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Techno-Economic Study of Biomass to Power with CO_2 Capture

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TESBiC

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Motivation and UK context

- IEAGHG, 2011: Despite its strong GHG reduction potential, there is a considerable **dearth of information** for **biomass CCS** as compared to that for **fossil based CCS**

- ETI's ESME toolkit's least-cost options for meeting the UK's energy demand and emissions reduction targets to 2050, identify biomass CCS as **vital** with large, **negative** emissions, **a high option value** and **high persistence**

- APGTF, 2011: RD&D strategic themes and priorities

  - whole system : focus on **virtual system simulation** and **optimisation**

  - capture technologies: focus on economics, efficiency penalty, emissions, **co-fired biomass, 2nd and 3rd generation technologies**

- TESBiC 2011: Significant gaps that exist in the understanding of biomass CCS - key technical and economic barriers, and **UK deployment potential to 2050**

TESBiC assessment criteria: a range of development, techno-economic, feedstock, feasibility and UK aspects

Development aspects and prospects

- Key drivers for development
- Key development issues, potential show-stoppers
- Main players internationally
- Pilot/demonstration /commercial plants and R&D activities
- Current TRL
- Likely TRL in 2020
- Environmental issues

Techno-economics

- Equipment scales (MW min, MW max), suitability for small-scale
- Plant LHV efficiency with capture
- Flexibility, ability to load follow
- Capital cost with capture

UK aspects

- UK activities and capabilities
- Opportunity space, IP considerations
- UK deployment potential
- Timing of demonstration plants

Feedstocks and feasibility

- Contaminants of risk, required specifications
- Pre-processing needs, benefits
- Appropriate feedstocks, robustness to variability
- Maximum % co-firing feasible
- Technical feasibility of component combination
- Ease of changing to high co-firing / 100% dedicated conversion

TESBiC approach

- Landscape review of **28** biomass based power generation combined with carbon capture technology combinations. Based on the assessment criteria, **8** technology combinations were shortlisted

- **High-level Engineering Case Studies** were performed focusing on the material and energy balances, capital and operating expenditures, emissions and environmental performance , process control strategies, current gaps and development needs

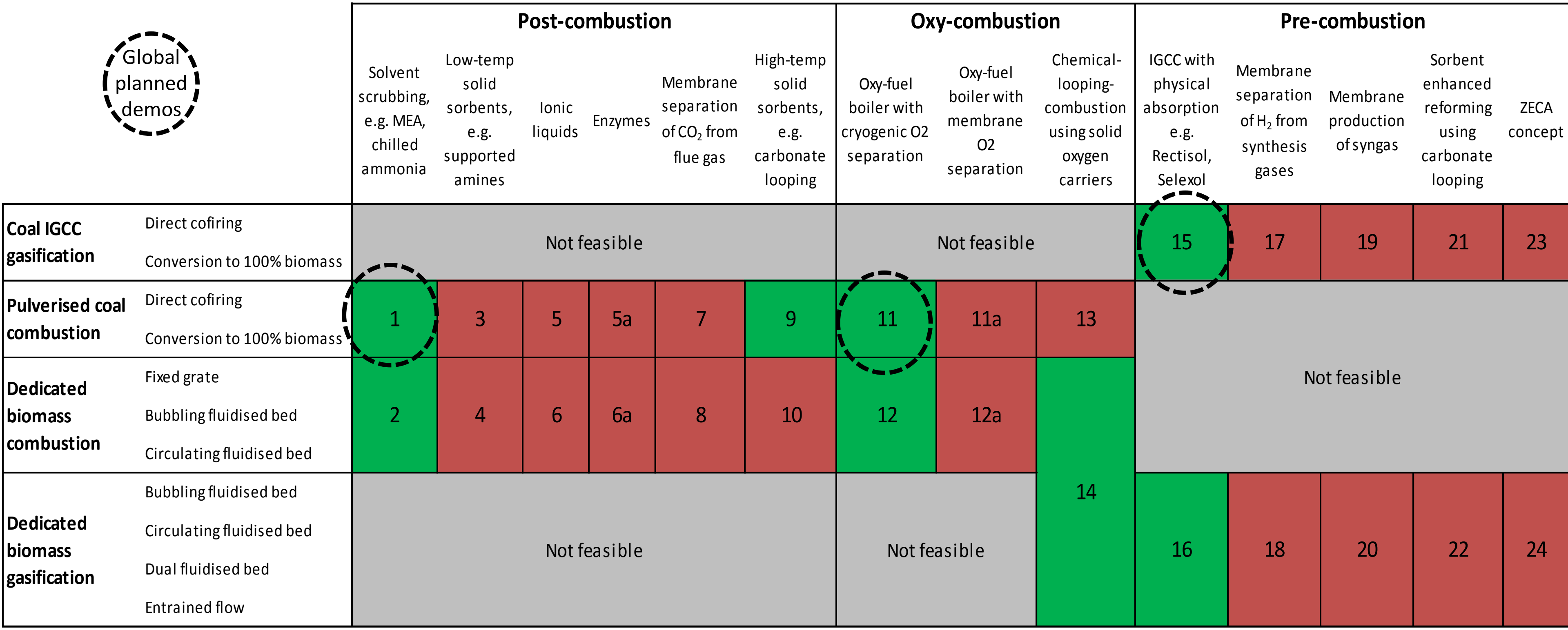
- **Models** were formulated for individual technology combinations to simulate

