Programme Area: Bioenergy

Project: Biomass to Power with CCS

Title: Executive Summary - BI2001: Biomass Power with CCS; Technology Landscape report and recommendations

Abstract:

The Biomass to Power with CCS project (2011-2012) consisted of an assessment of the technology and cost barriers for biomass fuelled power and the optimum scale-up potential of single-source and co-fired biomass to power with carbon capture technology.This executive summary is based on the summary provided by the consortium in their
Technology Landscape and Recommendations Report; this is the output of Work Package 1.

Context:

The Biomass to Power with CCS Phase 1 project consisted of four work packages: WP1: Landscape review of current developments; WP2: High Level Engineering Study (down-selecting from 24 to 8 Biomass to Power with CCS technologies); WP3: Parameterised Sub-System Models development; and WP4: Technology benchmarking and recommendation report. Reports generally follow this coding. We would suggest that you do not read any of the earlier deliverables in isolation as some assumptions in the reports were shown to be invalid. We would recommend that you read the project executive summaries as they provide a good summary of the overall conclusions. This work demonstrated the potential value of Biomass to Power with CCS technologies as a family, but it was clear at the time of the project, that the individual technologies were insufficiently mature to be able to ‘pick a winner’, due to the uncertainties around cost and performance associated with lower Technology Readiness Levels (TRLs).

Executive Summary

BI2001: Biomass Power with CCS; Technology Landscape report and recommendations

Project Manager's Introduction

The Project's Goal

An assessment of the technology and cost barriers for biomass fuelled power and the optimum scale-up potential of single-source and co-fired biomass to power with carbon capture technology

Outline Scope of the Project

While cost has been reported to be a major barrier in terms of CCS for biomass, the technical challenges and technology developments required are, also, not clear. Detailed work is currently ongoing in terms of assessing CO2 capture with coal and gas-fired generation, whilst limited work is being conducted on the assessment of dedicated biomass to power with CCS; or indeed, of co-firing fossil fuel fired generation with higher rates of biomass with CCS.

The fundamental requirements of this work will therefore be to develop a techno-economic assessment of the barriers in terms of biomass to power with CCS systems; provide an assessment and comparison of various potential biomass to power with CCS configurations (at both small and large scale); and an assessment and comparison of dedicated biomass/CCS combinations with co-fired biomass/fossil/CCS combinations.

The project comprises of the following four work packages:

1. Landscape Review of Current Developments
2. High Level Engineering Study
3. Parameterised Sub-System Models Development
4. Technology Benchmarking and Recommendation Report

The Project Consortium consists of

- CMCL Innovations (Project Lead)
- Doosan Babcock (Chief Technologist)
- E4Tech
- EDF
- Drax
- University of Cambridge
- Imperial College, London
- University of Leeds

Scope of this Executive Summary

This executive summary is based on the summary provided by the consortium in their Technology Landscape and Recommendations Report; this is the output of work package 1. The original project budget was £455k (fixed price), of which this work package cost £120k.

Status of report recommendations

The consortium recommended that eight, rather than five, technologies were taken forward for investigation in the three remaining work packages. The recommendation to increase the range of technologies was supported by most of the external reviewers. The ETI Executive, at their July meeting, agreed to extend the project scope to cover up to eight technologies with a revised project budget of £680k. The Executive delegated authority to the Strategy and Programme Manager to decide the specific technologies to be taken forward.

Next steps

The project is now working on the High Level Engineering Study and the Parameterised Sub-Systems Models Development. The former is led by Doosan Babcock and the later by Imperial College.

The project schedule is currently being updated to reflect the increase from five to eight technologies. We do expect, though, that:

- The High Level Engineering Study will be complete by early winter 2011
- The Parameterised Sub-System Modelling work will take until early spring 2012, though the first 5, prioritised, technology models, should be submitted to ETI before Christmas 2011.
- The Final Report will be submitted in early summer 2012.

Executive Summary: Technology Landscape report and recommendations

What is biomass CCS?

In the context of this project, biomass power with Carbon Capture and Storage (CCS) has three main components:

- A biomass feedstock supply chain
- A power plant conversion system
- A carbon capture technology

Since each of these components has a variety of options, there are numerous potential combinations that can form a viable biomass CCS route. These generally involve the combustion or gasification of biomass (either in dedicated systems or co-fired with fossil fuels), combined with one of the three carbon capture categories (post-combustion, oxy-combustion or pre-combustion).

