INTERACTION BETWEEN DIFFERENT INCENTIVES TO SUPPORT RENEWABLE ENERGY AND THEIR EFFECT ON CHP: Renewable Obligation and Renewable Heat Incentive

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AEA group
329 Harwell
Didcot
Oxfordshire
OX11 0QJ

t: 0870 190 6021
f: 0870 190 6334

Authors	Name	Ken Fletcher and Jeremy Stambaugh
Approved by	Name	Mahmoud Abu-Ebid
	Signature	
	Date	January 2010

Executive summary

This study, on behalf of the Department of Energy and Climate Change (DECC), has assessed the degree to which renewable CHP uptake could be affected by the proposed Renewable Heat Incentive (RHI) and changes to the Renewables Obligation (RO) banding for renewable CHP.

The overall aim is to model several scenarios to assess the impact on both renewable and non-renewable CHP capacity in relation to renewable energy targets and greenhouse gas emission reduction goals and their cost-effectiveness. The distributional outcomes from each of these scenarios are also important.

Specifically, the interaction between the RHI / RO in regard to renewable fuel- based CHP has been modelled to predict:

- Outcomes optimised in terms of their cost- effectiveness, carbon abatement and progress to renewables targets
- Unintended consequences for fossil fuel CHP that may arise from RHI/RO - and potentially perverse outcomes in terms of carbon targets and the efficient use of renewable materials.

Two growth restriction scenarios were considered: one where a practical restriction (similar to that applied to biomass boilers in the RHI study) on the use of renewable fuel on sites is considered, and one where there are no restrictions on use other than for small sites (in the non-EU ETS category).

The modelling work was carried out in 2 phases:

The first phase, completed in July 2009, produced projections of renewable CHP heat and power capacity based on biomass, fossil fuel and carbon prices as understood at that time with an estimated range of likely RHI values (£20-£40/MWh). These projections were used to estimate:

- The projected renewable CHP uptake from now to 2020
- The impact of moving from the current RO policy environment to one including the RHI
- The impact of projected renewable CHP uptake on conventional and total CHP capacity growth and carbon savings.

In the second phase, the projected biomass, fossil fuel and carbon prices were revised with central, high and low projection scenarios and a RHI value of £25/MWh. The conventional only and renewable+conventional CHP projections were then revised to estimate:

- A revised projected renewable CHP uptake from now to 2020
- The impact of moving from the current RO policy environment to one including the RHI revised policy impact of changing from the current RO policy to a proposed RHI
- The revised impact of projected renewable CHP on total projected CHP capacity and carbon savings
- The sensitivity of projected CHP uptake to the high and low energy and carbon price projection scenarios.

In the sensitivity analysis the high and low biomass prices were modelled alongside the central fossil fuel price scenarios whilst the high and low fossil fuel price scenarios were modelled alongside the central biomass price scenario. This avoided changing too many variables at once; however it was assumed that the high and low carbon price projections coincide with the high and low fossil fuel price projections.

Phase 1 Modelling Main Conclusions

- With a restriction on biomass CHP industry growth assumed, were the current RO policy to continue as it is without introducing RHI (Scenario 1R), the projected renewable Good Quality CHP electrical capacity by 2020 is 1.65 GWe and this would be operated to generate in the order of 6.9 TWh/Yr of renewable heat.

- Assuming an RHI policy were introduced awarding £40/MWh of renewable heat alongside a revised RO awarding all renewable power generating plant 1.5 ROCs/MWhe i.e. removing the current 0.5ROCs/MWhe incentive for CHP (Scenario 2R), a large increase in the projected renewable heat generation from CHP to 15.3 TWh/Yr, is anticipated with the same anticipated volume of electrical capacity to 1.67GWe, as a result of schemes generally being sized to meet the heat demands of sites (heat led approach).

- Without the practical growth restrictions mentioned above and a continuation of current RO policy (Scenario 1U) the projected renewable Good Quality CHP electrical capacity by 2020 increases to 2.7 GWe generating in the order 23.1 TWh heat/Yr. Under the proposed RHI (Scenario 2U) the projected Good Quality renewable CHP capacity is 3.0GWe generating 41.1 TWh/Yr of renewable heat. Thus in the unrestricted scenario a very modest increase in renewable electricity generation from CHP is expected together with a very substantial increase in the generation of renewable heat.

- Renewable CHP growth will compete with conventional CHP growth for sites, resulting in an overall reduction in CHP electrical capacity growth as compared to a CHP growth scenario without renewable CHP. This is because, for a given site,the most cost-effective electrical capacity and electrical output of renewable CHP is typically lower than that of conventional CHP. Furthermore, the proposed RHI will tend to encourage a renewable steam turbine CHP to be designed to operate near maximum heat capability whereas the current RO policy tends to encourage renewable CHP to be designed to maximise electricity output and entitlement to ROCs which occurs below the maximum heat capacity. Therefore for a given site heat load, the proposed RHI will tend to encourage a renewable steam turbine CHP with a lower power capacity than the current RO policy does

- The projected Good Quality CHP total (both renewable and conventional) electrical capacities by 2020 with biomass growth restrictions are 17.3GWe under the current RO policy, 17.0GWe with an RHI of £40/MWh and 17.2GWe with an RHI of £20/MWh, the last being higher than the second due to suppressed competition from renewable CHP for sites. This compares with a projection of 17.8GWe in a scenario where no renewable CHP is built

- Overall whilst the revision of current RO policy and the introduction of RHI is expected to result in a reduced projection of CHP electrical capacity and output, it is anticipated that a marginal long term increase in overall CO2 saving from CHP would occur by 2020 because more CHP would come from renewable and low carbon fuels. However before 2020 the CO2 saving may in fact be lower at certain times as projected for 2017. Furthermore, the results of phase 2 (as described below) indicate the long term carbon saving under an RHI may in fact be lower than that with the current RO policy unless more renewable electricity from non CHP power only plant is produced elsewhere but this is outside the scope of this report

- Under an RHI of £20/MWh rather than £40/MWh the CO2 saving would be even more marginal. However it is clear that the projected CO2 saving from conventional CHP alone would be significantly lower so policy support for renewable CHP either solely through the RO or through both RO and the RHI, is more environmentally beneficial.

Table S1: Projection results summary –Renewable CHP Heat Output

	*Actual 2008	2013	2017	2020
CHP Renewable Heat output (TWh/Yr)				
Renewable CHP Under **Scenario 1R** (Current RO Policy, ST heat extraction for QI = 100, practical biomass CHP growth restriction)	0.626	1.923	4.785	6.920
Renewable CHP Under **Scenario 2R** (Proposed RHI £40/MWh, ST designed to match site heat and power loads, practical biomass CHP growth restriction)	0.626	3.912	8.114	15.275
Renewable CHP Under **Scenario 3R** (Proposed RHI £20/MWh, ST designed to match site heat and power loads, practical biomass CHP growth restriction)	0.626	3.029	6.361	11.896
Renewable CHP Under **Scenario 1U** (As Scenario 1R but practical biomass CHP growth restriction removed)	0.626	5.700	15.677	23.148
Renewable CHP Under **Scenario 2U** (As Scenario 2R but practical biomass CHP growth restriction removed)	0.626	7.162	14.750	41.085

Note: all heat figures in this report are the total useful heat output from CHP schemes.

Graph S1 - Growth scenarios of Renewable CHP heat

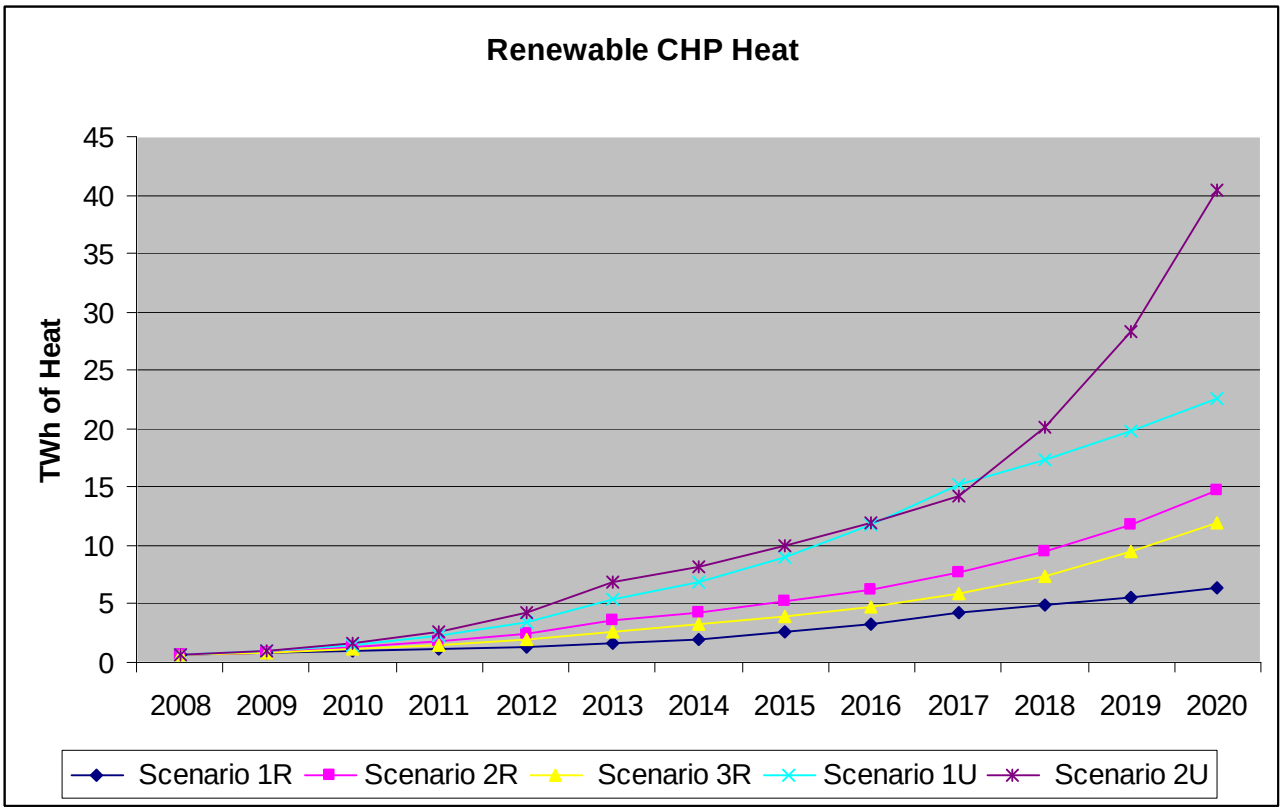


Table S2: Projection results summary –CHP Elec Capacity

	*Actual 2008	2013	2017	2020
Elec Capacity in CHP Mode (MWe)				
Renewable CHP Under Scenario 1R	49[1]	451	1,138	1,653
Conventional CHP Under Scenario 1R	5,420	9,245	12,017	15,622
Total CHP (Renewable + conventional under scenario 1R)	5,469	9,696	13,155	17,275
Renewable CHP Under Scenario 2R	49	420	878	1,670
Conventional CHP Under Scenario 2R	5,420	9,155	11,844	15,378
Total CHP (Renewable + conventional under scenario 2R)	5,469	9,574	12,722	17,049
Renewable CHP Under Scenario 3R	49	333	694	1,310
Conventional CHP Under Scenario 3R	5,420	9,446	12,268	15,897
Total CHP (Renewable + conventional under scenario 3R)	5,469	9,779	12,962	17,207
Renewable CHP Under Scenario 1U	49	670	1,811	2,665
Conventional CHP Under Scenario 1U	5,420	9,004	11,290	13,869
Total CHP (Renewable + conventional under scenario 1U)	5,469	9,674	13,101	16,534
Renewable CHP Under Scenario 2U	49	541	1,148	2,993
Conventional CHP Under Scenario 2U	5,420	8,880	11,170	14,002
Total CHP (Renewable + conventional under scenario 2U)	5,469	9,422	12,318	16,996
Compare previous study Conventional CHP Only (Central energy price)	5,474	10,470	13,789	17,754

Note: The average annual growth in renewable CHP capacity (MWe) in the early years 2008 to 2013 is 56% under current RO policy, 54% for the restricted £40/MWh RHI case and 47% for an RHI of £20/MWh. Between 2007 and 2020 the average annual growth is 13% under current RO, 24% for restricted RHI at both £40/MWh and £20/MWh, being higher under the RHI due to the slower growth in earlier years.

[1] Biomass CHP only

Table S3: Projection results summary –CHP Annual Elec Output

	*Actual 2008	2013	2017	2020
CHP Elec Output (TWh/Yr)				
Renewable CHP Under Scenario 1R	0.215[1]	3.647	9.214	13.378
Conventional CHP Under Scenario 1R	27.696[2]	74.831	97.266	126.446
Total CHP (Renewable + conventional under scenario 1R)	27.911	78.479	106.480	139.824
Renewable CHP Under Scenario 2R	0.215	3.396	7.105	13.520
Conventional CHP Under Scenario 2R	27.696	74.098	95.864	124.471
Total CHP (Renewable + conventional under scenario 2R)	27.911	77.494	102.969	137.991
Renewable CHP Under Scenario 3R	0.215	2.697	5.614	10.606
Conventional CHP Under Scenario 3R	27.696	76.454	99.300	128.668
Total CHP (Renewable + conventional under scenario 3R)	27.911	79.151	104.914	139.273
Renewable CHP Under Scenario 1U	0.215	5.422	14.655	21.570
Conventional CHP Under Scenario 1U	27.696	72.878	91.384	112.257
Total CHP (Renewable + conventional under scenario 1U)	27.911	78.300	106.039	133.827
Renewable CHP Under Scenario 2U	0.215	4.379	9.290	24.228
Conventional CHP Under Scenario 2U	27.696	71.879	90.410	113.336
Total CHP (Renewable + conventional under scenario 2U)	27.911	76.258	99.699	137.564
Compare previous study Conventional CHP Only (Central energy price)	27.695	84.743	111.604	143.702

[1] Biomass CHP only
[2] Includes other CHP at STWs and EfW

The effect on CO2 savings (Phase 1 Modelling)

For these calculations, we have used the following emissions factors.

