co-firing
  - $\eta \approx 37\%$ efficient,
  - CI $\approx 662\ kg_{CO2}/MWh$
  - WI $\approx 121 Te_{H2O}/MWh$
- Majority of increase in water demand is embodied water for the production of biomass

And in the long term…



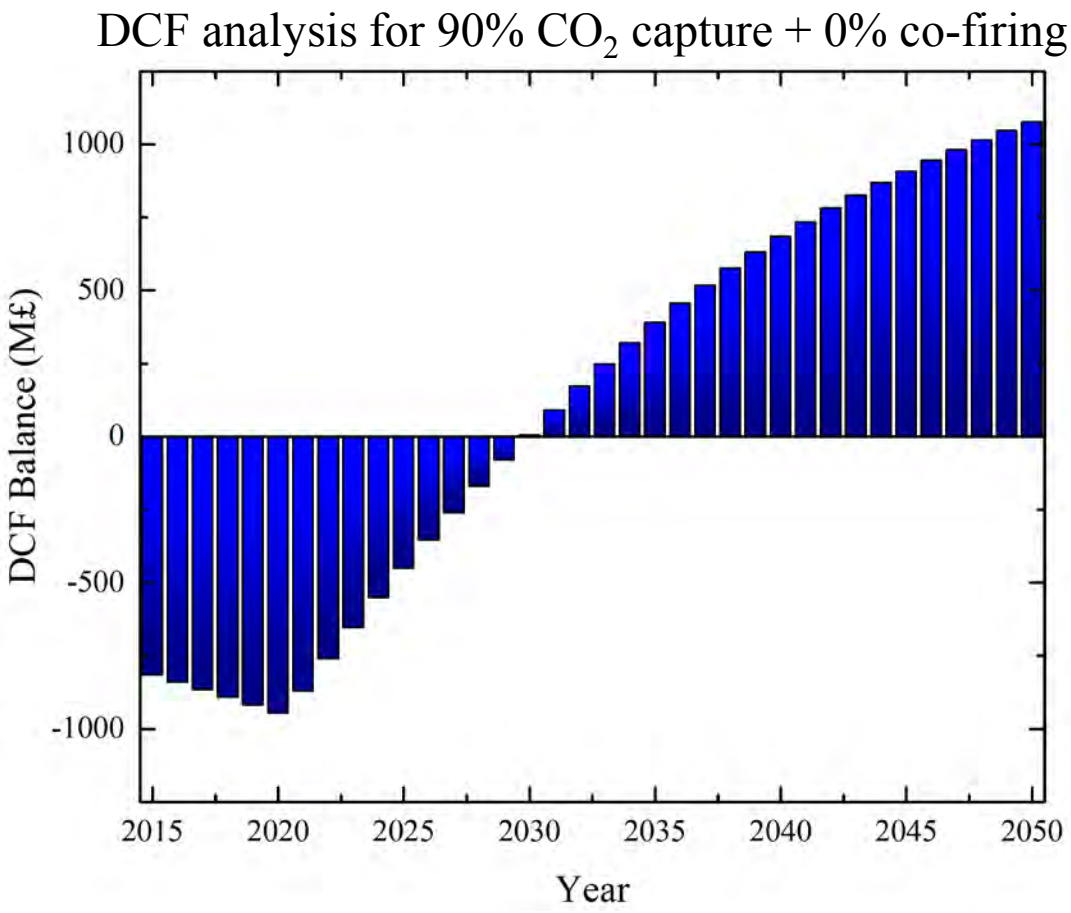
- "No" capital cost associated with co-milling biomass and fossil
- Owing to increasing carbon prices the profit generated consistently decreases
- By ~ 2040, the power plant will be loss making

What difference does CCS make?



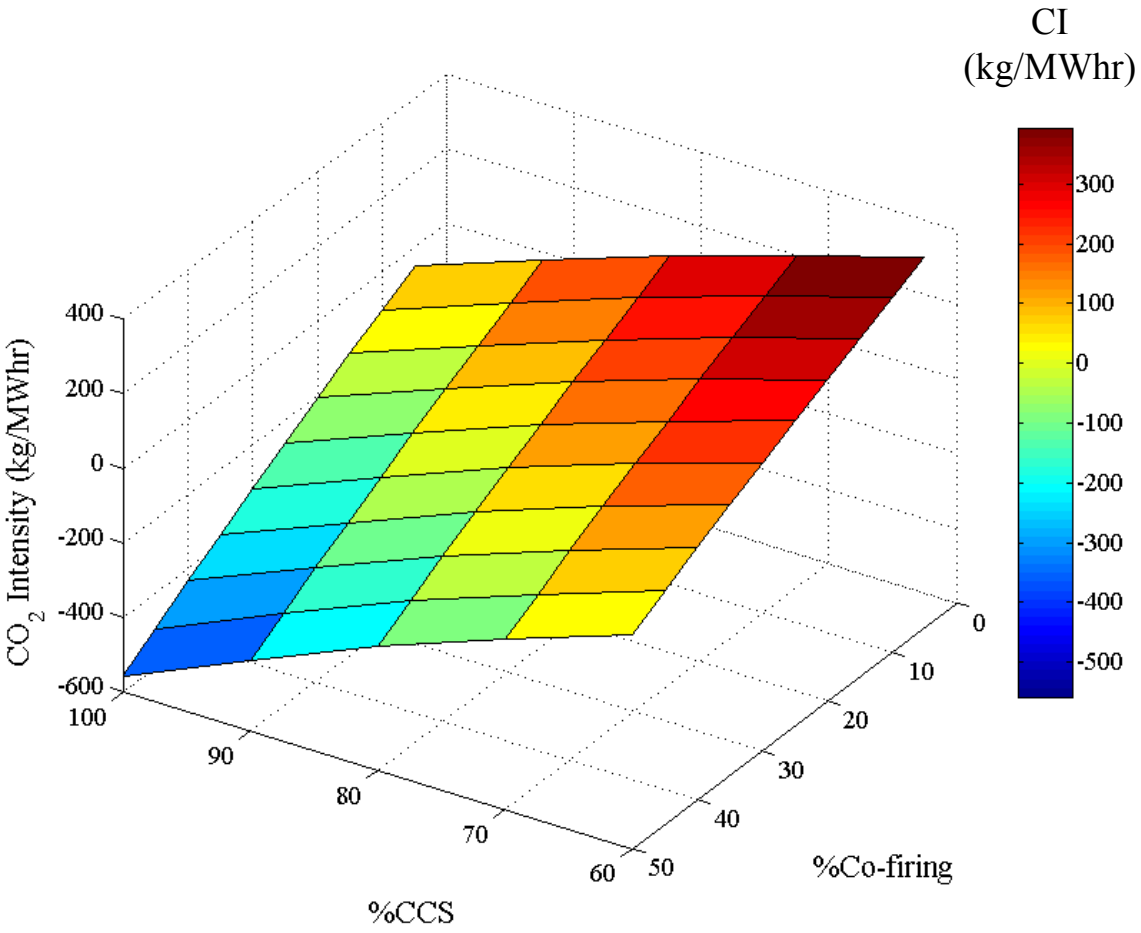
- 90% CO_2 capture
  - $\eta \approx 25\%$ efficient
  - CI $\approx 115\ kg_{CO2}/MWh$
  - WI $\approx 115 Te_{H2O}/MWh$
- Majority of increase in water demand is associated with an increased cooling load