Project context

CCS combined with fossil fuel based power generation is most commonly viewed as a bridging technology that will enable the transition to a longer-term solution, comprising only renewable energy sources. Some critics have argued that CCS might result in the perpetuation of fossil fuels as the dominant energy source, sometimes known as "reinforced fossil fuel lock-in". Biomass CCS, on the other hand, has a negative carbon emissions potential, and can help to avoid this risk. In this way, CCS technologies developed in the near-term for fossil fuels can, when combined with biomass utilisation, form part of a renewable energy future.

ETI's UK Energy System Model (EMSE) provides an evaluation of different options for meeting the UK's future energy demand and emissions reduction targets at the least costs, out to 2050. ESME provides a compelling case for UK deployment of biomass CCS, due to its large, negative emissions, persistence across scenarios, and high option value. Global interest in biomass CCS is also increasing, with studies estimating a potential for -3 to -10 GtCO2/yr savings in the power sector by 2050.

However, the level of development activity on biomass CCS (especially with dedicated biomass) has been significantly lower than for fossil fuel based CCS. There are therefore significant gaps in our understanding of biomass CCS; particularly in terms of the key technical and economic barriers, as well as the potential for deployment in the UK to 2050. This project sets out to address some of these issues.

The principal objective of the project is to provide technical information and a set of recommendations that will contribute towards the development of a "biomass CCS roadmap". It is envisaged that the results of this work will help ETI to guide the development and commercial deployment of biomass CCS, and to disseminate information on the benefits and risks associated with biomass CCS to potential stakeholders and the wider public.

Structure of the full report

This report is the final deliverable from the first work package of this project. The Work Package covered the following areas:

- Deliverable D1.1 focused on a landscape overview of current biomass based power generation and carbon capture technologies, and current global demonstration activities.
- Deliverable D1.2 assessed the various combinations of biomass power with CCS technologies, before recommending a shortlist of technologies for further detailed study in the rest of the TESBIC project.
- This report, Deliverable D1.3, posted on the ETI member portal, combines D1.1 and D1.2 and is updated following builds from the June 2011 Stage Gate Review with ETI.

The Deliverable D1.3 report is structured as follows:

- Section 0: An Executive Summary
- Section 1: An introduction to Biomass Power with CCS
- Section 2: Reviews the individual biomass power and carbon capture technologies, covering their development status, key issues, scales of operation, efficiency, economics, emissions and UK activities and capabilities. Biomass feedstock properties and pre-processing requirements are also presented
- Section 3: Introduces the combinations and groupings of biomass power and carbon capture technologies, followed by an overview of worldwide demonstration projects
- Section 4: Describes the prioritised assessment criteria used in the selection of the technology combinations for further study. These criteria cover a range of different development, techno-economic, feedstock, feasibility and UK aspects
- Section 5: Presents the assessment for each of the biomass power and capture technology combinations, bringing together information from the individual component reviews
- Section 6: Recommends a shortlist of eight technology combinations to be taken forward. This shortlist includes at least one technology combination suitable for small-scale power applications. The key criteria for these combinations are compared side-by-side in a summary matrix

Scope of Work Package 1

Finalisation of the project scope with ETI led to the exclusion of waste feedstocks, technologies which would not be commercially deployed by 2050, technologies only applicable at scales below 10 MWe, the use of algae for CO2 capture, biofuel refineries, downstream CO2 transport and storage technologies, and natural gas combined cycle plants along with indirect and parallel co-firing options.

The following 11 co-firing and dedicated biomass conversion technologies have therefore been reviewed in Section **Error! Reference source not found.**:

- Pulverised coal combustion, with direct co-firing of biomass, or conversion to 100% biomass
- IGCC coal gasification, with direct co-firing of biomass, or conversion to 100% biomass
- Dedicated biomass combustion: bubbling or circulating fluidised bed or grate
- Dedicated biomass gasification: bubbling, circulating or dual fluidised bed, or entrained flow

14 carbon capture technologies have also been reviewed in Section **Error! Reference source not found.**:

- Post-combustion (Solvent scrubbing, Low-temperature solid sorbents, Ionic liquids, Enzymes, Membrane CO2 separation, and High-temperature solid sorbents)
- Oxy-combustion (Cryogenic O2 separation, Membrane O2 separation, Chemical-looping-combustion using solid oxygen carriers)
- Pre-combustion (Integrated gasification combined cycle with physical absorption, Membrane H2 separation, Membrane syngas generation, Sorbent enhanced reforming using carbonate looping, Zero-Emission Coal Alliance concept)