CO2 factors (tCO2/MWh)	
CHP fuel (gas)	0.190
Elect	0.430

Table S4: Projected Total Carbon Savings (from Electricity and Heat) MtCO2/Yr

Carbon Savings from Renewable and Conventional CHP MtCO2/Yr	2013	2017	2020
Renewable CHP Under Scenario 1R	2.056	5.174	7.506
Conventional CHP Under Scenario 1R	13.993	16.981	20.264
Total CHP (Renewable + conventional under scenario 1R)	16.048	22.155	27.769
Renewable CHP Under Scenario 2R	2.451	5.111	9.683
Conventional CHP Under Scenario 2R	13.757	16.536	19.632
Total CHP (Renewable + conventional under scenario 2R)	16.208	21.646	29.315
Renewable CHP Under Scenario 3R	1.927	4.026	7.574
Conventional CHP Under Scenario 3R	14.282	17.204	20.405
Total CHP (Renewable + conventional under scenario 3R)	16.209	21.229	27.979
Conventional CHP Only Projection	15.737	19.260	22.679

Under the proposed RHI and RO policy revision, the balance of changes in overall carbon saving resulting from increased renewable heat, decreased heat and power from conventional CHP and either a modest increase or decrease in renewable electricity from CHP, is complex. It is concluded that the projected total carbon savings from renewable and conventional CHP are likely to be higher in the long term under the RHI than under the current RO policy.

In phase 2 as reported later, the long term carbon saving may be slightly lower overall for CHP (conventional + renewable) under an RHI than the existing RO.

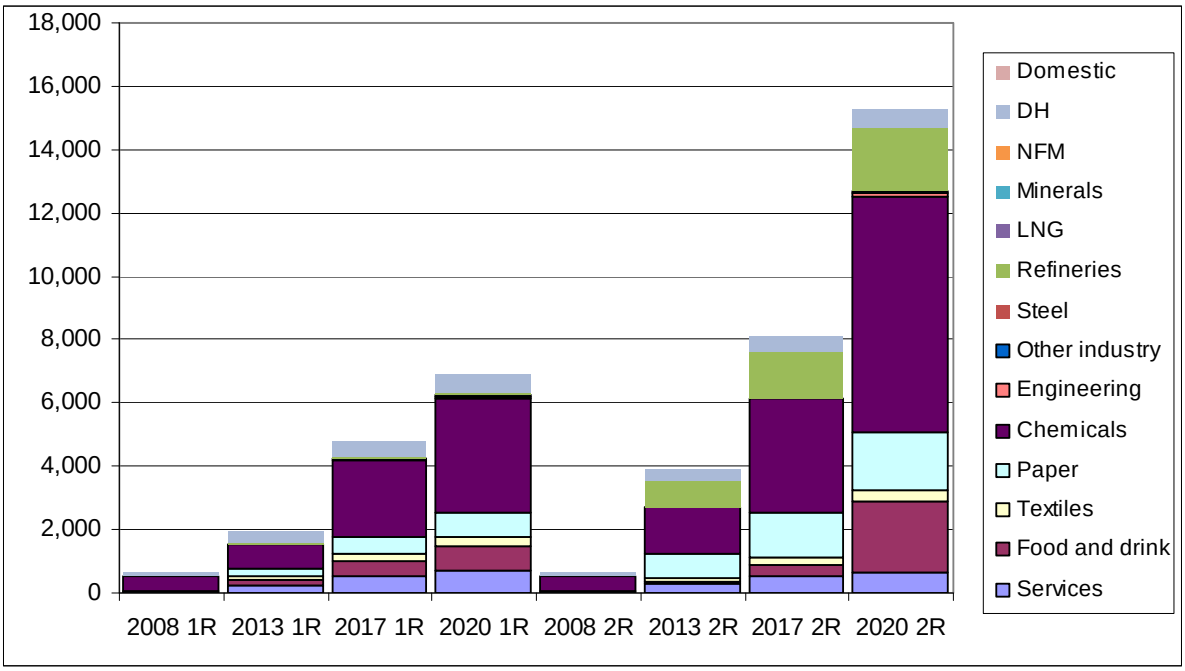
However even under an RHI policy the total volume of renewable energy (heat and power) increases whilst offering a clear increase in carbon saving compared to a scenario of no renewable CHP. In addition, the reduction in renewable electricity from CHP may coincide with an increase in generation by renewable power only plant but this is outside the scope of this report.

Phase 1 Summary of Scenarios 1R and 2R.

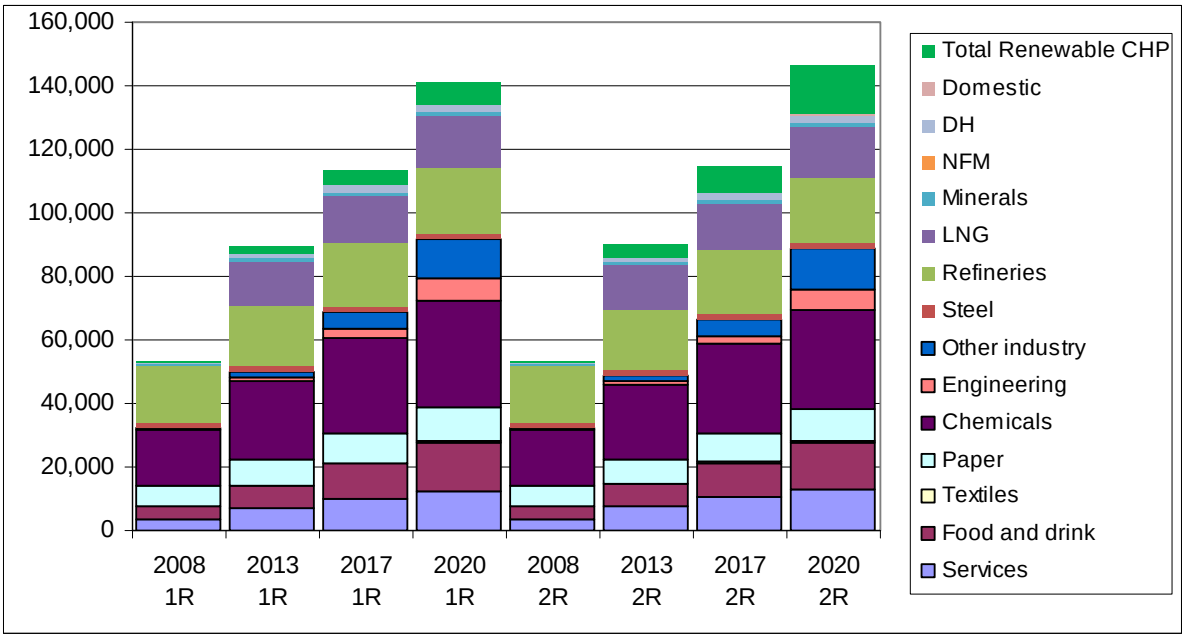
- **Scenario 1R = With existing RO policy, CHP designed and operated to maximise ROCs (minimum heat utilisation)**

- **Scenario 2R = With Proposed RHI = £40/MWh, CHP designed to follow site heat and power loads where possible with steam turbine technology**

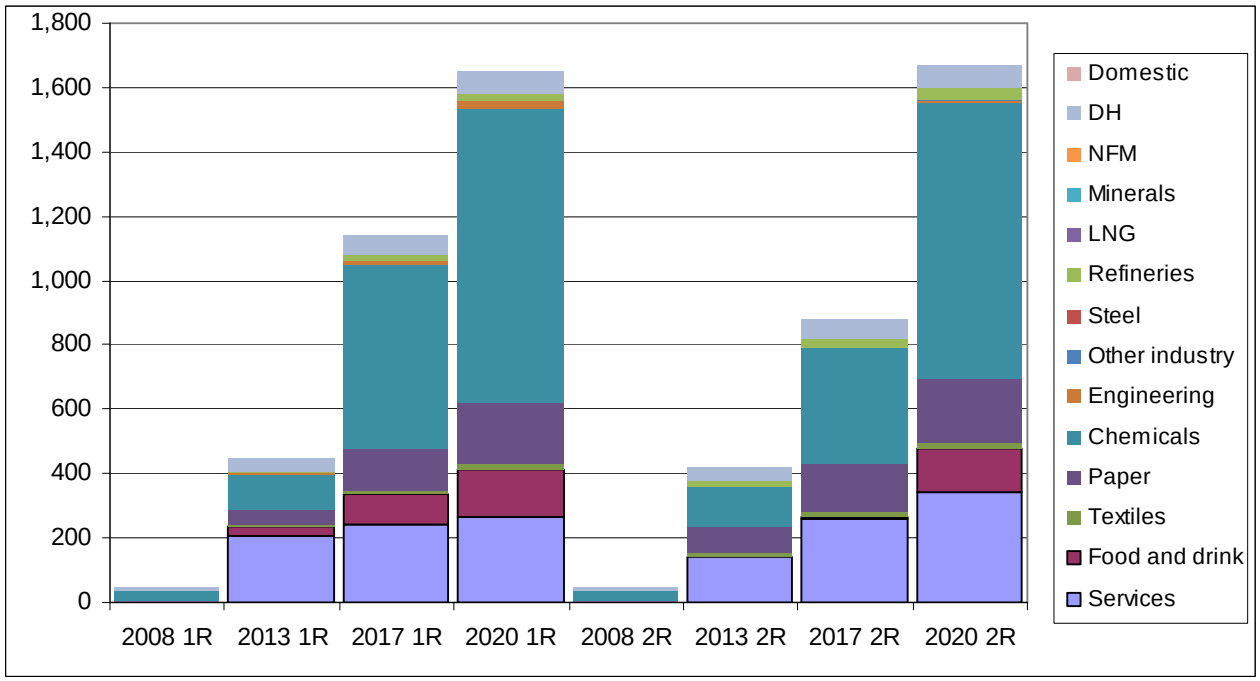
Graph S2: Renewable CHP Projection by Sector Heat Output GWh/Yr



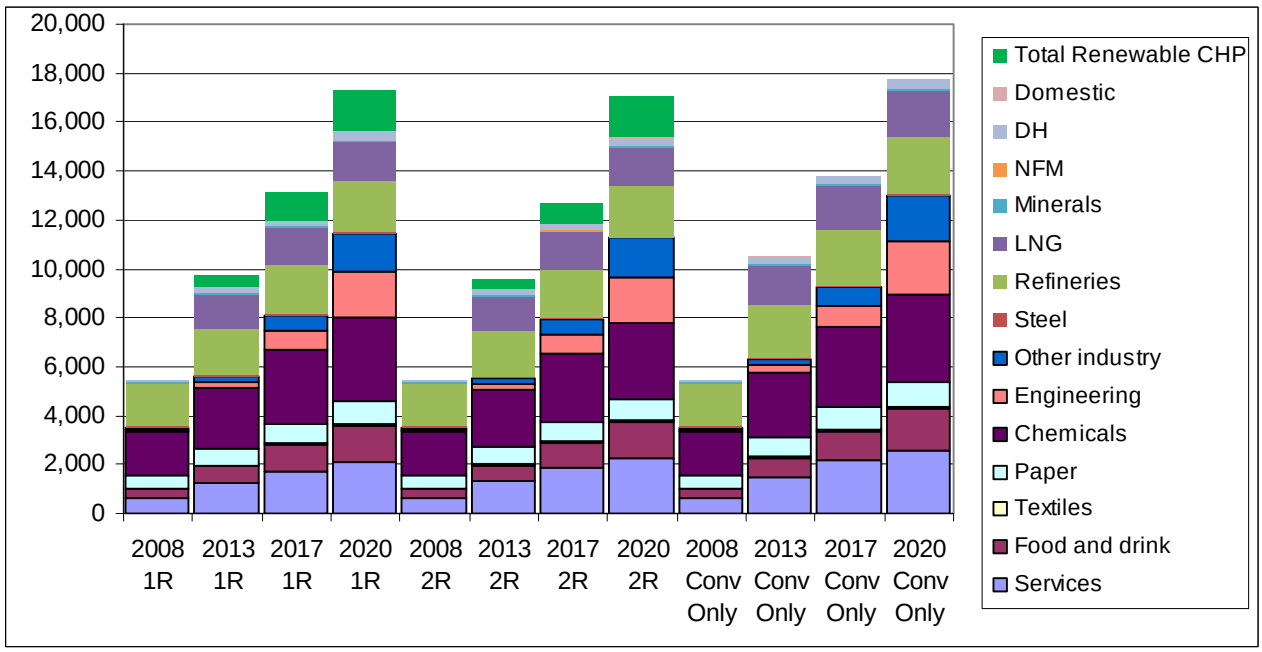
Graph S3: Conventional CHP Projection by Sector + renewable CHP Heat Output GWh/Yr



Graph S4: Renewable CHP Projection by Sector Elec Capacity MWe



Graph S5: Conventional CHP Projection by Sector + renewable CHP Elec Capacity MWe



Phase 2 Modelling Main Conclusions

- The projection is that renewable heat generated by CHP will be between 2 and 35 TWh/Yr depending on the growth and energy price sensitivity scenario: between 2 and 16 TWh/Yr is projected on the restricted scenario and between 3 and 35 TWh/Yr projected on the unrestricted scenario