Long term costs of CCS



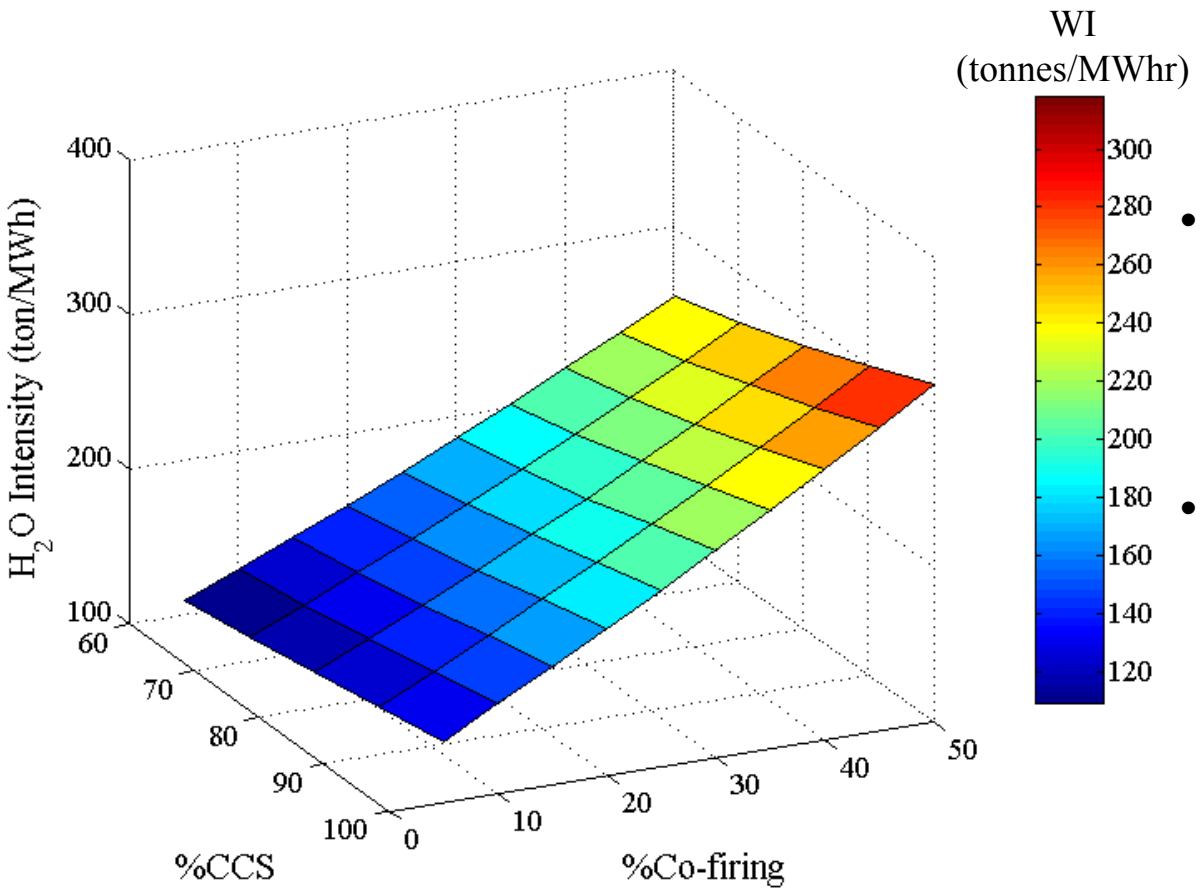
- Initial capital outlay is significant
- A strike-price of ≈ £120/MWh allows a break-even time of 10 years

What about carbon negative electricity?