A range of UK and imported solid biomass feedstocks were also characterised in Section **Error! Reference source not found.**:

- Forestry: timber, short roundwood, forestry residues, arboricultural arisings
- Woody energy crops: willow, poplar, eucalyptus
- Energy grasses: miscanthus, switchgrass, reed canary grass
- Agricultural residues: wheat, barley and oil seed rape straws, imported olive, palm and sunflower residues, and bagasse
- Waste wood: sawdust, chip board, medium-density fibreboard

The project has identified which chemical compositions, fuel and physical properties are compatible with different power conversion technologies, and if any pre-processing is required. The main issues with using biomass feedstocks are low ash fusion temperatures, along with high alkali and halide contents – due to slagging and agglomeration along with fouling and corrosion. There are few impacts on capture technologies of using biomass expected beyond those experienced using coal.

Many of the dedicated biomass technologies are able to take a wide range of biomass particle sizes and moisture contents, with little pre-processing required, although other mitigations such bed additives or temperature limits might be needed. In comparison, co-firing with coal generally requires small particle sizes – although milling energy consumption can be significantly reduced by torrefaction or pyrolysis pre-treatment.

UK forestry currently dominates power sector biomass consumption, with some UK straw and imported residues also used. The total available resource to the UK is likely to increase significantly to 2050, with imported energy crops expected to dominate. There will therefore be large supplies of feedstock available that are suitable for all combustion and gasification technologies; hence feedstock availability or suitability is not a deciding factor in the choice of which biomass CCS routes to progress.

Technology combination assessments

Using the information collected for each of the different power and capture technologies, the project formed 28 feasible combinations of component technologies. The project participants then assessed each combination against an agreed set of criteria, with the key benefits and risks highlighted in Section **Error! Reference source not found.**. The assessment criteria, discussed in Section **Error! Reference source not found.**, cover a range of different development, techno-economic, feedstock, feasibility and UK aspects. The most important criteria have been identified as the likely Technology Readiness Level (TRL) in 2020, key technical issues, plant efficiency with capture, capital costs with capture, and potential for UK deployment.

Recommendations

During a full day internal workshop, based on the key advantages and disadvantages given in each combination assessment, the project participants decided whether there were strong enough reasons to reject particular combinations, and provided evidence for these rejections. In summary, 20 of the 28 technology combinations have not been recommended for progression:

Low-temperature solid sorbents, ionic liquids, enzymes and membrane CO2 separation combinations (3, 4, 5, 6, 5a, 6a, 7, 8) potentially have reduced capital costs compared to amine scrubbing, but they generally only have marginal efficiency benefits, and there uncertainties regarding operating costs, as well as several major technical issues yet to be resolved

Membrane O2 separation, membrane H2 separation, membrane production of syngas, sorbent enhanced reforming and the ZECA concept combinations (11a, 12a, 17, 18, 19, 20, 21, 22, 23, 24) potentially have high plant energy efficiency, but there are numerous technical issues in addition to uncertain capital costs, and paucity of available data for the earliest stage concepts

Dedicated biomass with carbonate looping (10) was not progressed, as it is not yet known if the calciner can be biomass-fired – i.e. co-firing percentages might be limited to <70%. Our recommendation is therefore to begin by exploring only the co-firing option (9)

Co-firing chemical looping combustion (13) was not progressed, since coal gasification rates are slower than those for biomass, and unreacted char leads to carryover and loss of CO2. Also, chemical looping cannot be retrofitted to a pulverised coal plant – a CFB boiler is needed. Hence the dedicated biomass option (14) is preferred for progression instead

With feedback from the ETI Stage Gate Review meeting on 13th June 2011, this selection process left the project consortium with eight technologies combinations recommended for progression:

(1) Co-firing combustion, with post-combustion amine scrubbing

(2) Dedicated biomass combustion with post-combustion amine scrubbing

(9) Co-firing combustion, with post-combustion carbonate looping

(11) Co-firing oxy-combustion, with cryogenic O2 separation

(12) Dedicated biomass oxy-combustion, with cryogenic O2 separation

(14) Dedicated biomass chemical-looping-combustion using solid oxygen carriers

(15) Co-firing IGCC, with physical absorption

(16) Dedicated biomass IGCC, with physical absorption

An overall view of the combinations recommended for progression or rejected is given in Table 0.1. This shows that our recommendations cover all three main capture categories, and also give an equal split between large-scale co-firing combinations and small-scale dedicated biomass combinations.