- Based on the central energy and carbon price scenarios, the revised renewable CHP heat generation projections are 7.4 TWh/Yr by 2020 for the 'restricted' scenario, and 15.8 TWh/Yr in the 'unrestricted' case. This compares with the phase 1 projections for an RHI of £40/MWh of 15.3 TWh/Yr in the restricted growth case and 41 TWh/Yr in the unrestricted growth case, and 11.9TWh/Yr at an RHI of £20/MWh with the practical growth restriction. The revised projections for renewable CHP are thus lower under the revised central scenario set of energy and carbon prices and an assumed RHI value of £25/MWh. This is essentially due to much higher revised biomass price projections

- An RHI of £25/MWh is projected to encourage the growth of renewable heat from CHP at the expense of both total CHP electrical output and renewable electricity output in the short term (prior to 2020). As a result, based on the central fuel price scenarios, the projected total carbon savings from renewable and conventional CHP are projected to be slightly lower (24.2MtCO2/Yr) in the long term (by 2020) than the savings under the current RO policy (24.9MtCO2/Yr). Under an RHI policy, renewable CHP still appears to offer a clear increase in carbon saving compared to a scenario with no biomass CHP (18.5MtCO2/Yr) so support for renewable CHP through an RHI is still more environmentally beneficial, just not as much as through a continuation of the existing RO. However it is possible this apparent adverse environmental impact on CHP may be mitigated elsewhere by an increased growth of non CHP renewable power generation though this is outside the scope of this report

- These projected renewable heat figures likely to be delivered by renewable CHP are included in the RHI analysis[3]

- By 2020, the low biomass fuel price scenario results in an increase to 11.9 TWh/Yr for the 'restricted' scenario and to 22.8 TWh/Yr in the 'unrestricted' case. This is similar to the Phase 1 projection with RHI £20/MWh for the restricted scenario but lower than the phase 1 projection for the unrestricted scenario. The low biomass fuel price scenario results in a decrease to 3.4 TWh/Yr for the 'restricted' scenario and to 9.6 TWh/Yr in the 'unrestricted' case

- A further key sensitivity is the effects of the fossil fuel price scenarios on renewable CHP take-up, compared with conventional CHP. The latter is also affected very significantly by the fossil fuel price scenario used. The 'high-high' fossil fuel and carbon price scenario, results in an increase to 15.7 TWh/Yr for the 'restricted' scenario, and to 35.0 TWh/Yr in the 'unrestricted' case. The 'low' fossil fuel and carbon price scenario reduces heat output to 2.0 TWh/Yr for the 'restricted' scenario, and to 2.7 TWh/Yr in the 'unrestricted' case. It is therefore concluded that the fossil fuel price effects (within the range of the assumptions made about 'high-high' and 'low' price scenario differences) are much more pronounced than the effects of the biomass price scenario range of assumptions

- The effect of the fossil fuel and electricity price on conventional CHP capacity is also apparent. For the biomass CHP growth restricted case, the central price scenario level of conventional CHP is 15.0 GWe by 2020, and this increases only slightly to 15.3GWe in competition with increased biomass CHP under the high-high fossil fuel and electricity price scenario. However, under the low fossil fuel price scenario there is a significant reduction to 13.3 GWe of conventional CHP capacity with a reduction in projected biomass CHP capacity too.

[3] NERA (2010): Design of the Renewable Heat Incentive

Table S5: Projection results summary –Renewable CHP Heat Output – Scenario R (with practical biomass CHP growth restriction)

	*Actual 2008	2013	2017	2020
CHP Renewable Heat output (TWh)				
1R BAU Current RO policy Central biomass price scenario with central fossil fuel and electricity price scenario	0.626	1.279	3.077	4.415
2R RHI £25/MWh Central biomass price scenario with central fossil fuel and electricity price scenario	0.626	2.460	4.493	7.358
2R RHI £25/MWh High biomass price scenario with central fossil fuel and electricity price scenario	0.626	1.551	2.387	3.405
2R RHI £25/MWh Low biomass price scenario with central fossil fuel and electricity price scenario)	0.626	3.397	6.774	11.869
2R RHI £25/MWh Central biomass price scenario with high-high fossil fuel and electricity price scenario	0.626	3.955	8.350	15.700
2R RHI £25/MWh Central biomass price scenario with low fossil fuel and electricity price scenario	0.626	1.128	1.535	1.962

Table S6: Projection results summary –Renewable CHP Heat Output – Scenario U (with growth restriction removed)

	*Actual 2008	2013	2017	2020
CHP Renewable Heat output (TWh)				
1U BAU Current RO policy Central biomass price scenario with central fossil fuel and electricity price scenario	0.626	3.242	8.794	12.947
2U RHI £25/MWh Central biomass price scenario with central fossil fuel and electricity price scenario	0.626	3.447	6.843	15.820
2U RHI £25/MWh High biomass price scenario with central fossil fuel and electricity price scenario	0.626	2.398	4.403	9.629
2U RHI £25/MWh Low biomass price scenario with central fossil fuel and electricity price scenario)	0.626	4.476	9.394	22.805
2U RHI £25/MWh Central biomass price scenario with high-high fossil fuel and electricity price scenario	0.626	5.099	11.317	35.045
2U RHI £25/MWh Central biomass price scenario with low fossil fuel and electricity price scenario	0.626	1.334	1.953	2.701

Note the significant increase in the combined 'renewable + conventional CHP' totals with the 'high-high' fossil fuel and electricity price scenario, compared with the central scenario projections and the very large reduction when using the 'low' price scenario. This is a direct result of the relative fossil fuel and electricity price effects. The impact of the high and low biomass price scenarios is lower.

Table S7: Projection results summary –CHP Elec Capacity – Scenario R (with practical biomass CHP growth restriction)

	*Actual 2008	2013	2017	2020
Elec Capacity in CHP Mode (MWe)				
1R Renewable CHP under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	49	224	638	947
1R Conventional CHP	5420	9076	12403	14967
1R Total CHP (Renewable + conventional) under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	5469	9300	13041	15915
2R Renewable CHP under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	49	305	557	873
2R Conventional CHP	5420	8811	11360	15021
2R Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	5469	9117	11917	15894
Renewable CHP under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	49	224	363	496
Conventional CHP	5420	9000	11714	15556
Total CHP (Renewable + conventional) under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	5469	9224	12078	16052
Renewable CHP under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	49	387	768	1322
Conventional CHP	5420	8709	11170	14737
Total CHP (Renewable + conventional) under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	5469	9097	11938	16059
Renewable CHP under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	49	448	944	1759
Conventional CHP	5420	8717	11309	15253
Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	5469	9165	12253	17012
Renewable CHP under RHI £25/MWh central biomass price scenario with low fossil fuel and electricity price scenario	49	187	291	376
Conventional CHP	5420	8617	10664	13260
2R Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with low fossil fuel and electricity price scenario	5469	8804	10956	13636
Conventional CHP Only (Central energy price)	5,420	9,914	13,023	16,883

Table S8: Projection results summary –CHP Elec Capacity – Scenario U (with growth restriction removed)

	*Actual 2008	2013	2017	2020
Elec Capacity in CHP Mode (MWe)				
1R Renewable CHP under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	49	334	982	1467
Conventional CHP	5420	8854	11412	13399
Total CHP (Renewable + conventional) under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	5469	9187	12394	14866
Renewable CHP under central biomass price scenario with central fossil fuel and electricity price scenario	49	368	698	1371
Conventional CHP	5420	8697	11074	14467
	5469	9065	11772	15839
Renewable CHP under high biomass price scenario with central fossil fuel and electricity price scenario	49	276	477	858
Conventional CHP	5420	8917	11521	15210
	5469	9193	11998	16069
Renewable CHP under low biomass price scenario with central fossil fuel and electricity price scenario	49	457	933	1970
Conventional CHP	5420	8581	10833	14053
	5469	9038	11766	16024
Renewable CHP under central biomass price scenario with high-high fossil fuel and electricity price scenario	49	756	1847	2930
Conventional CHP	5420	8442	10430	13177
	5469	9198	12277	16108
Renewable CHP under central biomass price scenario with low fossil fuel and electricity price scenario	49	200	318	422
Conventional CHP	5420	8597	10624	13199
	5469	8797	10942	13622
Compare (Central energy price)	5,420	9,914	13,023	16,883

Phase 2 - Average annual Renewable CHP Capacity Growth Rates

Table S9: Projected Growth Rates in Renewable CHP Electrical Capacity under restricted growth scenario

	2008-2013	2013-2017	2017-2020
1R Renewable CHP under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	36%	23%	8%
2R Renewable CHP under central biomass price scenario with central fossil fuel and electricity price scenario	44%	13%	9%
Renewable CHP under high biomass price scenario with central fossil fuel and electricity price scenario	35%	10%	6%
Renewable CHP under low biomass price scenario with central fossil fuel and electricity price scenario	51%	15%	11%
Renewable CHP under central biomass price scenario with high-high fossil fuel and electricity price scenario	56%	16%	13%
Renewable CHP under central biomass price scenario with low fossil fuel and electricity price scenario	31%	9%	5%

Table S10: Projected Growth in Renewable CHP Electrical capacity under unrestricted growth scenario

	2008-2013	2013-2017	2017-2020
1U Renewable CHP under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	47%	24%	8%
2U Renewable CHP under central biomass price scenario with central fossil fuel and electricity price scenario	50%	14%	14%
Renewable CHP under high biomass price scenario with central fossil fuel and electricity price scenario	41%	12%	12%
Renewable CHP under low biomass price scenario with central fossil fuel and electricity price scenario	56%	15%	16%
Renewable CHP under central biomass price scenario with high-high fossil fuel and electricity price scenario	73%	20%	10%
Renewable CHP under central biomass price scenario with low fossil fuel and electricity price scenario	33%	10%	6%

For the central fuel price scenarios it can be seen that whilst an RHI would accelerate the growth in renewable CHP capacity in early years, in later years the growth rate would then be slower, primarily due to a higher level of market saturation.

Table S11: Projection results summary –CHP Annual Elec Output – Scenario R (with practical biomass CHP growth restriction)

	*Actual 2008	2013	2017	2020
Annual Elec Output (TWh/Yr)				
1R Renewable CHP under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	0.397	1.812	5.165	7.668
1R Conventional CHP	43.869	73.461	100.392	121.147
1R Total CHP (Renewable + conventional) under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	44.265	75.273	105.557	128.814
2R Renewable CHP under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	0.397	2.472	4.509	7.069
2R Conventional CHP	43.869	71.319	91.944	121.578
2R Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	44.265	73.791	96.454	128.647
Renewable CHP under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	0.397	1.811	2.941	4.017
Conventional CHP	43.869	72.847	94.816	125.907
Total CHP (Renewable + conventional) under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	44.265	74.657	97.757	129.923
Renewable CHP under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	0.397	3.133	6.219	10.702
Conventional CHP	43.869	70.495	90.406	119.280
Total CHP (Renewable + conventional) under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	44.265	73.628	96.625	129.982
Renewable CHP under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	0.397	3.622	7.639	14.240
Conventional CHP	43.869	70.558	91.533	123.457
Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	44.265	74.180	99.173	137.698
Renewable CHP under RHI £25/MWh central biomass price scenario with low fossil fuel and electricity price scenario	0.397	1.511	2.359	3.040
Conventional CHP	43.869	69.748	86.317	107.329
2R Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with low fossil fuel and electricity price scenario	44.265	71.260	88.675	110.368
Conventional CHP Only (Central energy price)	43.869	80.245	105.409	136.653

Table S12: Projection results summary –CHP Annual Elec Output – Scenario U (with growth restriction removed)

	*Actual 2008	2013	2017	2020
Annual Elec Output (TWh/Yr)				
1R Renewable CHP under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	0.397	2.702	7.949	11.874
1R Conventional CHP	43.869	71.661	92.365	108.449
1R Total CHP (Renewable + conventional) under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	44.265	74.363	100.315	120.323
2R Renewable CHP under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	0.397	2.980	5.647	11.100
2R Conventional CHP	43.869	70.392	89.636	117.100
2R Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	44.265	73.372	95.283	128.199
Renewable CHP under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	0.397	2.236	3.858	6.947
Conventional CHP	43.869	72.173	93.254	123.113
Total CHP (Renewable + conventional) under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	44.265	74.408	97.112	130.061
Renewable CHP under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	0.397	3.701	7.549	15.948
Conventional CHP	43.869	69.453	87.685	113.749
Total CHP (Renewable + conventional) under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	44.265	73.154	95.234	129.697
Renewable CHP under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	0.397	6.121	14.947	23.718
Conventional CHP	43.869	68.328	84.423	106.658
Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	44.265	74.449	99.370	130.377
Renewable CHP under RHI £25/MWh central biomass price scenario with low fossil fuel and electricity price scenario	0.397	1.620	2.571	3.418
Conventional CHP	43.869	69.582	85.994	106.836
2R Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with low fossil fuel and electricity price scenario	44.265	71.203	88.565	110.255
Conventional CHP Only (Central energy price)	43.869	80.245	105.409	136.653

The effect on CO2 savings (Phase 2 Modelling)

The following table shows the associated carbon savings from the above projections. As with phase 1, for these calculations, we have used the following emissions factors.