- The combination of co-firing and CCS provides useful flexibility in generating low-carbon electricity

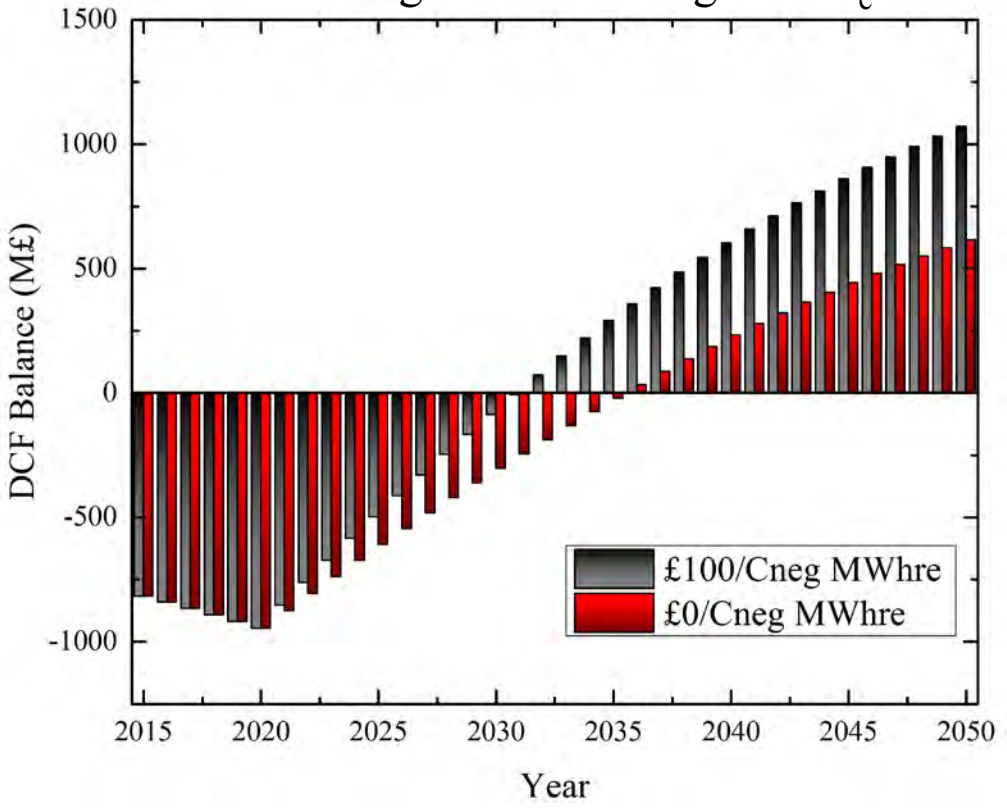
And the water footprint?



- The combination of co-firing and CCS very significantly increases the water footprint of a carbon negative power station
- The embodied water of the biomass is what drives this