  the impact of **inputs**: co-firing %, carbon capture extent, nameplate and operating capacities

  on the **outputs**: CAPEX, OPEX, Generation efficiency, CO_2, SO_x, NO_x emissions.

- These models can be seamlessly integrated within ETI's modelling toolkits, namely, the **Biomass Value Chain** and the **ESME**.

Power generation and CO_2 capture combinations



◌ Global planned demos

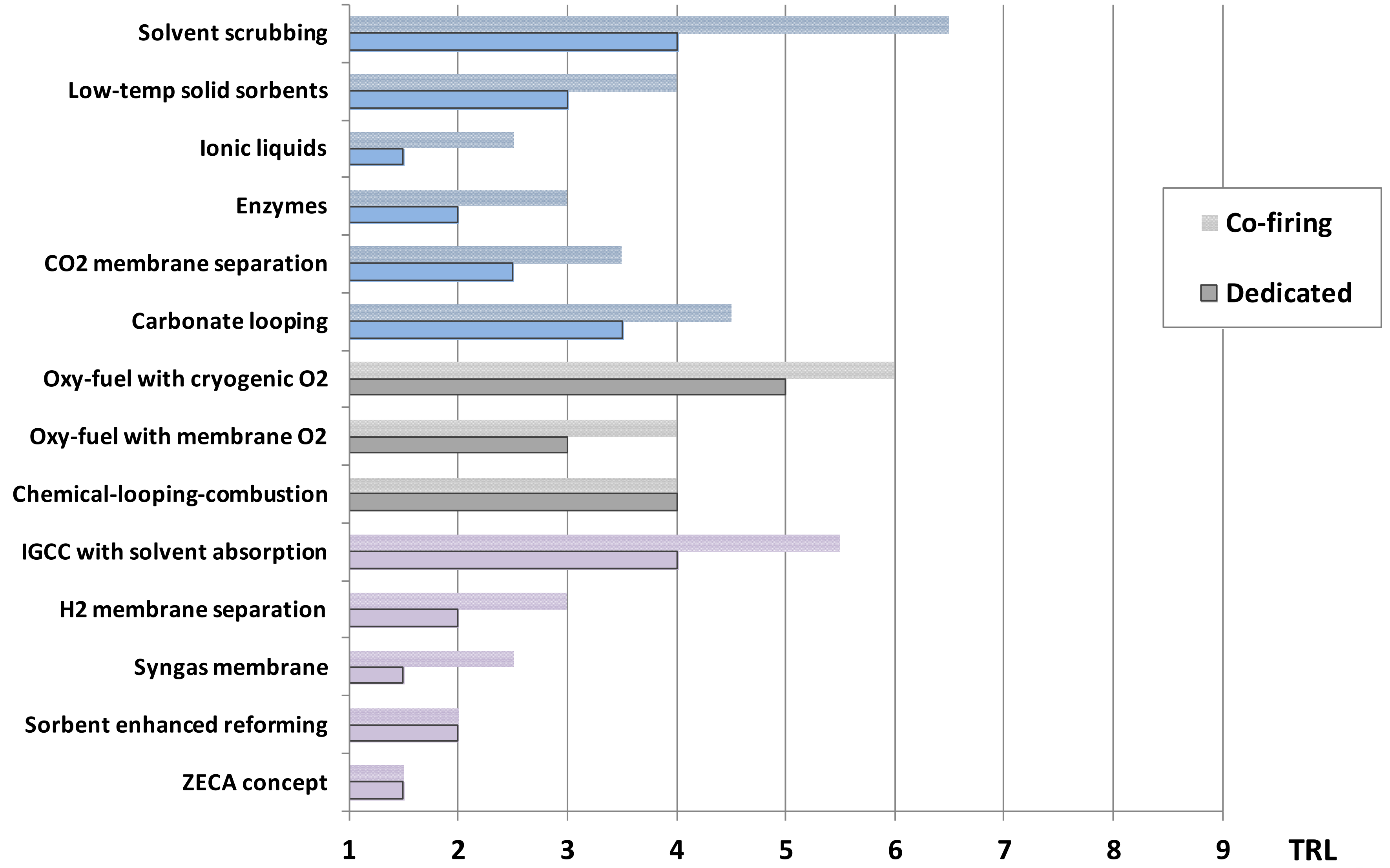
		Post-combustion						Oxy-combustion			Pre-combustion				
		Solvent scrubbing, e.g. MEA, chilled ammonia	Low-temp solid sorbents, e.g. supported amines	Ionic liquids	Enzymes	Membrane separation of CO_2 from flue gas	High-temp solid sorbents, e.g. carbonate looping	Oxy-fuel boiler with cryogenic O2 separation	Oxy-fuel boiler with membrane O2 separation	Chemical-looping-combustion using solid oxygen carriers	IGCC with physical absorption e.g. Rectisol, Selexol	Membrane separation of H_2 from synthesis gases	Membrane production of syngas	Sorbent enhanced reforming using carbonate looping	ZECA concept
Coal IGCC gasification	Direct cofiring Conversion to 100% biomass	Not feasible						Not feasible			🟩 15 ◌	🟥 17	🟥 19	🟥 21	🟥 23
Pulverised coal combustion	Direct cofiring Conversion to 100% biomass	🟩 1 ◌	🟥 3	🟥 5	🟥 5a	🟥 7	🟩 9	🟩 11 ◌	🟥 11a	🟥 13	Not feasible				
Dedicated biomass combustion	Fixed grate Bubbling fluidised bed Circulating fluidised bed	🟩 2	🟥 4	🟥 6	🟥 6a	🟥 8	🟥 10	🟩 12	🟥 12a	🟩 14					