CO2 factors (tCO2/MWh)	
CHP fuel (gas)	0.190
Elect	0.430

Table S13: Projection results summary –Total Carbon Savings (from Electricity and Heat) MtCO2/Yr – Scenario R (with practical biomass CHP growth restriction)

	2013	2017	2020
Carbon Savings from Renewable and Conventional CHP MtCO2/Yr			
1R Renewable CHP under BAU RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	1.103	3.000	4.415
Conventional CHP	14.157	17.706	20.460
Total CHP (Renewable + conventional) under BAU RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	15.261	20.706	24.875
2R Renewable CHP under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	1.686	3.077	4.904
Conventional CHP	13.667	16.223	19.332
Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	15.353	19.300	24.235
2R Renewable CHP under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	1.171	1.869	2.590
Conventional CHP	13.984	16.811	20.201
Total CHP (Renewable + conventional) under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	15.156	18.680	22.790
2R Renewable CHP under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	2.208	4.390	7.609
Conventional CHP	13.494	15.904	18.861
Total CHP (Renewable + conventional) under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	15.702	20.294	26.470
2R Renewable CHP under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	2.559	5.400	10.101
Conventional CHP	13.455	15.910	19.024
Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	16.014	21.310	29.125
2R Renewable CHP under central biomass price scenario with low fossil fuel and electricity price scenario	0.936	1.403	1.804
Conventional CHP	13.679	16.029	18.695
Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with low fossil fuel and electricity price scenario	14.614	17.432	20.500
Conventional CHP Only (Central energy price)	13.303	15.703	18.504

Under the proposed RHI and RO policy revision, the balance of changes in overall carbon saving resulting from increased renewable heat, decreased heat and power from conventional CHP and either a modest increase or decrease in renewable electricity from CHP, is complex.

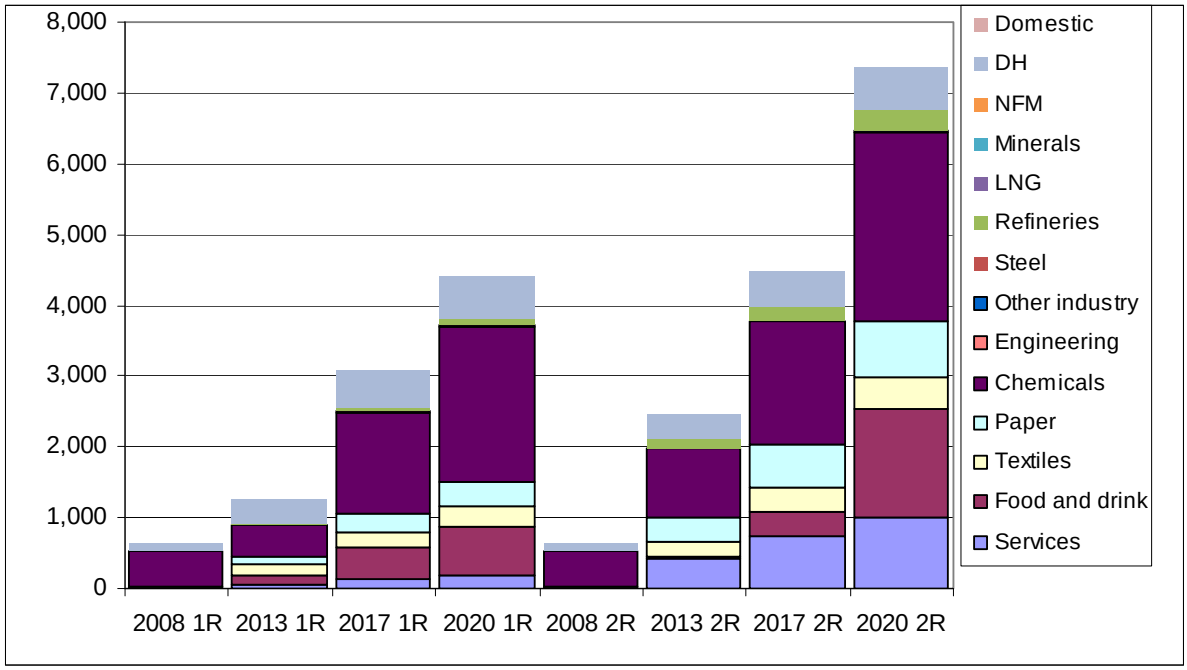
It is concluded that, in the central fossil fuel and renewable fuel price projections, the projected total carbon savings from renewable and conventional CHP may be slightly lower in the long term than the savings under the current RO policy.

However even under an RHI policy the total volume of renewable energy (heat and power) increases whilst offering a clear increase in carbon saving compared to a scenario of no renewable CHP. In addition, the reduction in renewable electricity from CHP may coincide with an increase in generation by renewable power only plant but this is outside the scope of this report.

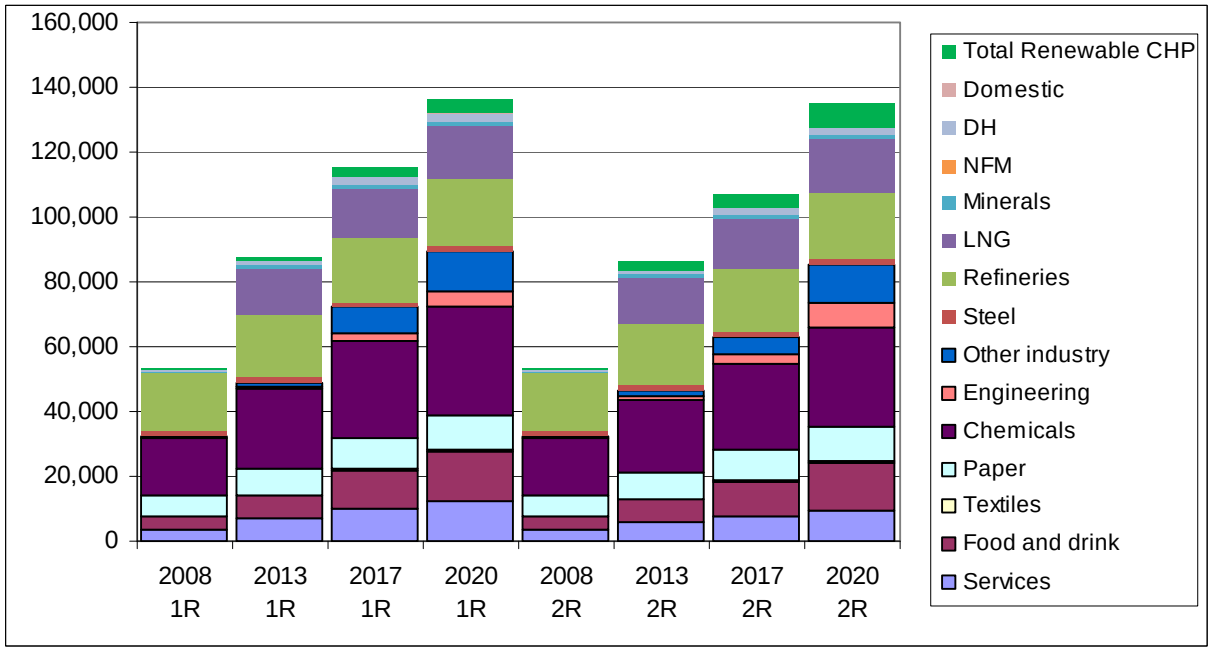
Phase 2- Sector Results Summary for central fuel price scenarios

- **Scenario 1R = With existing RO policy, CHP designed and operated to maximise ROCs**
- **Scenario 2R = With Proposed RHI = £25/MWh, CHP designed to follow site heat and power loads where possible with steam turbine technology**

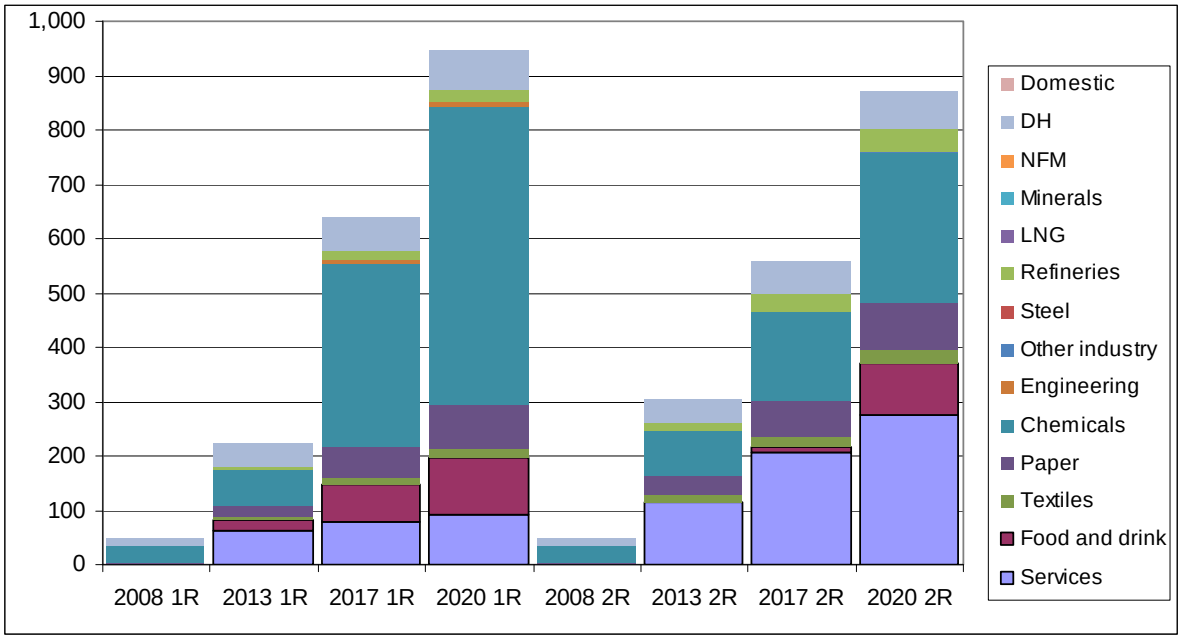
Graph S6: Renewable CHP Projection by Sector Heat Output GWh/Yr



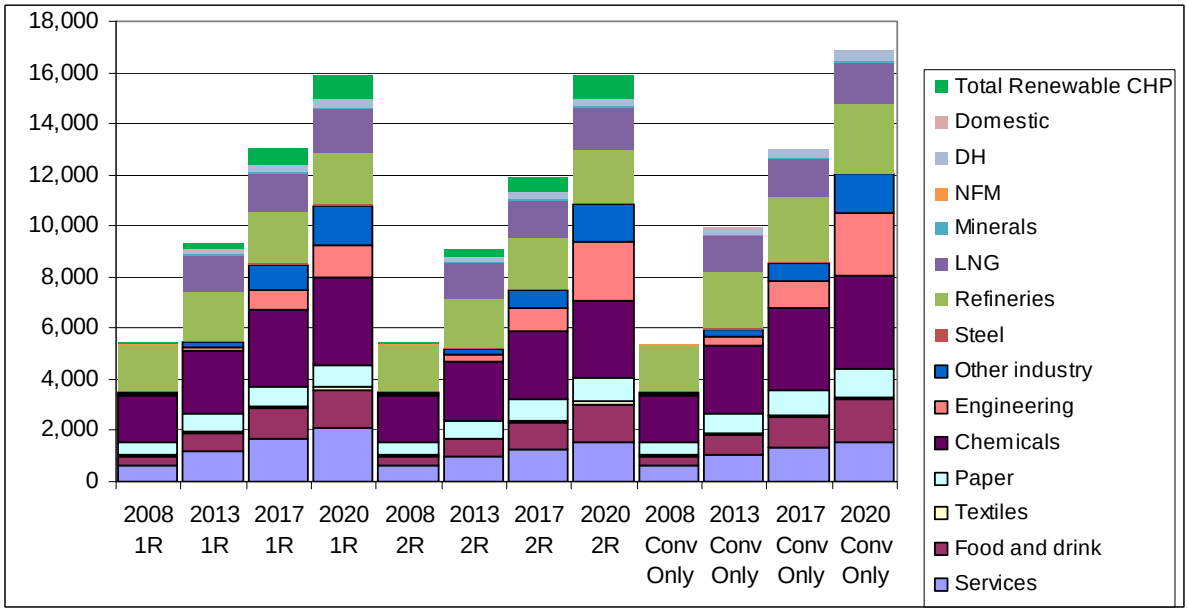
Graph S7: Conventional CHP Projection by Sector + renewable CHP Heat Output GWh/Yr



Graph S8- Renewable CHP Projection by Sector Elec Capacity MWe



Graph S9 - Conventional CHP Projection by Sector + renewable CHP Elec Capacity MWe



Introduction

The Department of Energy and Climate Change (DECC) is seeking a greater understanding of the costs of renewable CHP and the economic modelling of the likely impact of the establishment of a Renewable Heat Incentive (RHI) and revised Renewable Obligation (RO) banding measures on the uptake of:

- CHP systems fuelled by renewables and
- CHP systems fuelled by fossil fuels, such as gas, coal and oil

The main variables to be considered are:

- Different levels of support for different technologies through the RHI A banding range for the RO appied from April 2009, with options that include modifications to the banding of renewable CHP that recognises the RHI;

This study is assessing the degree to which renewable CHP uptake will be incentivised by the RO and the RHI and specifically:

- The interaction between the RHI / RO in regard to renewable CHP to optimise outcomes in terms of cost-effectiveness, carbon abatement and progress to renewables targets, as well as optimal use of resources such as biomass;
- Identifying and addressing any unintended consequences for fossil fuel CHP that may arise from RHI/RO - and potentially perverse outcomes in terms of carbon targets and the efficient use of renewable materials

The overall aim is to model several scenarios and assess the impact on both renewable and non-renewable CHP capacity in relation to renewable energy targets and greenhouse gas emission reduction goals and their cost-effectiveness. The distributional outcomes from each of the scenarios are also important.

The study estimates the contribution of renewable CHP to offsetting central generation and heat-only plant and the impact on existing conventional CHP are being determined.

The key questions being addressed are:

- What is the cost structure of renewable CHP?
- What is the impact on the capacity of CHP fuelled by renewable resources given current proposals to develop a range of support mechanisms for renewable heat?
- What is the impact on the capacity of CHP fuelled by fossil fuels of the proposed Renewable Heat Incentive and Renewables Obligation?