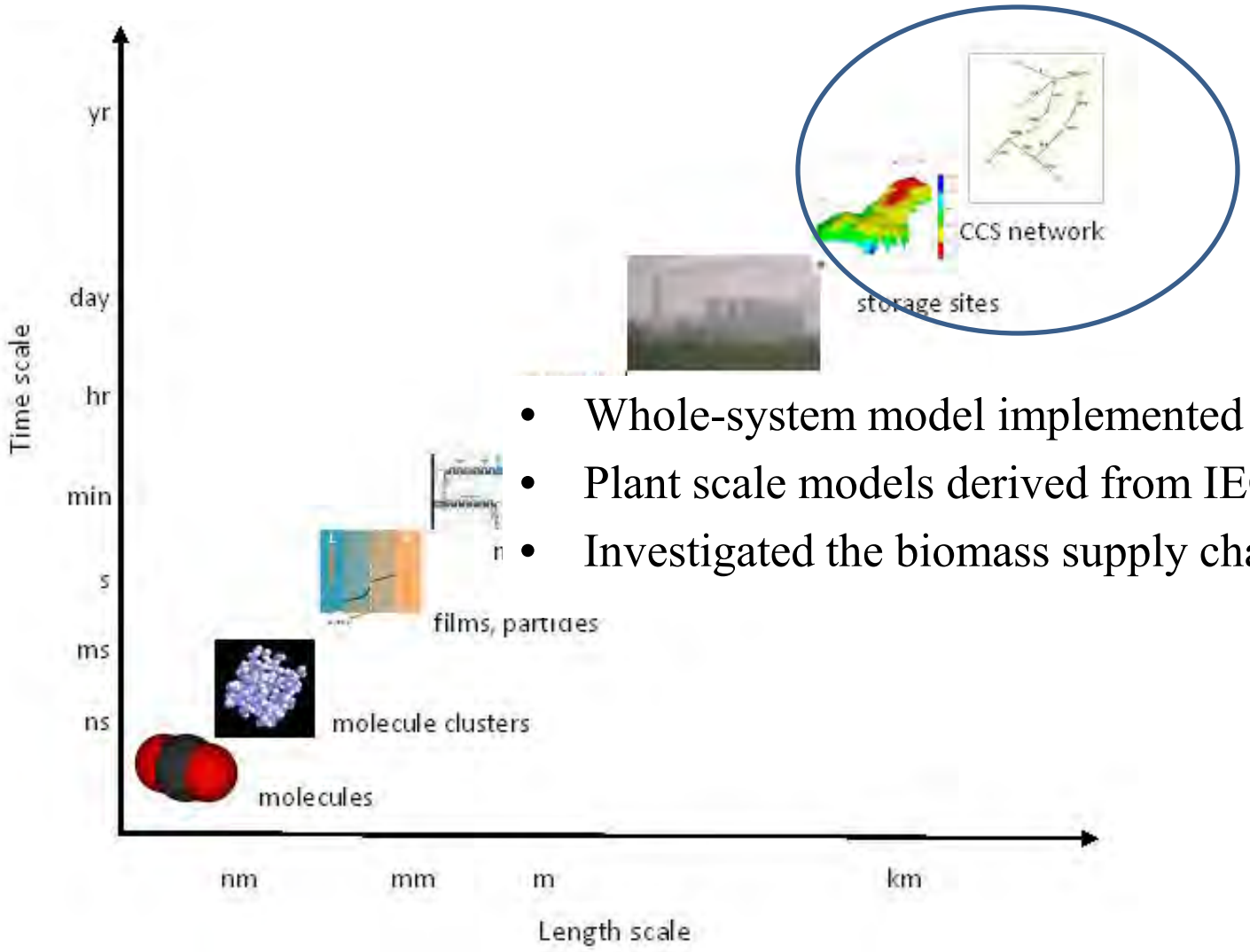
But at a much greater cost…

DCF analysis for 90% CO_2 capture + 25% co-firing CI ≈ -131.3 kg/$MWhr_e$



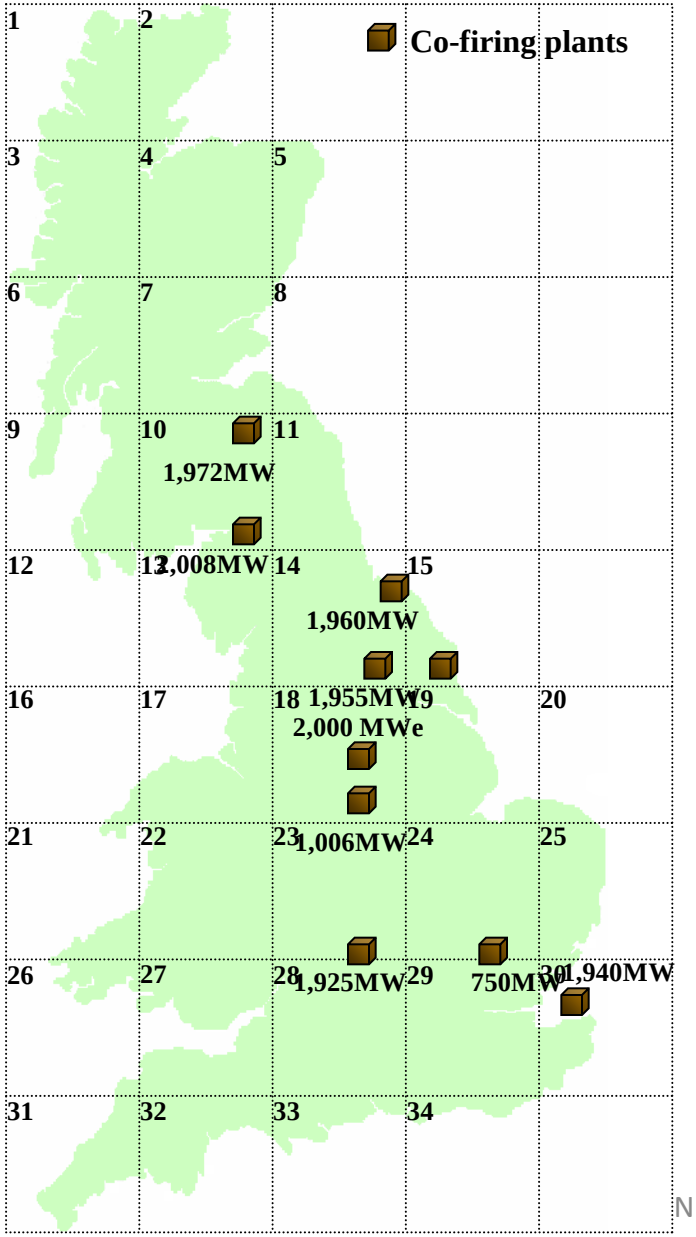
- The absence of an incentive to generate carbon negative electricity delays break even by ≈ 5 years and reduces lifetime profit by ≈ £461M wrt 90% CO_2 capture case
- A strike-price of ≈ £120/$MWhr_e$ of low carbon energy **plus** an additional ≈ £100/Cneg $MWhr_e$ of carbon negative energy allows a break-even time of ≈ 10 years and a lifetime profit ≈ to that of the 90% CO_2 capture case

BECCS from the top down

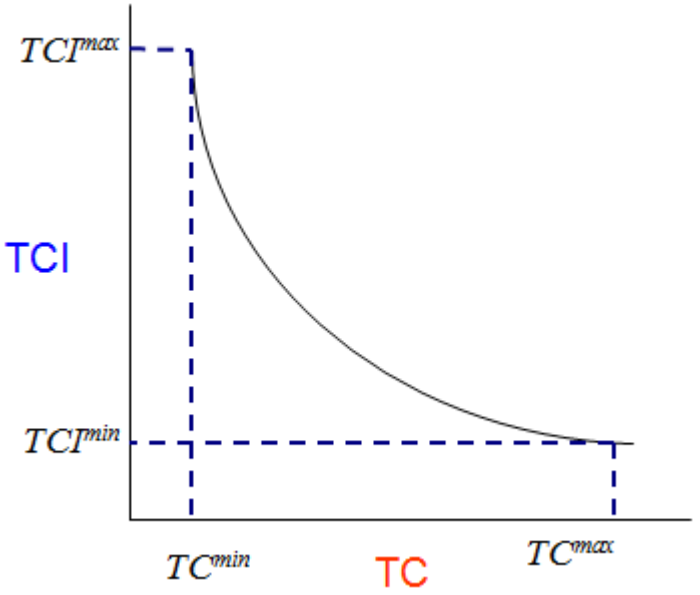


- Whole-system model implemented in GAMS
- Plant scale models derived from IECM
- Investigated the biomass supply chain issues

BECCS Network: Problem Statement



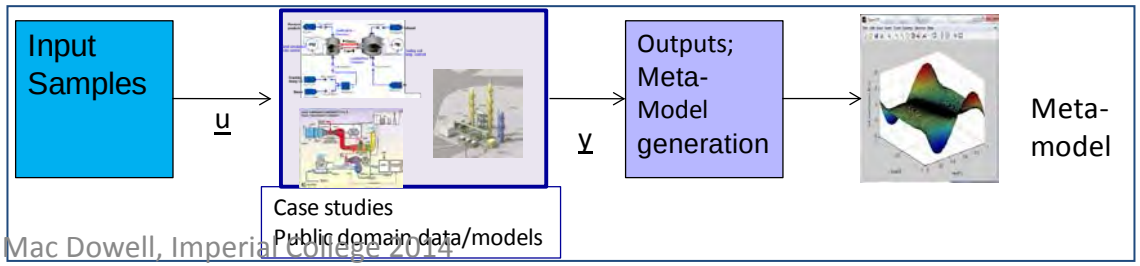
- 10 Power plants
- Capacity = 19 GW
- Demand = 9 GW



Given
- Biomass availability and cost
- Fuel and CO_2 cost
- Energy demand

Determine
- Which plants
- % Co-firing
- % CO_2 capture

Meta process model $y = y_b + A(x - x_b)$



Akgul et al., Int. J. GHG. Con., 2014

What is the whole-system objective function?