Dedicated biomass gasification	Bubbling fluidised bed Circulating fluidised bed Dual fluidised bed Entrained flow	Not feasible						Not feasible			🟩 16	🟥 18	🟥 20	🟥 22	🟥 24

🟩 Progress
🟥 Reject

Shortlisted technology combinations

Criteria	Co-firing amine scrubbing	Dedicated biomass with amine scrubbing	Co-firing oxy-fuel	Dedicated biomass oxy-fuel	Co-firing carbonate looping	Dedicated biomass chemical looping	Co-firing IGCC	Dedicated biomass BIGCC
Likely TRL in 2020	7 to 8	6 to 7	7	6	5 to 6	5 to 6	7	5 to 6
Key technical issues	Scale-up, amine degradation,	Scale-up, amine degradation,	O_2 energy costs, slow response	O_2 energy costs, slow response	Calciner firing, solid degradation, large purge of CaO	Loss in activity, reaction rates, dual bed operation	Complex operation, slow response, tar cleaning, retrofit impractical	Complex operation, slow response, tar cleaning, retrofit impractical
Suitability for small scale	Low	High	Low	High	Low	High	Low	High
Plant efficiency with capture	OK	Low	OK	Low	Good	Good	High,	Good
Capital costs with capture	OK	Expensive	OK	High ASU costs	OK	Low cost	OK	Expensive,
UK deployment potential	Immediate capture retrofit opportunities ,	retrofit opportunities high long-term potential	retrofit opportunities , long-term doubtful	retrofit opportunities , high long-term potential	capture retrofit opportunities, cement integration	Likely first demos in Europe, UK in ~2020. High long term potential	No current UK plants, several demos by 2020 Long-term doubt	No current UK plants, demo unlikely by 2020. High long-term potential