The analysis is based upon an extension to the current CHP ‘bottom-up’ projection model, adapted to also suit biomass CHP take-up projections.

The methodology used to assess the ‘likelihood of investment’, and hence the future take-up of CHP, is based on a model in which the uncertainty in the future financial returns from CHP is linked (multiplied) with a ‘propensity to invest function’, which allows the percentage likelihood of a particular CHP investment to be calculated. The input ‘uncertainties’ such as future fuel prices, additional capital cost etc. and the investment response function have all been consulted over through meetings arranged with, and by, the CHP Association.

Previous CHP modelling work did not included renewable CHP, mainly because it is generally concluded that conventional CHP and renewable CHP will compete for the same potential sites and markets, and in principle, will not affect the overall future take-up. The final stage of the modelling described above is therefore to make some estimates of the likely fuel switching that might occur towards renewable energy in the future and how much heat is likely to be delivered by renewable fuelled CHP.

Renewable CHP Modelling

The methodology being developed as part of the current study will allow policy support effects for renewable CHP to be included in the growth estimates. The effects of existing and possible future support policies for conventional CHP are also included by considering the result of policy on CHP financial returns and the uncertainty in future investment outcomes. In principle, it is also possible to adjust the 'propensity to invest' function to recognise changes in investment behaviour as policies become more established (and secure).

Renewable CHP systems are technically different to the conventional system studied in the past; this set of projections is based on two types of technology: Biomass steam turbines (three different size ranges) and a small hot air Turbine "BG100". The operating conditions for these technologies have been considered in detail and the operation and their costs have been consulted on (with the industry) at a meeting on 4th June 2009.

This report covers the following issues:

- Renewable CHP cost structure, operating data and system optimisation
- A description of the modelling approach we have adopted
- Projected electrical capacity and heat output of CHP fuelled by renewable resources, given the current proposals of support mechanisms (RO and RHI) and various energy and carbon price scenarios and sensitivities
- Results of the consequential impact on the potential capacity of 'conventional' CHP fuelled by fossil fuels
- An analysis of the CO2 savings derived from the projections of both conventional and renewable fuel- based CHP and a comparison with that of the projected conventional CHP uptake if the renewable option were removed. This provides an assessment of the impact of biomass CHP in increasing or reducing carbon savings from all CHP as a whole.

Renewable CHP technical and cost characteristics and operating revenue optimisation scenarios under current RO and proposed RHI policies

Main assumptions

- The vast majority of renewable CHP schemes are fuelled by biomass combustion
- There are 4 main types of biomass power generators, which are all suitable for CHP

  1 Pass-out Condensing Steam turbines (most common but usually >1MWe)
  2 Back Pressure Steam Turbines (not common for new schemes)
  3 Indirect air turbine
  4 Steam engines (not practical or economically viable in most cases)

Technical characteristics

In steam turbines, a boiler burns fuel to generate high-pressure steam which is then fed into a turbine which consists of several different sets of turbine blades or stages each with angles optimised to capture power from steam with a decreasing density.

A back pressure steam turbine is designed such that the steam leaves the final stage of turbine under pressure to be used subsequently to serve the heat demand. With this arrangement the power generation and available heat increase and decrease in tandem with the fuel input rate and so there is no flexibility to vary the heat to power ratio to match that of the site demand.

In a condensing steam turbine, the steam leaves the final turbine stage at a very low-pressure to maximise power generation before being condensed and returned to the boiler. A pass-out condensing steam turbine is designed with outlets between turbine stages to allow steam to be diverted to serve heat loads. This reduces the volume of steam going to downstream turbine stages and thus the power generation as compared with fully condensing power only mode where no steam is extracted but is more efficient than a back pressure turbine as it allows flexibility to generate more electricity to be generated when the heat load is low whereas a back pressure turbine would either have to generate less power or waste heat to continue generating the same amount of power.

In an indirect air turbine clean air is compressed, heated in a closed loop via a heat exchanger by the hot combustion products of biomass and then expanded through a turbine (which also drives the compressor) as in any gas turbine set and hot water is then generated by the waste heat. As with a back pressure steam turbine, the power generation and available heat increase and decrease in tandem with the fuel input rate and so there is no flexibility to vary the heat to power ratio to match that of the site demand.

The technical and cost characteristics of the latest biomass CHP technology are summarised below. As shown in the following table, the biomass technologies covered in this study range from 100kWe air turbines to >25MWe steam turbines. Back pressure steam turbines are less common and steam engines are rare and therefore not considered in this analysis.

Generic CHP technical and cost characteristics Example

CHP Electrical Capacity	100 kWe - 1 MWe (1 - 10 x 100kWe units)	1 - 5 MWe	5 - 25 MWe	> 25 MWe
Example Fuel	Agricultural Biomass	Agricultural Biomass	Agricultural Biomass	Agricultural Biomass
CHP technology	Small Indirect Hot Air Turbine	Pass-out Steam Turbine	Pass-out Steam Turbine	Pass-out Steam Turbine
Electrical efficiency in Maximum Power Mode (Gross Power GCV fuel basis)	20.00%	23.00%	25.00%	28.00%
Parasitic Load % of Generated Electricity	10.00%	10.00%	10.00%	10.00%
Electrical efficiency in Maximum Power Mode (Net Power GCV fuel basis)	18.00%	20.70%	22.50%	25.20%
Example Grade of Heat Recovery	Hot Water	11.4Bara Steam	11.4Bara Steam	11.4Bara Steam
Ratio of heat Extracted / reduction in gross power output (Zratio)	N/A	5.7	5.3	4.4
Operating thermal efficiency in Maximum Heat Mode (GCV fuel basis)	40.00%	67.78%	73.61%	74.31%
Operating electrical efficiency in Maximum Heat Mode (Net Power GCV fuel basis)	18.00%	10.00%	10.00%	10.00%
Maximum CHP Heat to Net Power Capacity Ratio	2.22	6.78	7.36	7.43
Capex	£4000 / kWe	£3000 / kWe	£3000 / kWe	£3000 / kWe
Opex	£140 / kWe / Yr	£140 / kWe / Yr	£140 / kWe / Yr	£140 / kWe / Yr
Opex % of Capex	3.50% / Yr	4.67% / Yr	4.67% / Yr	4.67% / Yr
Min power turndown ratio	50%	25%	25%	25%
Example Run Hrs / Yr	8094	8094	8094	8094
CHPQA X value ROCs entitlement based on GN44	370.00	370.00	370.00	338.00
CHPQA Y value ROCs entitlement based on GN44	130.00	130.00	130.00	130.00

Heat to Power Ratio

For the air turbines the ratio of available heat to the amount of power generated (heat to power ratio) is fixed. However for pass-out steam turbines any utilised heat is usually extracted as high-pressure steam between turbine stages, though this results in a drop in power efficiency as electricity is no longer produced by condensing steam in any downstream turbine stages. Note: the ratio of heat extracted to loss of power output is defined as the Z ratio (see later), not to be confused with heat to power ratio.

The heat to power ratio (at maximum high-pressure steam turbine boiler capacity) is therefore variable between 0 (fully condensing mode) where power generation is maximised and a maximum where all the steam is extracted after the first turbine stage and the reduction in power output is greatest. Heat could be extracted from the condenser, which would not incur a penalty in power production but this is uncommon as the grade of heat available in the condenser is very low (water at approximately 50^{o}C so such applications are not yet common but are likely to increase. One such application is the re-evaporation of Liquefied Natural Gas (LNG), as facilitating heat transfer from ambient free heat such as sea water to the LNG at the rates required can be problematic, particularly in winter. Therefore a slightly higher temperature heat source is required and use of waste heat from the condenser is ideal and likely to avoid gas being burned in boilers.

Of course high-pressure steam could be taken off before entering the first turbine stage, but this does not meet the definition of CHP where the working fluid must generate some power before heat is recovered from it.

When the heat and/or power demands fall below the capabilities of a renewable CHP, it may not be economically viable to operate at maximum capacity and so the fuel input and consequently the heat and/or power outputs can also be modulated to suit. The ratio of power output at a reduced fuel input to that at full capacity is the turndown ratio. Generally it is surplus heat rather than surplus power which calls for modulation of plant as it is usually economic to export power with the associated RO benefit (once the plant is in place even if it is not economic to design for large amounts of export).

In the case of a pass-out steam turbine CHP there is usually less need to modulate the high-pressure steam boiler operation as it is possible to reduce the CHP heat output by merely extracting less steam and increasing power output. This is beneficial provided it is economic to export power. However if this is not the case then the CHP would modulate. In the table above the minimum turndown ratio for steam turbine CHP is the ratio of power generated in fully condensing mode with minimum fuel input to that at maximum capacity, not to be confused with the reduction in power generated at maximum heat extraction.

CHPQA uses a Quality Index (QI) to assess the overall efficiency of CHP compared to the alternative forms of separate heat and power generation and if a QI of 100 is met, all generated electricity is considered as coming from Good Quality CHP (www chpqa.com). The overall CHP efficiency increases with increasing heat utilisation and there is a certain minimum amount of heat required for QI = 100 and therefore for the total power output (TPO) to fully qualify as good quality CHP electricity (Qualifying Power Output QPO). At lower heat extraction rates only a proportion of electricity will qualify as QPO.

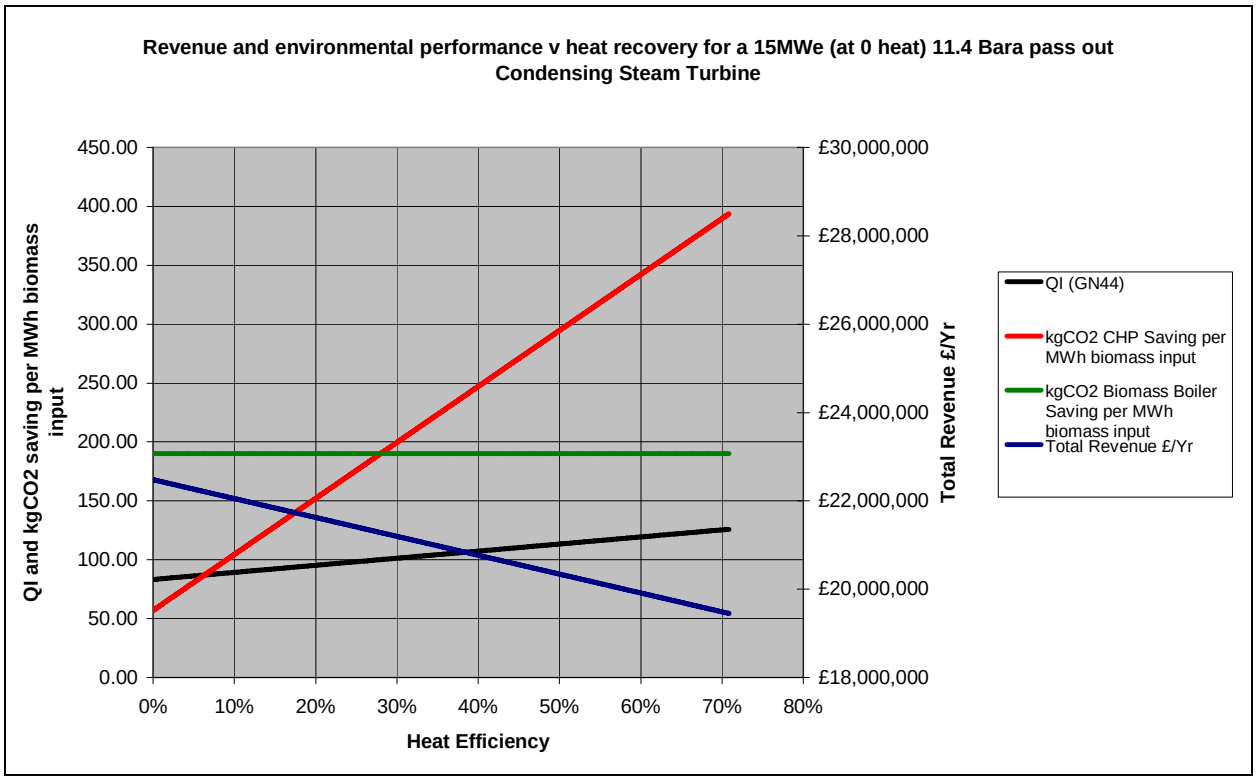
For renewable CHP, the current RO policy awards 2 ROCs per MWh for QPO. Where QI<100 and therefore QPO<TPO, the non qualifying element of power output from CHP is only awarded 1.5 ROCs/MWh, as is the case for renewable power only electricity generation.

The following analysis of current RO policy effect on CHP operation illustrates the fact that, for a given CHP capacity, ROCs and the total operating cost benefit is typically maximised when CHP is designed to extract the steam needed to achieve a CHPQA QI of 100. The CHP would be sized either on electrical demand or heat demand whichever gives the most economical design. It is believed that, under the RO banding, developers are commonly sizing renewable CHP schemes to give the maximum electrical output which can achieve a QI=100 for a given site heat load which is usually in excess of a site's electrical demand and the surplus exported.