Economic objective function

$$TAC = \sum_{p\in P}\sum_{g\in G} CRF\ IC_p E_{pg}$$ Total pellet production plant capital cost

$$+ \sum_{i\in R}\sum_{g\in G} \alpha USC_{ig} P_{ig}$$ Total biomass supply cost

$$+ \sum_{i\in R}\sum_{g\in G}\sum_{p\in P} \alpha UPC_{ip}\ \gamma_i\ Df_{ipg}$$ Total pellet production cost

Biomass + SRF cost

$$+ \sum_{g\in G} \alpha UGC_g P_{elec.,g}$$ Total non-fuel power generation cost

$$+ \sum_{g\in G} \alpha UFOC_g\ \dot{m}_g \varphi_{fossil,g}$$ Total fossil fuel cost

Power plant cost

$$+ \sum_{g\in G} \alpha UCARC\ P_{elec.,g} CI_g$$ Total carbon cost

CO_2 cost

$$+ \sum_{i\in R}\sum_{g\in G} \alpha UTC^{*} ALD_g P_{ig}$$ Total raw material transportation cost

Supply chain cost

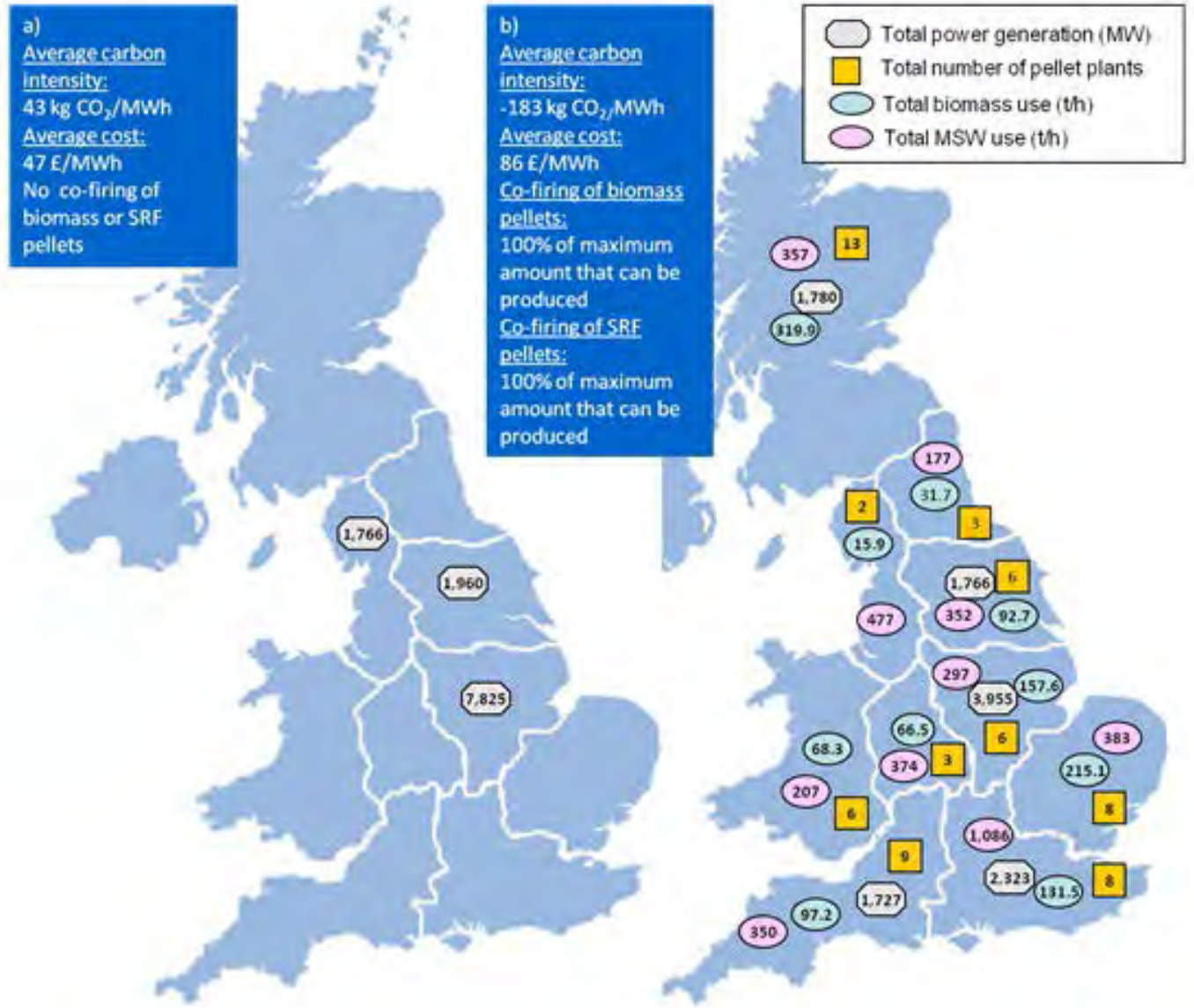
Environmental objective function

$$TAE = \sum_{g\in G} \alpha\ P_{elec.,g}\ CI_g$$ Total annual CO_2 emissions

Environmental cost

Akgul et al., Int. J. GHG. Con., 2014

What does the UK look like in 2020?