Internationally, the current set of CCS demonstration projects considering using biomass are, mainly, being developed in Europe; most plan to be operational soon after 2015. As expected, these projects are only looking to co-fire biomass at modest percentages in the most mature coal CCS plant concepts – i.e. combinations (1), (11) and (15).

Purpose – Governance
No additional restrictions

Table 0.1: Power-capture technology combinations proposed for progression/rejection

Progress
Reject

		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

Quantitative supporting data

Further quantitative data is provided below for each technology combination, comparing factors such as the plant efficiency with capture, the CO2 capture rate (Figure 0.1) and the estimated cost of avoided CO2. Full details and explanations are given in the full report.

The quantitative data used has only been taken from the literature values and information already gathered and reviewed in Work Package 1. These are the best estimates available to us at this early stage of the project – carrying out the detailed Case Studies and modelling in later Work Packages is required before more accurate figures can be given. Note that the error bounds on the estimates provided are especially large for the early stage technologies.

An illustrative measure of risks vs. rewards is given in Figure 0.2.The higher the TRL, and the fewer the number of development issues and technical showstoppers, then the lower the "risk" (x-axis). Cost of avoided CO2 was felt to be an appropriate measure of the "rewards" (y-axis), since it includes a variety of economic factors such as capture rate, plant efficiency and capital costs with capture in its calculation, and is also a useful indication of the carbon prices required to enable competitive viability with unabated fossil fuel or biomass generation.

Figure 0.2 gives a clear justification for why the shortlist of 8 technologies was chosen for progression. These 8 technologies have the lowest risk, i.e. are further left on the x-axis, and hence are most likely to be developed in time for 2050 mass-deployment. Whilst attractive in terms of potential deployment, they still cover a broad range of avoided CO2 costs:

- The 'benchmark' near-term cases of co-firing with amine scrubbing (1) and oxy-fuel with cryogenic O2 separation (11) have average costs of avoided CO2
- The corresponding dedicated biomass systems (combinations 2 and 12) are more expensive, and at a slightly earlier stage of development, but there are not expected to be major technical differences to the co-firing cases
- Both co-firing (15) and dedicated biomass (16) IGCC with physical absorption are cheaper than the options above, mainly due to their higher efficiencies. However, (16) has only been considered theoretically so far, and there is not a clear development pathway since the current BIGCC plants without capture are not well suited to adding capture. There are, however, no major technical showstoppers, and knowledge spill-over from (15) and biofuels applications could accelerate (16)'s development. Of the dedicated biomass gasification combinations, (16) is still a clear winner over (18), (20), (22) & (24), both in terms of risk and reward. There may also be interesting options for small-scale integration with future syngas infrastructure, or H2 storage
- The more technically risky options of dedicated biomass Chemical Looping Combustion (14) and co-firing with post-combustion carbonate looping (9) show low costs of avoided CO2. (9) also has the potential benefit of cement industry decarbonisation at low cost. (14) could have even higher efficiencies (above 50%) via process integration options with gas turbines or H2 production, and would appear to be the technology most suited to small-scale power applications

The summary matrix in Table 0.2 compares the key assessment criteria for each of the eight combinations recommended for progression.

Purpose – Governance
No additional restrictions

Figure 0.1: Estimated plant LHV efficiencies with capture, and CO_2 capture rates, for each technology combination (error bars not shown)