Example of a CHP sized to match site's heat demand whilst operating at a heat to power ratio giving a QI of 100 (which generally maximises the operating income for any given size of turbine under existing RO Policy)

CHP Electrical Capacity	100 kWe - 1 MWe (1 - 10 x 100kWe units)	1 - 5 MWe	5 - 25 MWe	> 25 MWe
Site Energy Demand H:P ratio	2.22	1.64	1.64	1.64
CHP Operating H:P ratio (based on net power out)	2.22	1.34	0.61	0.44
Operating thermal efficiency in CHP Mode (GCV fuel basis)	40.00%	22.89%	12.46%	10.08%
Operating electrical efficiency in CHP Mode (gross power GCV fuel basis)	20.00%	18.98%	22.65%	25.71%
Operating electrical efficiency in CHP Mode (net power GCV fuel basis)	18.00%	17.09%	20.38%	23.14%
Operating total efficiency in CHP Mode (GCV fuel basis)	58.00%	39.98%	32.84%	33.22%
Approx Opex £/MWhe	£17.32/MWhe	£20.98/MWhe	£19.11/MWhe	£18.86/MWhe
QI for ROCs entitlement based on GN44	126.00	100.00	100.00	100.00
Example Heat Led CHP Power Output rate	100kWe	2.5MWe	15.0MWe	25.0MWe
Example Heat Led CHP Heat Output rate	222kWe	3.3MWe	9.2MWe	10.9MWe

Renewable CHP Environmental and Economic performance Under the previous Renewable Obligation Policy (1 ROCs/MWhe for all renewable power generating plants including CHP)



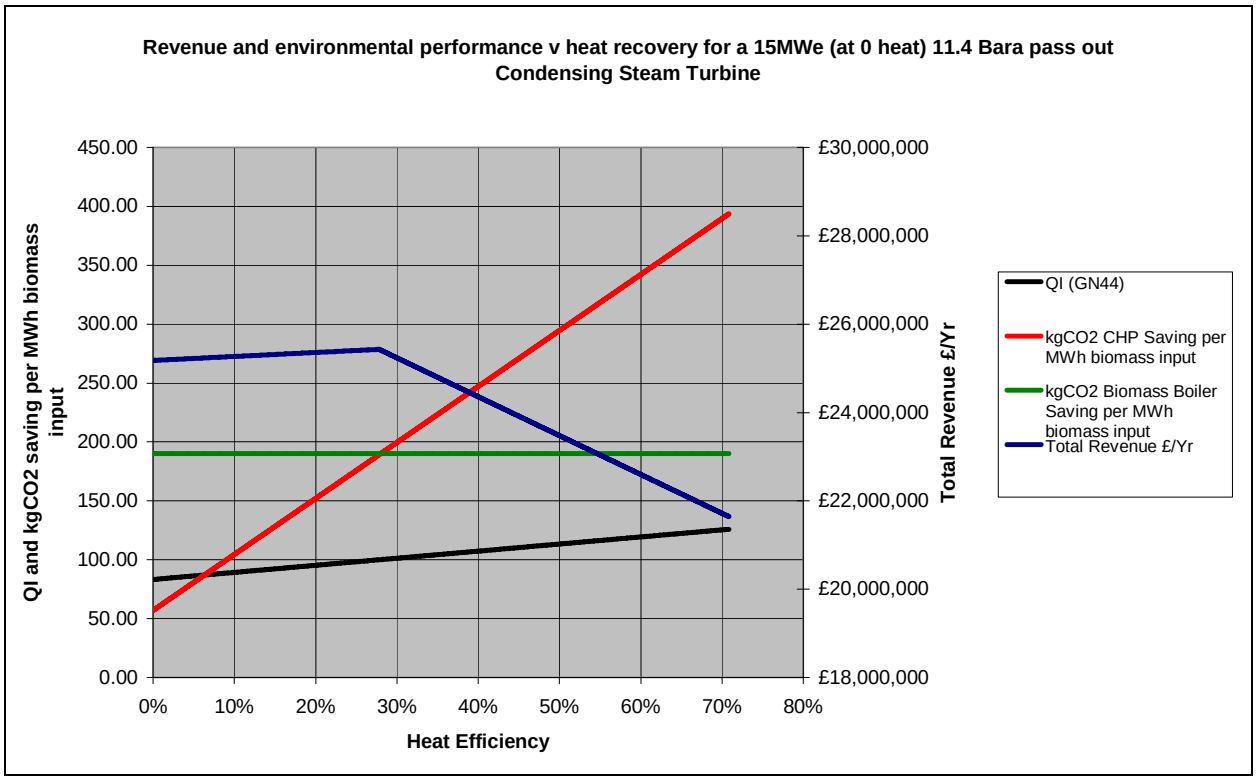
The chart above shows an example of how the following parameters vary as a function of CHP heat efficiency (the ratio of heat extracted to fuel input) with existing technologies. In all cases it is assumed that the high pressure steam turbine boiler is operating at maximum capacity i.e. maximum fuel input and so the operating costs do not vary, thus the overall operating cost benefit is optimised when the total income (revenue) is maximised.

- The typical CO2 (kg) saving of CHP (the red line quantified by the left hand y axis)
- The CHPQA Quality Index of Renewable CHP (the black line) per MWh of biomass input (quantified by the left hand y axis)
- The total annual operating income (£) (the blue line) of CHP from heat and power generation (quantified by the right hand y axis).
- For an environmental performance comparison with biomass boilers, the CO2 saving per MWh of biomass input is also shown (the green line quantified on the left hand y axis whose efficiency is fixed and not related to the CHP efficiency shown on the x axis.).

It can be seen that carbon saving increases with increased heat extraction and is maximised at maximum cogeneration mode. Above about 27.5% heat efficiency, the CHP displaces more CO2 from fossil fuel boilers and power stations than a biomass boiler for the same fuel input (where the CHP performance (red line) crosses over) and at this point the CHPQA Quality Index (black line) is about 100.

Under the previous RO policy, 1 ROC/MWh of power generated was awarded regardless of technology. This acted as a deterrent to renewable CHP versus power only generation as the ROCs generated woul d be reduced along with the power if steam was extracted and this loss of ROCs coupled with the loss of the value of the power itself usually outweighed the financial value of heat extracted. For this reason renewable CHP uptake, without any capital grants, was close to zero, and most projects developed during that period were power only plants.

Renewable CHP Environmental and Economic performance under the new Renewable Obligation banding,1.5 ROCs/MWh are awarded for biomass power only plants and 2 ROCs/MWh for Good Quality CHP electricity.

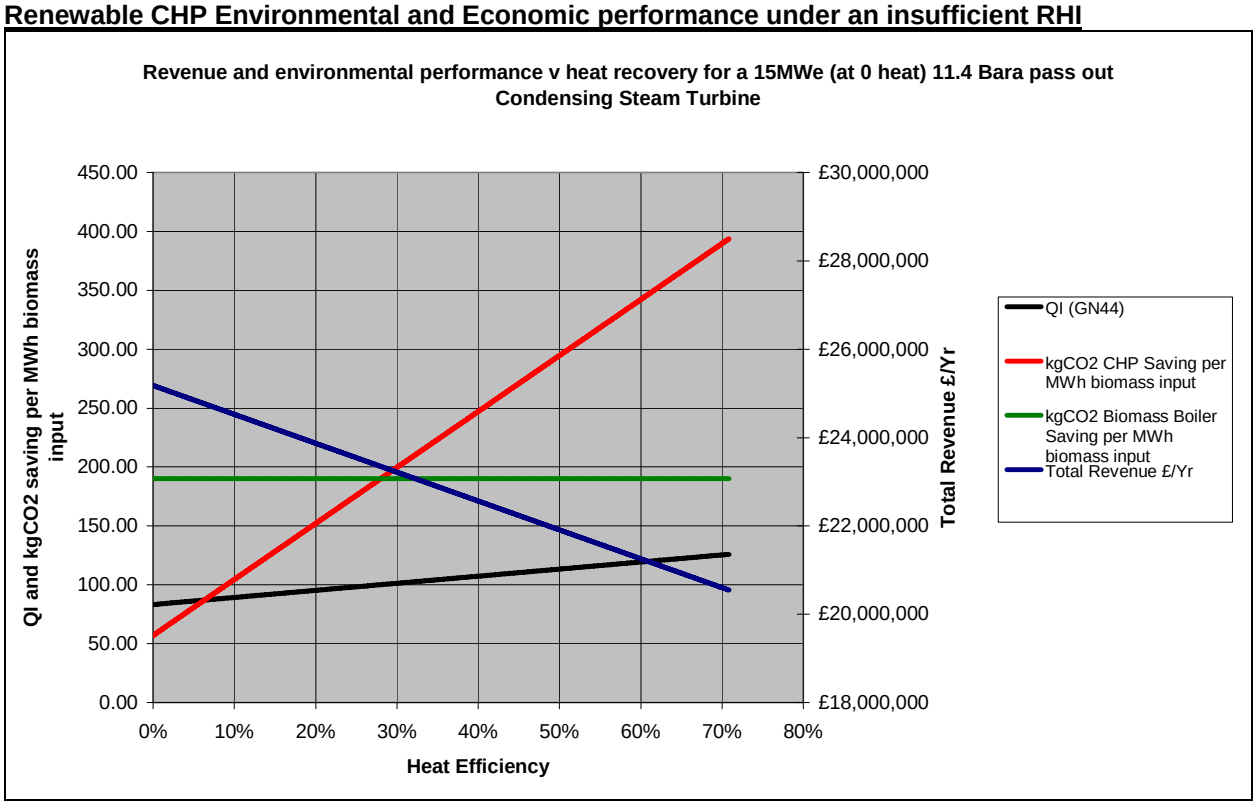


This differential is usually sufficient to encourage heat extraction from CHP such that the quality index under the provisions of CHPQA GN 44, which maximises revenue, will be at least 100. However, as with the old ROCs banding, beyond this point the loss of revenue from power and ROCs discourages increased heat extraction and usually this outweighs the benefits from heat extraction and in fact this disincentive is greater than previously as 1.5 ROCs are lost per MWh power reduction as opposed to 1 under the old ROC banding.

Proposed Renewable Heat Incentive and revised RO policy

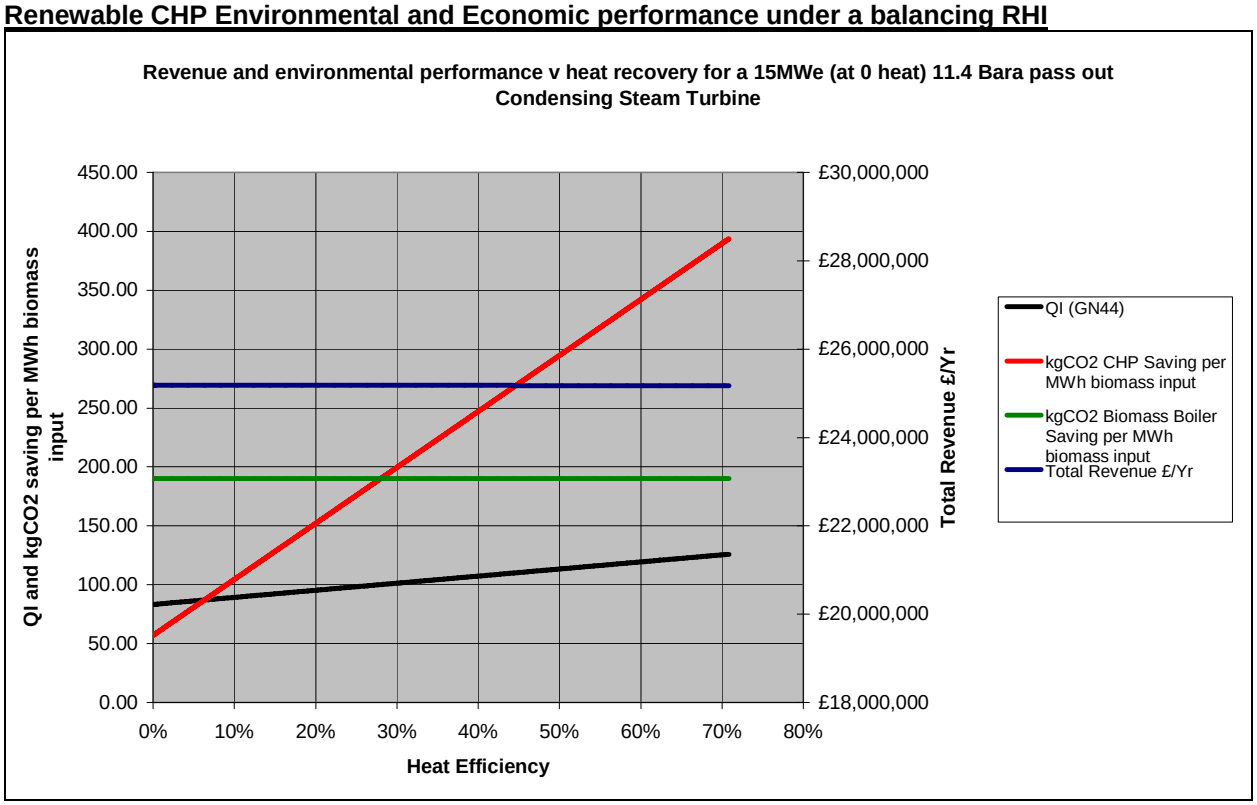
It is proposed that a RHI be awarded to any heat generated by renewable fuel (including the heat from a renewable CHP) but that at the same time, the current additional 0.5 ROCs/MWh for electricity from Good Quality renewable CHP as opposed to renewable power only generation be removed thus 1.5 ROCs/MWh are awarded for electricity generated by renewable fuel regardless of whether it is good quality CHP electricity or not.

Renewable CHP Environmental and Economic performance under an insufficient RHI



If the extra 0.5 ROCs/MWh for Good Quality CHP electricity is removed, without an RHI the circumstances would be almost identical to those under the old ROCs banding the only difference being that 1.5 ROCs are awarded per MWh of power instead of 1 thus there is greater disincentive for heat extraction from steam turbines and there is no turning point as there is at QI=100 with the new RO banding where there is a differential based on meeting good quality CHP standards. Any RHI will make the revenue v heat extraction line less negative and a sufficient RHI will make it neutral/positive.