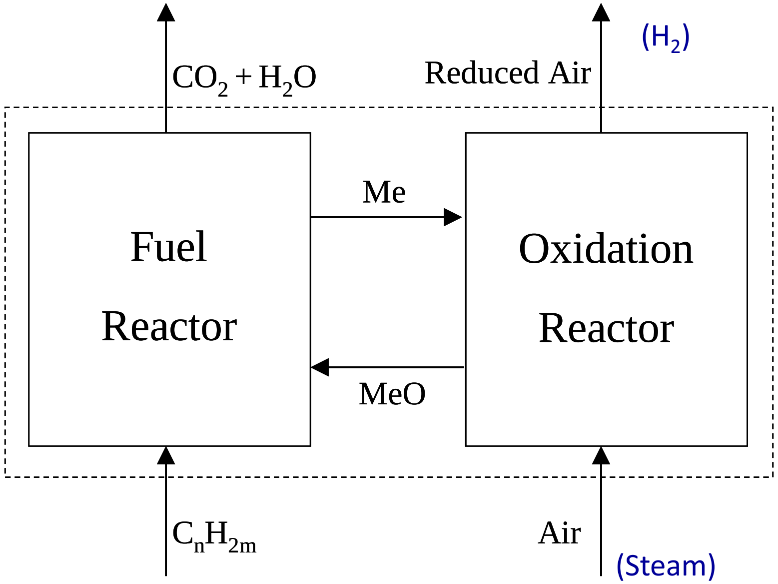
Current Technology Readiness Levels



Chemical-looping-combustion using solid oxygen carriers

- Cu-based oxygen carrier, cycled between between CuO and Cu_2O *via* the following “uncoupling” reaction:

$$4CuO \leftrightarrow 2Cu_2O + O_2$$

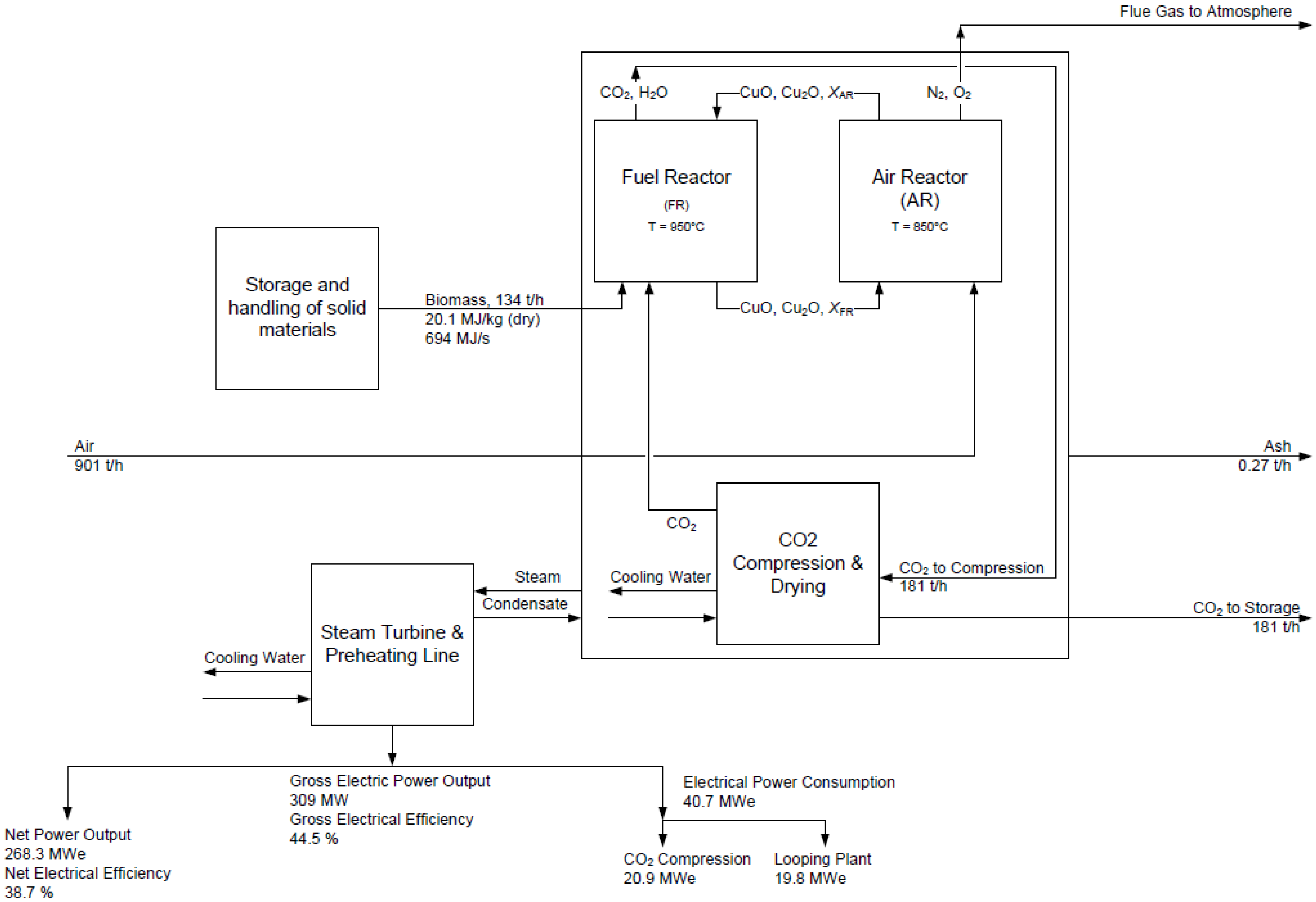


- Net reaction in the fuel reactor is exothermic, and so heat is extracted from the reactor to raise steam for power generation.

- Very high CO_2 capture rates possible, and minimal plant efficiency penalty

- Pilot and lab-scale testing at TU Darmstadt, Vienna, Chalmers, Imperial and Cambridge. Increasing industrial interest from Alstom, Air Liquide and Vattenfall

Dedicated biomass chemical looping combustion



Plant performance, CAPEX and OPEX estimates

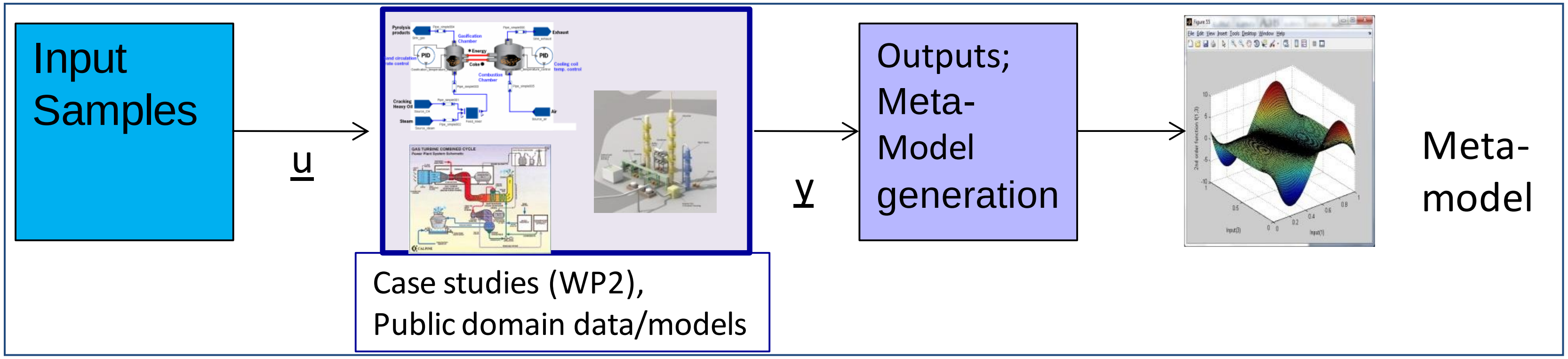
300 MWe, net efficiency ~ 41%

Item	£M, 2011
Storage and handling of solid materials	41.1
Boiler island	220.5
CO_2 compression and drying plant	31.4
Power island	76.5
Air reactor (458 m^3)	64.8
Fuel reactor (581 m^3)	74.9
Total installed CAPEX	**509.2**
Operation and utilities (% of TIC)	25.5
Civils and land costs (% of TIC)	50.9
Project Development Costs (% of TIC)	25.5
Contingency (% of TIC)	50.9
Total investment cost	**661.9**
Specific investment cost (£M/MW_e)	**2.21**