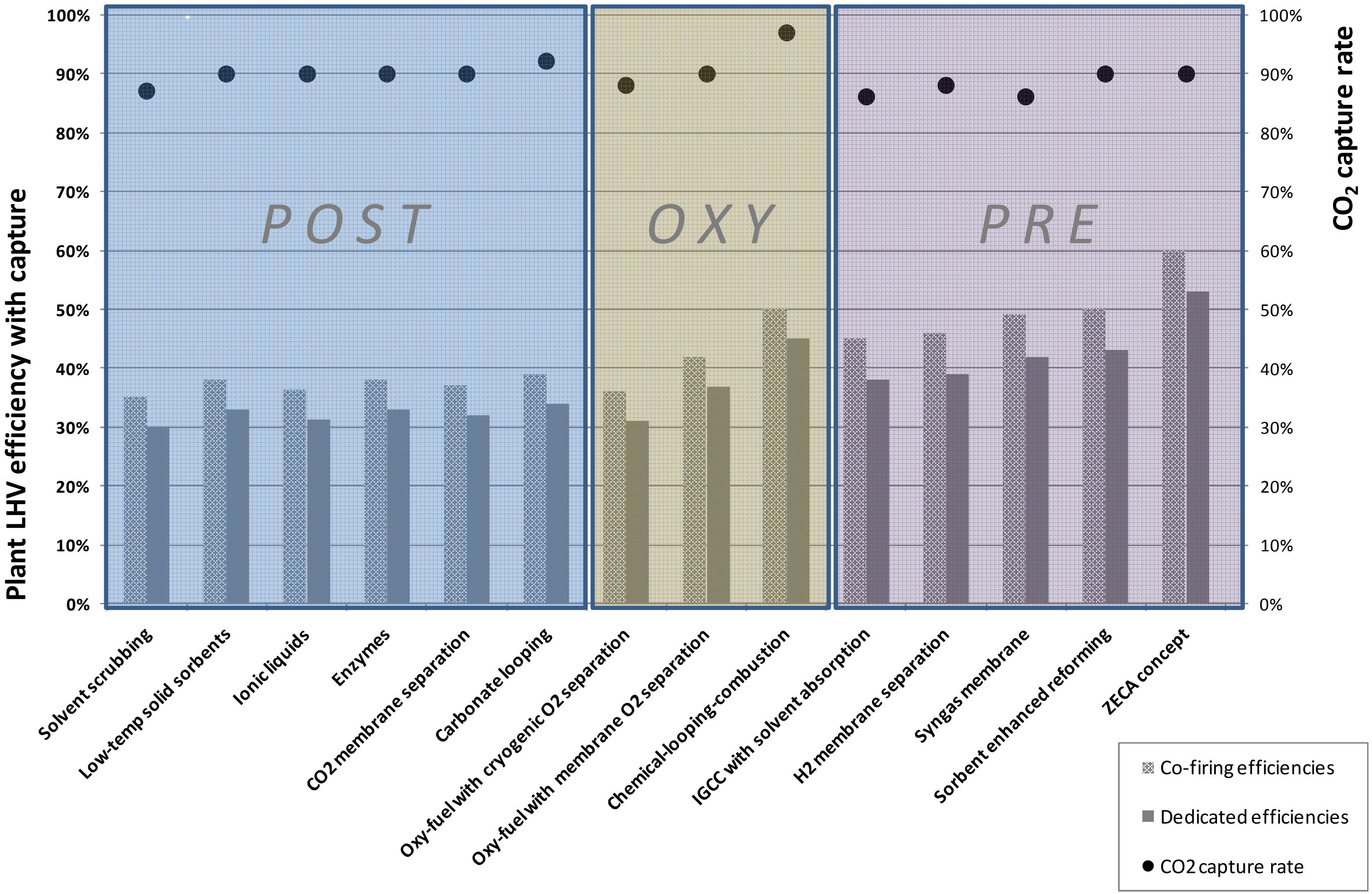

Figure 0.2: Estimated cost of avoided CO_2 vs. technical issues to overcome, for each technology combination (error bars not shown)