Renewable CHP Environmental and Economic performance under a balancing RHI



In the example above the RHI is set such that the income from heat and RHI balance the reduced income from electricity and ROCs. A higher RHI would mean income would be maximised at maximum heat extraction. This balance is site specific. Our projection modelling is based on scenarios with RHI of £20/MWh, £40/MWh and £25/MWh which as shown later, would be sufficient to encourage most CHP schemes to extract as much heat as possible, at least as much as there is on site demand for. Meanwhile the incentive on renewable electricity from CHP is reduced and therefore so is the incentive to oversize the turbine to export power. It is therefore possible that CHPs would be sized only to meet on site power requirements. However, a CHP sized only to match a site's electricity demand in maximum cogeneration mode would typically generate well in excess of a site's thermal demand and so external customers for heat would need to be found. In the extreme scenario, the CHP may instead be sized using the smallest steam turbine which can meet the site's heat load operating in maximum cogeneration mode, thus generating the least electricity for a given heat load.

Example of a CHP sized to match site's heat demand whilst operating at a maximum heat to power ratio (assumed to maximise operating income for any given size of turbine under proposed RHI Policy)

CHP Electrical Capacity	100 kWe - 1 MWe (1 - 10 x 100kWe units)	1 - 5 MWe	5 - 25 MWe	> 25 MWe
Site Energy Demand H:P ratio	2.22	1.64	1.64	1.64
CHP Design H:P ratio (based on net power out)	2.22	6.78	7.36	7.43
Operating thermal efficiency in CHP Mode (GCV fuel basis)	40.00%	67.78%	73.61%	74.31%
Operating electrical efficiency in CHP Mode (gross power GCV fuel basis)	20.00%	11.11%	11.11%	11.11%
Operating electrical efficiency in CHP Mode (net power GCV fuel basis)	18.00%	10.00%	10.00%	10.00%
Operating total efficiency in CHP Mode (GCV fuel basis)	58.00%	77.78%	83.61%	84.31%
Approx Opex £/MWhe	£17.32/MWhe	£35.85/MWhe	£38.96/MWhe	£43.63/MWhe
QI for ROCs entitlement based on GN44	126.00	129.22	136.80	134.16
Example Heat Led CHP Power Output rate	100kWe	0.5MWe	1.2MWe	1.5MWe
Example Heat Led CHP Heat Output rate	222kWe	3.3MWe	9.2MWe	10.9MWe

However, it is believed that a more likely scenario is that whilst a drop from 2 ROCs/MWhe to 1.5 ROCs/MWhe is likely to reduce the optimal CHP size from the maximum possible for a given heat load (as commonly experienced with the current RO policy) the remaining RO of 1.5ROCs/MWhe would still be sufficient to encourage the CHP to be sized and operated to at least match the site's power demands thus maximising the RHI and RO benefits whilst minimising exporting of heat or power. However, on average, the site's heat to power demand ratio is larger than would be needed to meet the QI of 100, so it is expected that CHP operators would operate a CHP of given size in a more environmentally friendly way (on a CO2 saved per unit biomass input) than would be the case under the current ROCs regime (maximising electricity out put) although the design capacity and therefore total CO2 savings might be lower than under the current regime which incentivises export power to a greater extent due to the extra 0.5 ROCs/MWhe.

Example of a CHP sized to match site's heat and power demand

CHP Electrical Capacity	100 kWe - 1 MWe (1 - 10 x 100kWe units)	1 - 5 MWe	5 - 25 MWe	> 25 MWe
Site Energy Demand H:P ratio	2.22	1.64	1.64	1.64
CHP Design H:P ratio (based on net power out)	2.22	1.64	1.64	1.64
Operating thermal efficiency in CHP Mode (GCV fuel basis)	40.00%	26.94%	28.83%	30.92%
Operating electrical efficiency in CHP Mode (gross power GCV fuel basis)	20.00%	18.27%	19.56%	20.97%
Operating electrical efficiency in CHP Mode (net power GCV fuel basis)	18.00%	16.45%	17.60%	18.88%
Operating total efficiency in CHP Mode (GCV fuel basis)	58.00%	43.39%	46.44%	49.79%
Approx Opex £/MWhe	£17.32/MWhe	£21.80/MWhe	£22.13/MWhe	£23.12/MWhe
QI for ROCs entitlement based on GN44	126.00	102.63	109.86	111.08
Example Heat Led CHP Power Output rate	100kWe	2.0MWe	5.6MWe	6.6MWe
Example Heat Led CHP Heat Output rate	222kWe	3.3MWe	9.2MWe	10.9MWe

Aggregate Energy and Carbon Price Summaries

Phase 1

Typical Total Energy Prices incl CO_2 costs in 2009 real terms	2008	2012	2013	2021
Total Elec Value (Central) for a Conventional CHP Incl ROCs, LECs and CO2 £/MWh	59.89	80.41	81.43	86.12
Total Elec Value (Central) for a Renewable CHP Incl ROCs, LECs and CO2 £/MWh	133.30	153.83	154.85	159.54
Central Fossil Fuel Price Projection incl CO2 £/MWh	20.68	19.33	20.63	26.16
Central CHP Biomass Price Scenario (Approx Avg Scenario E4Tech Long Term delivered Import Price Projection Inflated in line with oil) £/GJ	4.35	4.84	5.32	5.81
High CHP Biomass Price Scenario (E4Tech Renewable Energy Directive Import Price Projection) £/GJ	7.91	6.86	5.34	4.86
CHP Biomass Price (Central) £/MWh	15.66	17.41	19.16	20.92
CHP Biomass Price (E4 Tech Projection) £/MWh	28.49	24.69	19.24	17.51

Phase 2

Typical Total Energy Prices incl CO_2 costs in 2009 real terms	**2008**	**2012**	**2013**	**2020**
Total Elec Value (Low) for a Conventional CHP Incl ROCs, LECs and CO2 £/MWh	99.78	63.93	61.25	62.22
Total Elec Value (Central) for a Conventional CHP Incl ROCs, LECs and CO2 £/MWh	99.79	108.29	109.63	122.09
Total Elec Value (High) for a Conventional CHP Incl ROCs, LECs and CO2 £/MWh	99.78	128.46	162.38	184.43
Total Elec Value (Central) for a Renewable CHP Incl ROCs, LECs and CO2 £/MWh	167.29	162.04	163.39	174.07
Total Fossil Fuel Price (Low) Projection incl CO2 £/MWh	30.87	17.68	19.19	20.69
Central Fossil Fuel Price (Central) Projection incl CO2 £/MWh	30.87	32.49	35.47	40.27
Central Fossil Fuel Price (High) Projection incl CO2 £/MWh	30.87	51.25	57.50	69.44
Low CHP Biomass Price (Low) £/GJ	4.29	4.90	5.05	6.11
Low CHP Biomass Price (Central) £/GJ	5.82	6.20	6.29	6.94
Low CHP Biomass Price (High) £/GJ	6.57	6.97	7.07	7.78
CHP Biomass Price (Low) £/MWh	15.45	17.64	18.18	22.00
CHP Biomass Price (Central) £/MWh	20.96	22.31	22.65	25.00
CHP Biomass Price (High) £/MWh	23.64	25.09	25.45	28.00

The high and low sensitivities on fossil fuel prices are paired with central biomass prices and high and low biomass sensitivities are paired with central fossil fuel prices.

Energy and Carbon Price Data sources

In phase 1, the fossil fuel and electricity prices are as supplied by DECC at that time, the carbon price assumed was £29.17 and the final delivered prices of biomass imports used in this modelling study are based on the E4Tech (2010)[4] study which projected a scenario "the high case" which estimates the current price at around £7.28/GJ (~£26.2/MWh) falling to £4.21/GJ (~£15.2/MWh) by 2022 and around £4/GJ under the EU Renewable Energy Directive (RED) (2006 money)

In our central case we assume the long term price is near to the current price and that it will then increase rather than fall in line with the treasury oil price projection following a discussion in a meeting with prominent members of the CHP industry.

The assumptions used in the In phase 2 for fossil fuel, biomass and carbon prices can be found on the assumptions Annex published alongside the RHI Impact Assessment[5]. The assumed carbon prices are summarised as follows.

Traded Carbon Prices in 2009 Real Terms £/tCO2	**2008**	**2012**	**2013**	**2020**
Low	**12.00**	**13.00**	**13.00**	**14.00**
Central	**21.00**	**22.00**	**23.00**	**25.00**
High	**26.00**	**28.00**	**28.00**	**31.00**

[4] E4Tech 2010: Biomass prices for the heat and electricity sectors in the UK
[5] Analytical Annex on the RHI IA

Environmental performance vs. heat extraction

As summarised above, the carbon saving of biomass CHP increases with a corresponding increase in the amount of iheat extraction. The plant tends to save less carbon than biomass boilers in fully condensing mode (maximum power generation), but more in maximum heat extraction mode. This is discussed in detail below

Carbon savings analysis

With biomass CHP the fuel is carbon neutral and thus considered carbon free but it displaces fossil fuel which would have been burned in a boiler and the power station grid mix in order to produce the same amounts of heat and power.

- In this case it is assumed the heat would have been produced in a natural gas boiler at an efficiency of 80% (GCV).
- Carbon emission factor for Natural gas = 0.19 tCO2/MWh
- The carbon displaced by CHP heat = 0.19/ 80% =0.2375tCO2/MWh of heat.
- The current average carbon emission of fossil fuel power stations is 0.527tCO2/MWh. Thus the total carbon emissions = 0.527 x Power gen (MWh) + 0.2375 x CHP heat (MWh)

For CHP Schemes which include fully or partially condensing (pass-out) steam turbines, Power Efficiency will decline as steam extraction increases for a given fuel consumption, so there is a trade-off between increasing heat recovery and reducing power output.

- Power gen (MWh) = Power gen (fully condensing mode) – CHP heat / Z ratio

Where as defined above, Z ratio is the ratio of heat extracted to power reduction.

Thus carbon saving is

- 0.527 x Power gen (fully condensing mode) – 0.527 x CHP heat / Z ratio + 0.2375 x CHP heat

So as long as Z ratio>2.2, then carbon savings increase with heat extraction. Z ratio is invariably >2.2 so carbon savings are maximised when the maximum amount of heat is extracted from a steam turbine.

Renewable CHP v renewable heat-only boilers

It can be shown that any CHP saves the most carbon when the most heat is extracted at the minimum grade (i.e. high Z factor). This makes sense since the heat has provided as much power as possible, and therefore has less potential for further power generation.
The CO2 saving of a biomass boiler of similar efficiency as a standard boiler and therefore displacing 1MWh of natural gas per MWh of biomass is 0.19TCO2/MWh, and it can be seen in the following table that in practice CHP will always be capable of displacing more carbon per unit of biomass input than a renewable heat-only boiler if enough steam is extracted from a high efficiency turbine at a low enough grade which is feasible for most new schemes where the turbine would typically achieve a net electrical efficiency of 22.5% or more in fully condensing mode.

Biomass Pass Out Condensing Steam Turbines												
CHP Cond Peff (Net Power/Gross Fuel)	**30%**											
Min Pos CHP Peff at maxheat	**10%**											
Max Pos Overall eff	**90%**											
CHP Z Ratio (Heat/power loss)		**3.50**	**4.00**	**4.50**	**5.00**	**5.50**	**6.00**	**6.50**	**7.00**	**7.50**	**8.00**	**8.50**
Example Steam Grade		**Unusually High Grade**	**>50MWe 21Bara**	**25-50MWe 12.5 Bara**	**10-25MWe 11 Bara**	**10-25MWe 7 Bara**	**5-10MWe 7 Bara**	**5-10MWe 4 Bara**	**2-5MWe 4 Bara**	**2-5MWe 3 Bara**	**2-5MWe 2.5 Bara**	**Unusually Low Grade**
Min Peff		10.00%	10.00%	12.86%	15.00%	16.67%	18.00%	19.09%	20.00%	20.77%	21.43%	22.00%
Maxheat eff		70%	80%	77%	75%	73%	72%	71%	70%	69%	69%	68%
Tot Eff		80%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
TCO2 Saving/MWh biomass		**0.219**	**0.243**	**0.251**	**0.257**	**0.262**	**0.266**	**0.269**	**0.272**	**0.274**	**0.276**	**0.277**
Worse/Better than biomass boiler		Better	Better	Better	Better	Better	Better	Better	Better	Better	Better	Better
CHP Cond Peff (Net Power/Gross Fuel)	**25%**											
Min Pos CHP Peff at maxheat	**10%**											
Max Pos Overall eff	**90%**											
CHP Z Ratio (Heat/power loss)		**3.50**	**4.00**	**4.50**	**5.00**	**5.50**	**6.00**	**6.50**	**7.00**	**7.50**	**8.00**	**8.50**
Min Peff		10.00%	10.00%	10.00%	10.00%	10.56%	12.00%	13.18%	14.17%	15.00%	15.71%	16.33%
Maxheat eff		53%	60%	68%	75%	79%	78%	77%	76%	75%	74%	74%
Tot Eff		63%	70%	78%	85%	90%	90%	90%	90%	90%	90%	90%
TCO2 Saving/MWh biomass		**0.177**	**0.195**	**0.213**	**0.231**	**0.244**	**0.248**	**0.252**	**0.255**	**0.257**	**0.259**	**0.261**
Worse/Better than biomass boiler		Worse	Better	Better	Better	Better	Better	Better	Better	Better	Better	Better
CHP Cond Peff (Net Power/Gross Fuel)	**22.5%**											
Min Pos CHP Peff at maxheat	**10%**											
Max Pos Overall eff	**90%**											
CHP Z Ratio (Heat/power loss)		**3.50**	**4.00**	**4.50**	**5.00**	**5.50**	**6.00**	**6.50**	**7.00**	**7.50**	**8.00**	**8.50**
Min Peff		10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.23%	11.25%	12.12%	12.86%	13.50%
Maxheat eff		44%	50%	56%	63%	69%	75%	80%	79%	78%	77%	77%
Tot Eff		54%	60%	66%	73%	79%	85%	90%	90%	90%	90%	90%
TCO2 Saving/MWh biomass		**0.157**	**0.171**	**0.186**	**0.201**	**0.216**	**0.231**	**0.243**	**0.246**	**0.249**	**0.251**	**0.253**
Worse/Better than biomass boiler		Worse	Worse	Worse	Better	Better	Better	Better	Better	Better	Better	Better
CHP Cond Peff (Net Power/Gross Fuel)	**20%**											
Min Pos CHP Peff at maxheat	**10%**											
Max Pos Overall eff	**90%**											
CHP Z Ratio (Heat/power loss)		**3.50**	**4.00**	**4.50**	**5.00**	**5.50**	**6.00**	**6.50**	**7.00**	**7.50**	**8.00**	**8.50**
Min Peff		10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.67%
Maxheat eff		35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	79%
Tot Eff		45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	90%
TCO2 Saving/MWh biomass		**0.136**	**0.148**	**0.160**	**0.171**	**0.183**	**0.195**	**0.207**	**0.219**	**0.231**	**0.243**	**0.245**
Worse/Better than biomass boiler		Worse	Worse	Worse	Worse	Worse	Better	Better	Better	Better	Better	Better
Biomass Pass Out ST's in general												
Min Peff	**10%**											
CHP Power TCO2 Saving / MWh biomass	**0.053**											
CHP Heat eff required to match biomass b	**58%**											
Tot eff required to match CO2 saving of b	**68%**											

For example for a large steam turbine with a fully condensing efficiency of 25%, extracting as much heat as possible at a Z factor of 4 (e.g. a 50MWe steam turbine with steam extraction <21bar) the CHP will displace as much carbon as a biomass boiler would and so extracting enough heat at lower grades would guarantee this.