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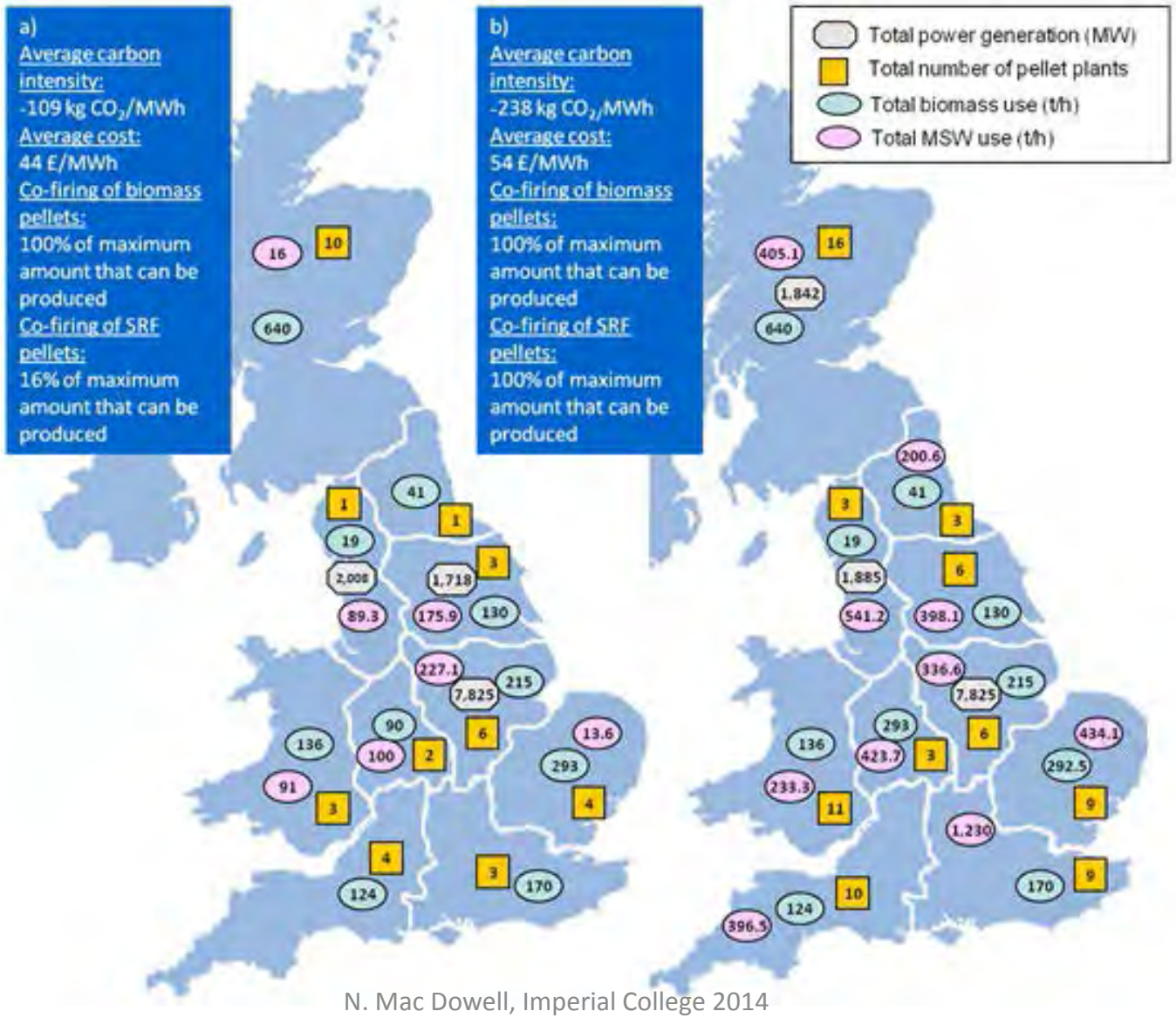
…and in 2050?



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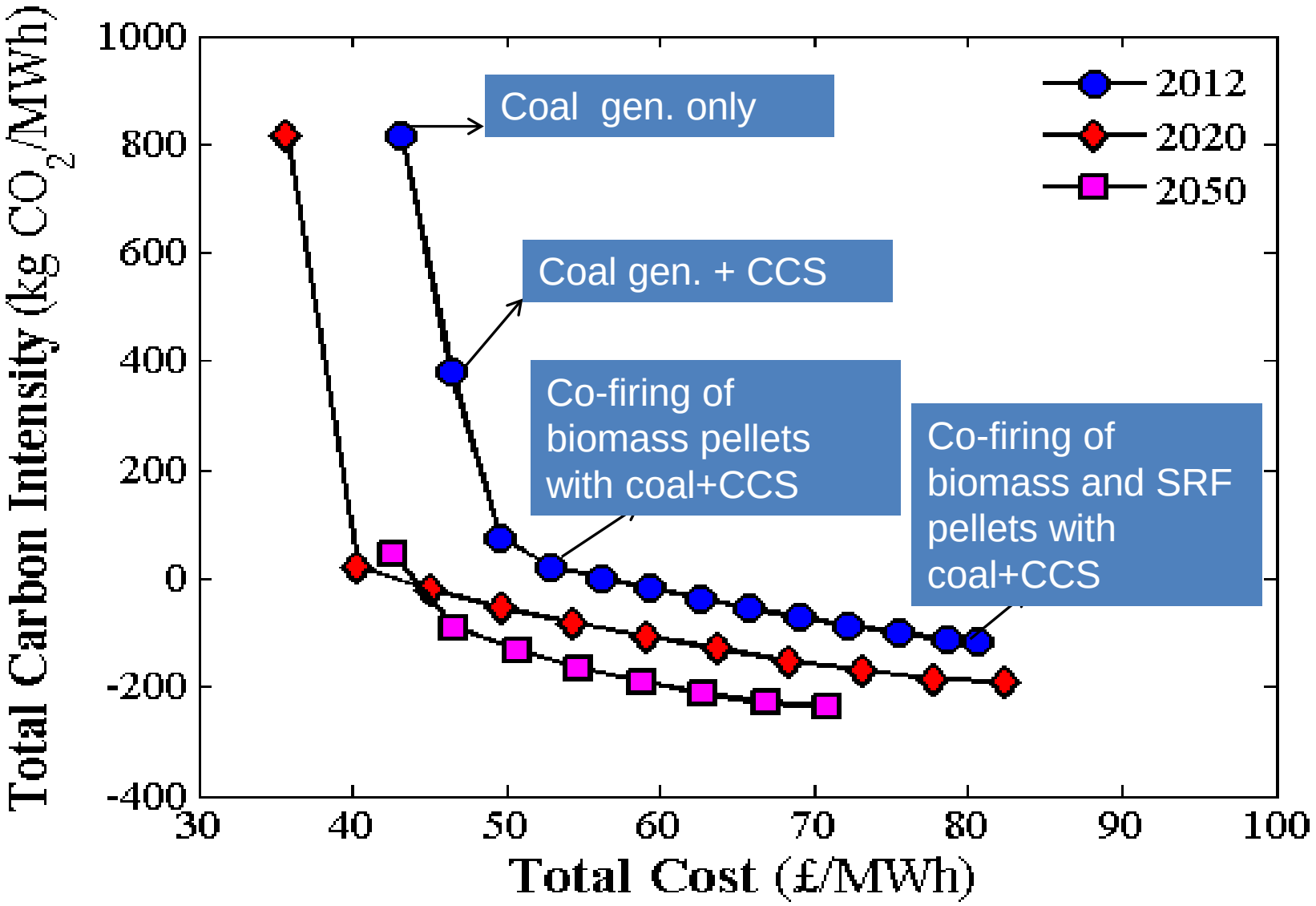
What are the trade-offs in cost? (Low Carbon price)