Variable Costs	**Usage**	**£M/yr**
1. Wood fuel	8.29×10^8 kg/yr	116.0
2. Oxygen carrier (new)	1.19×10^6 kg/yr	4.74
3. Spent carrier (credit)		-4.22
4. Fly ash disposal	1.78×10^6 kg/yr	0.00356
5. Cooling water make-up	9588 kg/s	51.4
Variable costs		**167.9**
Maintenance and Labour		20.37
Insurance		5.09
Fixed costs		25.46
Total O&M costs		**193.36**

Capacities investigated: 40 to 300 MW_e → CLC more suitable for small scales ~40MW_e

Model formulation



Input Samples

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Case studies (WP2),
Public domain data/models

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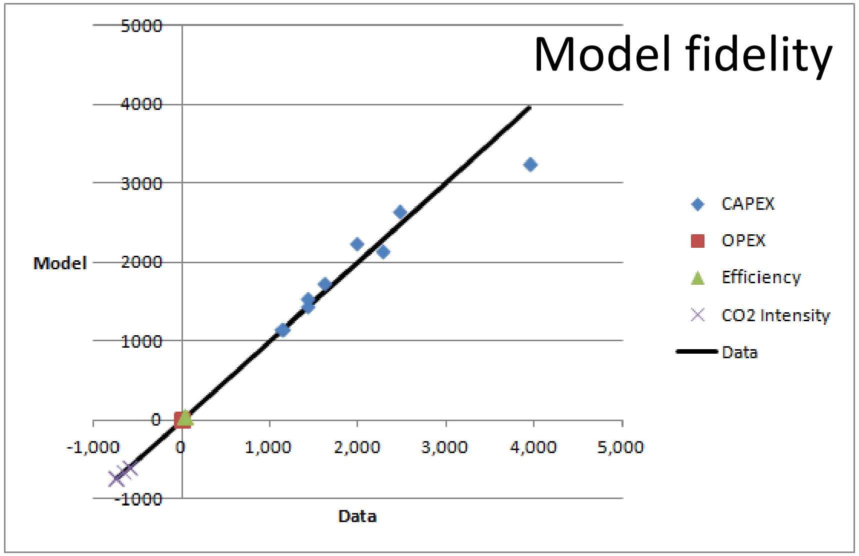
Outputs; Meta-Model generation