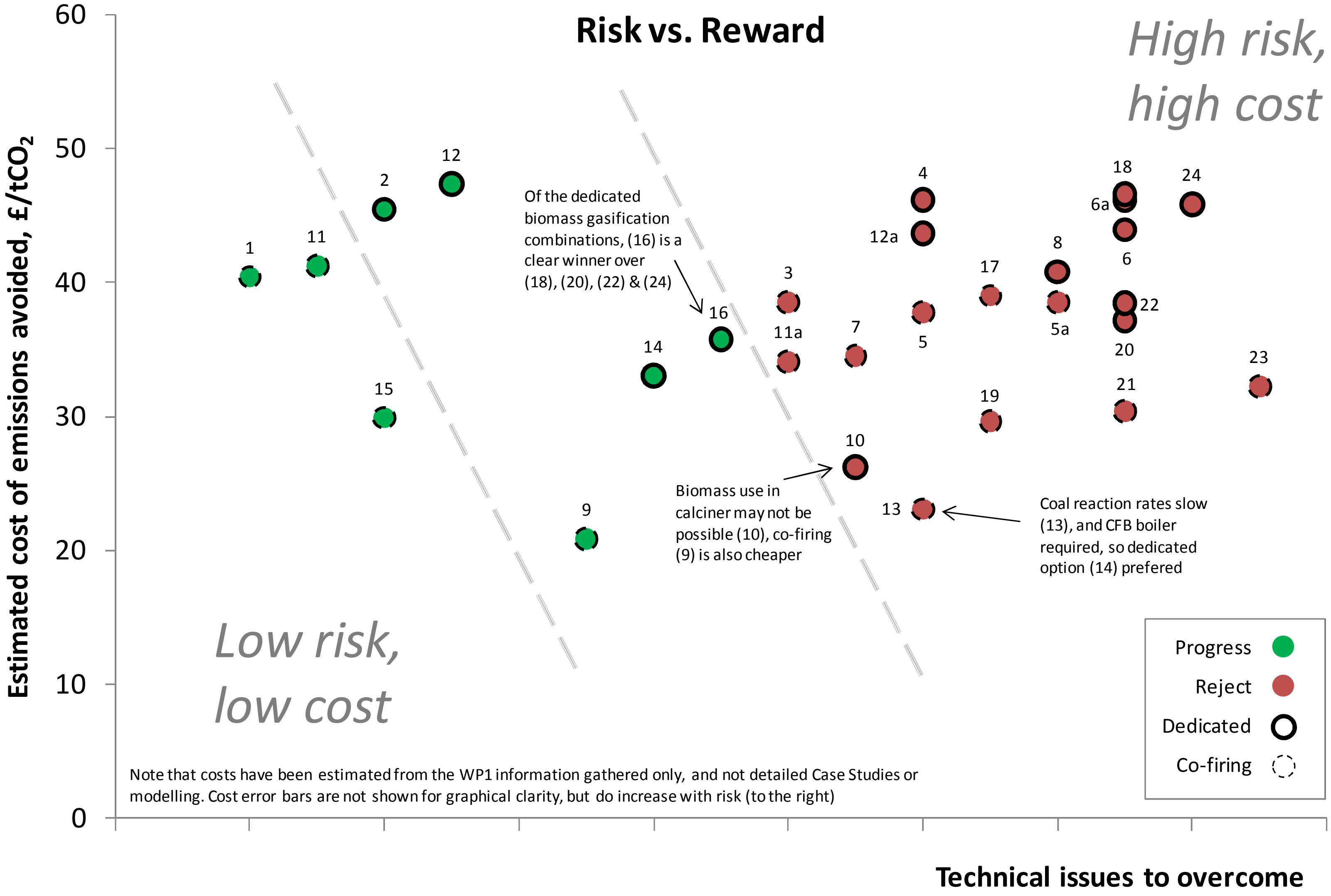

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Table 0.2: Summary matrix comparing key criteria for the recommended combinations

Criteria	(1) Co-firing amine scrubbing	(2) Dedicated biomass with amine scrubbing	(9) Co-firing carbonate looping	(11) Co-firing oxy-fuel	(12) Dedicated biomass oxy-fuel	(14) Dedicated biomass chemical looping	(15) Co-firing IGCC	(16) Dedicated biomass BIGCC
Current TRL	6 to 7	4	4 to 5	6	5	4	5 to 6	4
Likely TRL in 2020	7 to 8	6 to 7	5 to 6	7	6	5 to 6	7	5 to 6
Key technical issues	Scale-up, amine degradation, potential losses to environment	Scale-up, amine degradation, potential losses to environment	Calciner firing, degradation, large purge of CaO	Corrosion, O_2 energy costs, slow response	Corrosion, O_2 energy costs, slow response	Loss in activity, reaction rates, dual bed operation	Complex operation, slow response, tar cleaning, retrofit unattractive	Complex operation, slow response, tar cleaning, retrofit unattractive
Suitability for small scale	Low	High	Low	Low	High	High	Low	High
Plant efficiency with capture	OK	Low	Good	OK Some gains with O_2 membrane	Low Some gains with O_2 membrane	Good High if at pressure, or H_2 for fuel cells	High, Very High with new gas turbines	Good, High with new gas turbines
Capital costs with capture	OK	Expensive	Low cost, although repowering requires capex	OK ASU costs could fall with O_2 membranes	Expensive ASU costs could fall with O_2 membranes	Low cost	OK, could fall with new gas turbines	Expensive, could fall with new gas turbines
UK deployment potential	Immediate capture retrofit opportunities, long-term doubtful	Numerous capture retrofit opportunities by ~2015, high long-term potential	Immediate capture retrofit opportunities, cement integration	Near-term retrofit opportunities, long-term doubtful	Numerous capture retrofit opportunities by ~2015, high long-term potential	Likely first demos in Europe, UK in ~2020. High long term potential	No current UK plants, several demos by 2020, could co-fire. Long-term doubt	No current UK plants, demo unlikely by 2020. High long-term potential