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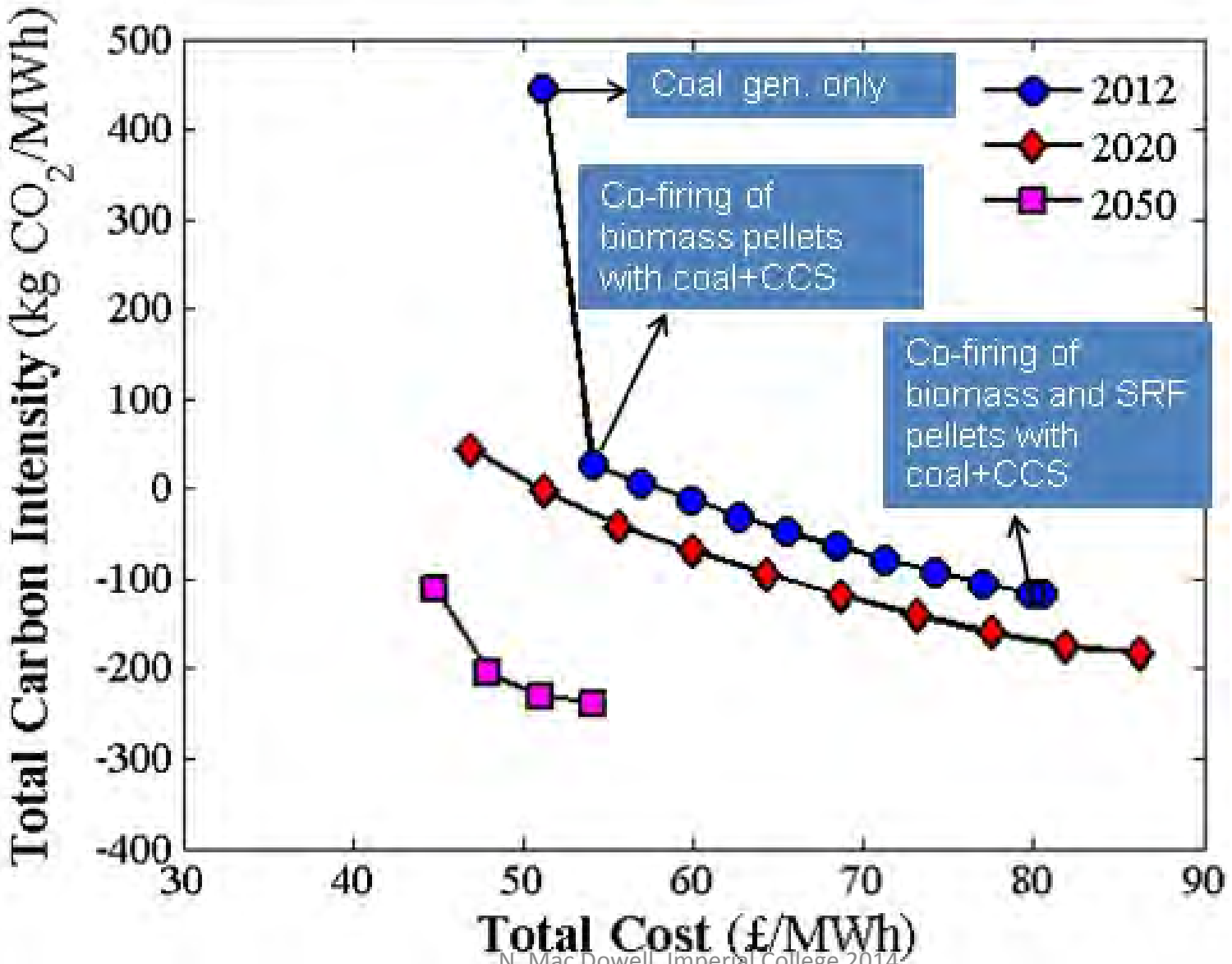
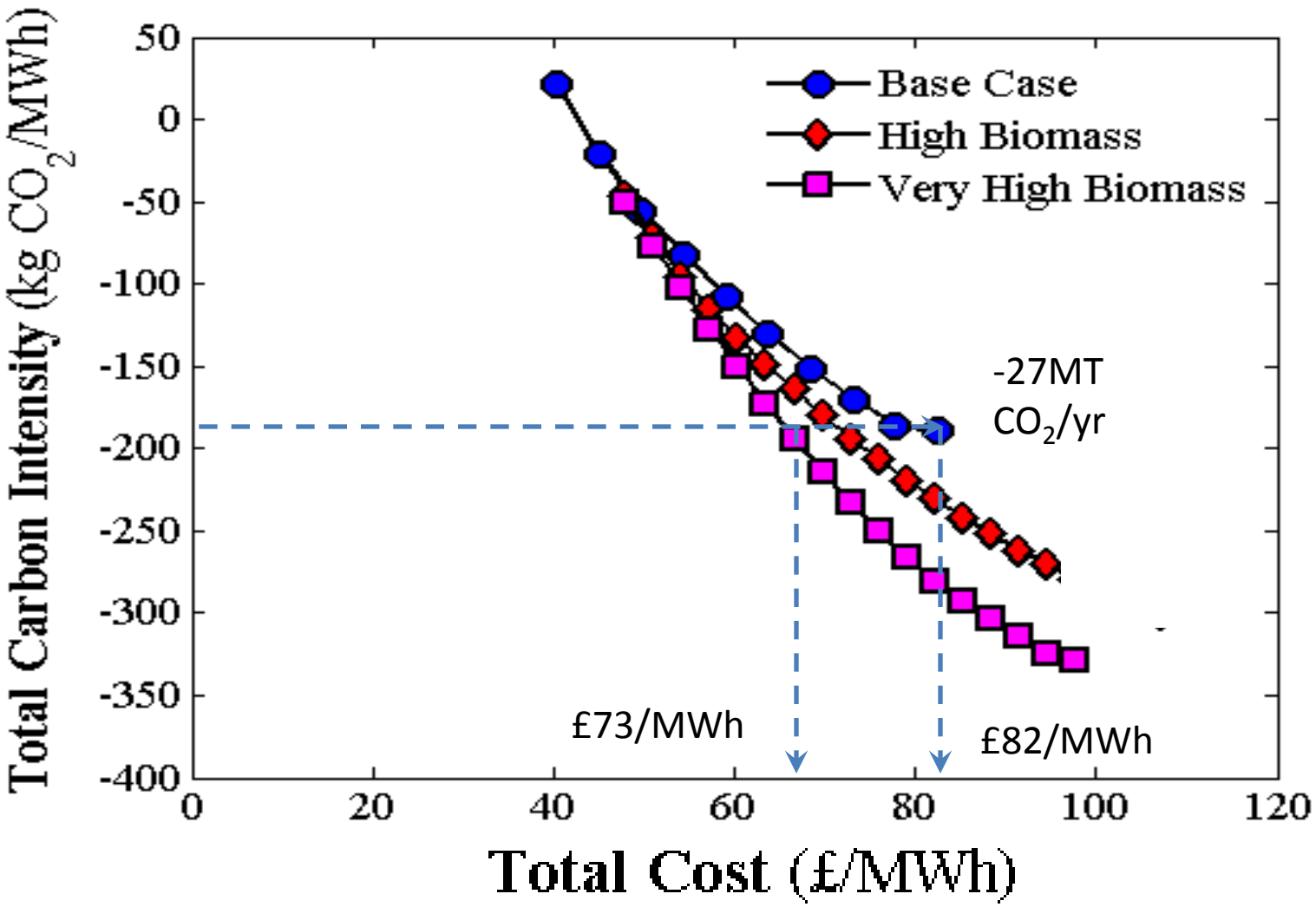
What are the trade-offs in cost? (Central Carbon price)