Meta-model

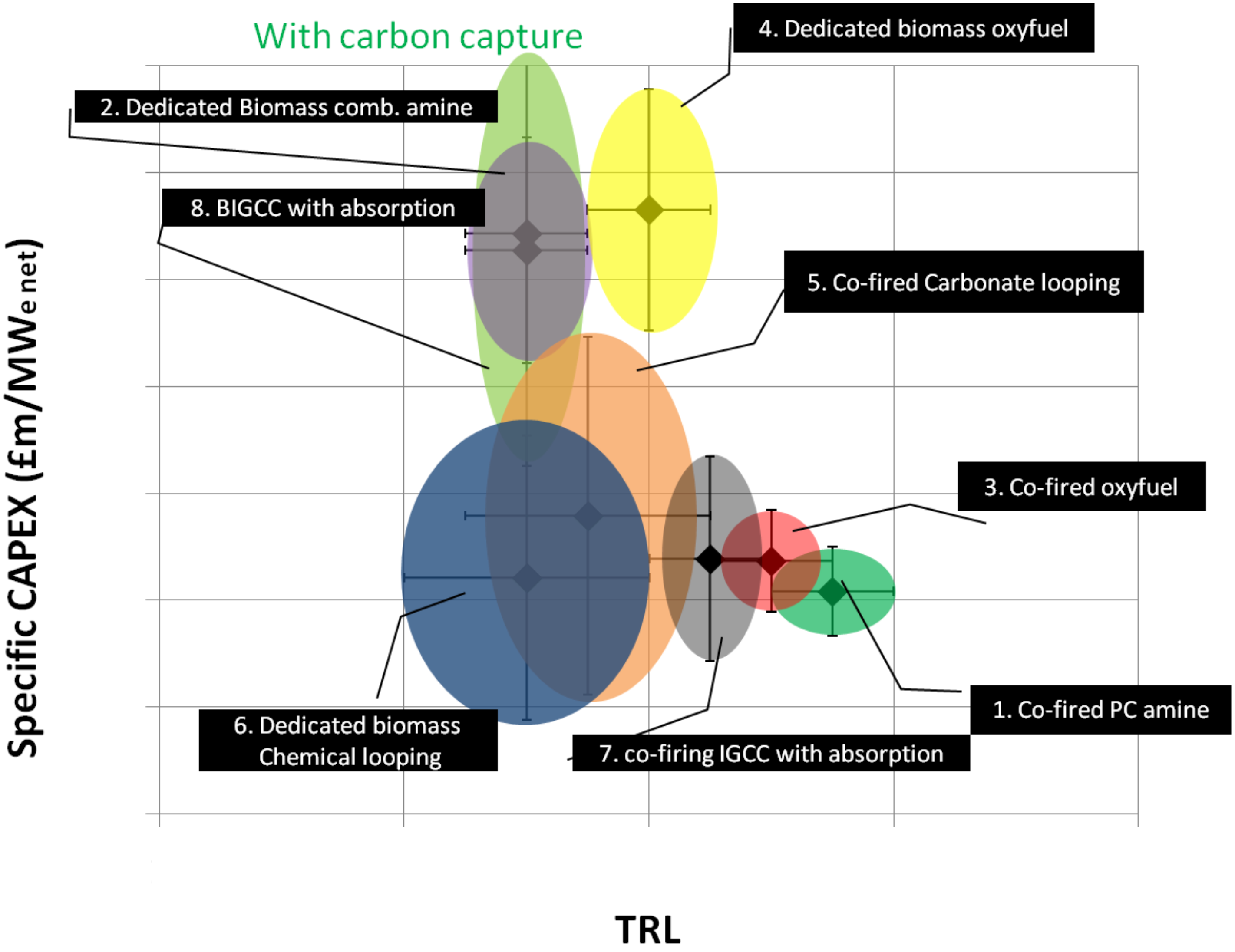
Input variables	Lower bound	Upper bound
Nameplate capacity (MWe)	40	300
Capacity Factor (%)	0	100
CO_2 capture extent (%)	0	100



Model fidelity

Model response: CAPEX, OPEX, generation efficiency, CO_2, SO_x, NO_x emissions as a function of the 3 input variables.

Capital costs and TRLs



Summary I - Overview

- To date**, little activity at industrial scale** on the application of CO_2 capture technologies to co-fired or dedicated biomass power plants
- The industry's progression to the large fossil-based CCS demonstration projects is slow due to **high costs** and **requirement of significant government subsidies**
- **Dependency on fossil based CCS:** Recent setbacks and cancellations of the coal-based CCS projects will further delay the development of biomass CCS
- **TESBiC** project focuses on addressing the **existing gaps** in understanding **biomass CCS** through a detailed landscape review, high level engineering study and robust model development and validation
- The tools developed in TESBiC are seamlessly compatible with the ETI's simulators thereby enabling **comprehensive virtual engineering and optimisation** applied to the whole biomass CCS system; a critical RD&D priority that has been identified in the APGTF strategy

Summary II: Techno-economic parameters

- The TESBiC consortium exploited its unique composition [industry-SMEs-academia] to rigorously debate the techno-economic parameters

- The TRLs for the eight technology combinations and associated components assessed, varied over a wide range from **TRL 3 to TRL 8**

- Range of **techno-economic parameters** over the 8 biomass-based power generation combined with carbon capture technologies
  - ~ 5% to 15% : Range of the efficiency drop
  - ~ 45% to 130%: Range of the increase in specific CAPEX (£/MW$_e$) with carbon capture
  - ~ 4% to 36%: Range of increase in OPEX (£/yr) with carbon capture

Q&A

Thank you for your attention!

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