Akgul et al., Int. J. GHG. Con., 2014

What is the effect of increased biomass availability?



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Akgul et al., Int. J. GHG. Con., 2014

Conclusions

BECCS

- is a promising technology to generate carbon negative electricity
- may be important to providing flexibility to CCS-enabled power plants
- could be used to off-set some hard-to-reach point sources
- with biomass indigenous to the UK it is possible to offset ~ 27 Mte CO_2/yr or ≥ 20% of UK's ground transport emissions in 2012

But

- is likely to be much more costly than merely low carbon electricity
- the additional H_2O footprint and supply chain constraints may be limiting
- it is likely that an additional subsidy/incentive will be required to generate carbon negative electricity, on top of what is required for low carbon

➢ There is significant scope for technology improvements

What is the fuel composition?

Parameter	Bituminous coal	Biomass
GCV (MJ kg^{-1})	24.6	18.7
Moisture	12.0	7.0
C	59.6	43.5
H	3.8	4.5
N	1.5	0.2
O	5.5	42.6
S	1.8	0.01
Cl	0.2	0.01

- This is important as the fuel energy density and moisture content are key contributors to overall system cost, efficiency and carbon intensity
- The biogenic MSW is assumed to have the same composition as "standard" biomass

- Coal: standard bituminous coal, UK BCURA coal bank
- Biomass fuel specification from Orchid Environmental

Akgul et al., Int. J. GHG. Con., 2014

What are the cost scenarios?

	Low carbon price scenario		Central carbon price scenario		High carbon price scenario	
	CO_2 (£/t)	Coal (£/t)	CO_2 (£/t)	Coal (£/t)	CO_2 (£/t)	Coal (£/t)
2012	13	80	22	84	28	89
2020	14	52	25	71	31	98
2050	100	52	200	71	300	100

- We use coal and CO_2 price projections from UK Department of Energy and Climate Change
- Biomass price = £60/Te
- Notable for rather conservative coal prices and generally optimistic CO_2 prices
- Is this realistic?

Akgul et al., Int. J. GHG. Con., 2014