Where power efficiency = 10% which is approximately the power efficiency where all heat is extracted after the first stage of a condensing steam turbine, the min heat efficiency required to match heat-only carbon saving = 0.8-0.222 = 57.8% therefore total CHP eff = 67.8%.

The best scenario for a steam turbine (or a combined cycle gas turbine) is if the very low grade heat in the condenser can be used as there is then no power reduction associated with heat extraction. Such applications are not yet common but are likely to increase. One such application is the gasification of liquefied natural gas (LNG) planned by a major LNG terminal under development. Note this scenario is not shown in the table above, which only considers steam pass-out prior to condensing, the nearest comparison being with maximum Z ratio.

This can be further illustrated algebraically as follows

If we assume the thermal efficiency of a biomass boiler equals that of a gas boiler, the carbon displaced = 0.19tCO2/MWh renewable fuel

As stated above the carbon intensity of grid electricity is 0.527tCO2/MWh and of gas boiler heat displaced by CHP heat is 0.2375 tCO2/MWh (0.19/80%)

The carbon in tCO2/MWh biomass displaced by renewable CHP is therefore = 0.527 x power efficiency+ 0.2375 x heat efficiency

Therefore the carbon saving from CHP heat per MWh biomass in required to equal the carbon saving of a heat-only boiler = (0.19 - 0.527 x power efficiency) / 0.2375 = 0.8 – 2.22 power efficiency

If the power efficiency > 0.8/2.22 (36.05%) then the CHP will displace more carbon than a heat only renewable fuel boiler burning the same amount of biomass without recovering any heat.

Put another way, a renewable fuel generator with a 36.4% electrical efficiency or above would save more CO2 than a biomass boiler burning the same amount of biomass, without having to extract any heat.

This can be shown another way. If a biomass boiler has the same efficiency as a biomass CHP then 1MWh of biomass displaces 1MWh of gas = 0.19tCO2. In a biomass generator, 1 unit of biomass displaces 1/peff units of electricity = 1/power efficiency x 0.527 tCO2. Therefore if the electrical efficiency exceeds 0.19/0.527 then a biomass CHP will save more carbon than the biomass boiler. 0.19/0.527 = 36.05%. Note the long term projection is for the average carbon intensity of electricity to drop to 0.43tCO2/MWh so the required power efficiency of a plant generating power only to compete with renewable fuel boilers would be 0.19/0.43 = 44.2%.

Indications of RHI required.

If the additional 0.5 ROCs/MWh elec are removed for future CHP schemes, they will simple receive 1.5 ROCs/MWhe. Thus for every MWh of heat extracted they will lose 1.5/Zratio x ROC value. Thus the RHI required to balance lost ROCs under such a future banding is £1.5 x ROC/Zratio which at the current £45/ROC is £67.50/Zratio

However the required RHI price will also depend on the value of the power and other associated benefits (e.g. LECs) and the value of the heat itself. Another indication is the RHI, which would be required to balance the current 0.5 ROCs/MWh differential for CHP schemes just meeting the Quality Index of 100.

It can be seen from the table below, that more efficient schemes would require a higher RHI to balance the current RO benefits. This is because less heat is required to meet the Quality Index of 100. For high efficiency schemes this is much higher than that required to balance the lost 0.5 ROCs so it would probably not be desirable or practical to design the RHI on such a compensatory basis since the level required would potentially be so high and vary so much from scheme to scheme. However were a compensatory approach taken, an RHI tailored to highly efficient schemes would greatly encourage maximum heat extraction, whereas one tailored to low efficiency schemes would be insufficient to encourage any heat extraction.

RHI levels required under the proposed revision of RO policy to encourage heat extraction and RHI levels required to balance the reduction of RO revenue for existing CHP schemes.

Z ratio	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
Example Steam Grade	Very high grade unusual	>50MWe 21Bara	25-50MWe 12.5 Bara	10-25MWe 11 Bara	10-25MWe 7 Bara	5-10MWe 7 Bara	5-10MWe 4 Bara	2-5MWe 4 Bara	2-5MWe 3 Bara	2-5MWe 2.5 Bara
ROCs/MWhe	RHI (£/MWht) required to balance a loss of 1.5 ROCs/MWhe benefit through heat extraction									
1.5	£19.29	£16.88	£15.00	£13.50	£12.27	£11.25	£10.38	£9.64	£9.00	£8.44
Fully Cond Peff	RHI (£/MWht) required to replace differential 0.5 ROCs/MWhe CHP at QI=100									
20.00%	N/A	N/A	£2.62	£4.17	£5.43	£6.48	£7.37	£8.13	£8.80	£9.38
21.00%	N/A	£1.78	£3.94	£5.66	£7.07	£8.24	£9.24	£10.09	£10.83	£11.47
22.00%	N/A	£3.16	£5.60	£7.55	£9.14	£10.47	£11.60	£12.56	£13.40	£14.13
23.00%	N/A	£4.95	£7.76	£10.01	£11.84	£13.38	£14.67	£15.78	£16.75	£17.59
24.00%	£3.13	£7.39	£10.70	£13.35	£15.51	£17.32	£18.85	£20.16	£21.29	£22.29
25.00%	£5.70	£10.89	£14.92	£18.15	£20.78	£22.98	£24.84	£26.44	£27.82	£29.03
26.00%	£9.71	£16.34	£21.49	£25.62	£28.99	£31.81	£34.19	£36.23	£38.00	£39.54
27.00%	£16.81	£26.00	£33.15	£38.87	£43.55	£47.45	£50.75	£53.58	£56.04	£58.18
28.00%	£32.86	£47.85	£59.51	£68.84	£76.48	£82.84	£88.22	£92.83	£96.83	£100.33

The projection of renewable CHP uptake was estimated at RHI values of £40/MWh and £20/MWh in phase 1 analysis and £25/MWh in phase 2. The table above indicates that under the proposed revision of RO policy, all these RHI levels are sufficient to encourage CHP schemes to recover heat but may not replace the reduction in RO benefit that high efficiency CHP schemes built under the current RO policy would experience.

Description of bottom-up modelling approach

Overview of the CHP modelling procedure

The bottom-up model(s) developed by AEA to date include 'mappings' of the potential sites for CHP use, by different energy demand size tranches and industrial/service sub-sectors. The AEA bottom-up 'CHP potential' model is used to screen the sites to identify where CHP is likely to be cost- effective and what technical configuration is most appropriate. The 'investment model' (the Monte Carlo simulation model) is then used to analyse the specific sites and situations identified, to assess the likelihood of investment.

We have used a similar approach in considering the potential for all renewable CHP, though in this case we used specific information on costs for the renewable CHP technologies. By comparing the percentage likelihood of investment (with time) for renewable CHP technologies against standard fossil-fuel CHP types we are then be able to make assessments of the likely ratio of uptake of renewable CHP versus standard fossil fuel CHP. Both types of CHP will often be competing for the same site applications, and the probability of investment in the two different types is used to assess likely future penetrations.

Specifically, the approach we have adopted is a parallel analysis of renewable technologies and standard CHP technologies using the same previous modelling framework. This begins by a using the AEA bottom-up model to 'screen' the potential sites using both renewable technology data (new) and the existing standard CHP information separately. We then use the investment model to assess the likelihood of investment in the identified sites/sectors. In some cases standard CHP is more cost-effective and in other less prevalent cases renewable CHP is more cost-effective. Our investment model is set up to look at both technology types relevant to the identified sites to assess the technology splits likely in future take-up.

In our approach, we have considered the following issues:

1. The take-up of the two types of technology are proportional i.e. if there is a 20 per cent likelihood of standard CHP and only a 5 per cent likelihood of take-up of renewable CHP, this will mean that overall, the CHP potential uptake would be split in the ratio of 20 to 5 in the proportional number of sites involved.
2. It is possible (and might even be likely) that the 'propensity to invest' function could differ between the two types of technology. However, the outcome of our consultation with the industry over attitudes towards renewable CHP versus conventional has indicated that we should use the same criteria for both technologies.
3. We have used the same end-use size tranche splits and sub-sector splits for both technology applications, although we ignore renewable CHP for certain site sizes/areas because of technical/commercial restrictions.
4. We have different 'current policy' influences on the different technologies because of the differing effects on fuel prices, investment and operating costs etc.

Specific modelling tasks

The following defines in detail the tasks undertaken in this set of analyses:

Task 1. Identify and obtain the technology cost and operating information required for renewable CHP technologies at the tranche sizes and sector breakdown within the existing site and sub-sector end-use mappings. Currently conventional CHP is split according to technology types (gas engines, OCGT, CCGT - all gas) and application size (typically below 4 MWe, 4-12 MWe and > 12 MWe). Operating efficiencies and costs, and total investment costs have been recently re-evaluated through consultation with the industry. A similar exercise has been required for renewable CHP technologies.

This work has been described in the previous section and established the technical suitability and operation of biomass CHP technologies for each of the market segments in the model.

Task 2. Insert the renewable CHP technology data into the AEA 'CHP bottom-up model' to screen for sites where renewable technologies are elected be cost-effective under the scenario/policy conditions being investigated. This identified the cost-effective potential for both conventional and renewable CHP and the identification of sites/sectors for the 'investment model' analysis.

Key considerations included:

- The heat to power ratio that optimises carbon reduction and minimised costs (see the previous section);
- Capex and Opex derived;
- Efficiencies and other CHP indices calculated.

The existing bottom-up model was then modified:

- With performance figures and cost data for each new CHP example type;
- To cope with the proposed range of incentives.

Task 3. Re-build the Monte Carlo investment model using the new renewable CHP technology information and costs, to run in parallel with the existing standard fossil fuel CHP investment model.

Task 4. Run the investment model for the required policy/ input scenarios and build up a composite summary spreadsheet to include the probabilities of investments for both renewable CHP and conventional CHP. This task provided forecasts of renewable and conventional CHP up to 2021.

The input uncertainties leading to an output NPV distribution has generally given different spreads compared with the current CHP analysis. This therefore gave rise to different probabilities of 'going ahead'. We consulted with the industry on the new propensity to invest (curves) for the renewable CHP cost distributions.

From this, we are able to develop an analysis of the competition of conventional CHP v renewable CHP, and hence, a view on the likely development/projection of each; at the particular level of incentive provided to each. They compete for the same end-use areas that we have already defined in the bottom-up modelling so far.

How the practicality of renewable CHP is modelled

For conventional CHP, our future take up assessment is based only on the propensity to invest analysis. However, the probability of sites being amenable to renewable CHP is less straightforward, because other considerations need to be made about the practicality of installing and operating a renewable CHP scheme (location, size etc).

We have approached this by considering each potential application (mapped in the bottom-up modelling procedure) and have categorised the practicality by 5 levels of probability: zero, 25%, 50%, 75% and 100%.

In the latest runs presented here, all EU ETS sites are all given a zero restriction and the non-EU ETS sites are given zero restriction for the largest tranche only (and zero probability for the rest) provided that the CHP capacity is >0.2 MWe. We have done this to give an initial level 'playing field' comparison with conventional CHP.

Applying a more 'restrictive' approach, significantly reduced the take-up projection for renewable CHP.

Example of site mappings in the chemical and engineering sectors and the probability ascribed to particular sites being practically amenable for renewable CHP

	Size Tranche 1	Size Tranche 2	Size Tranche 3	Size Tranche 4	Size Tranche 5	Size Tranche 6
CHEMICLS rubber poly	**0.00**	**0.00**	**0.75**	**0.75**	**0.75**	**0.75**
CHP Type	Talbott's BG100	Talbott's BG100	Biomass ST	Biomass ST	Biomass ST	Biomass ST large
Avg Site CHP electric capacity (MW)	0.00	0.00	2.03	13.01	14.94	67.51
Avg Site CHP heat capacity (MW)	0.00	0.00	2.72	7.96	9.13	29.41
Demand H:P	#DIV/0!	#DIV/0!	1.34	0.61	0.61	0.44
CHEMICLS miscell	**0.00**	**0.00**	**0.50**	**0.75**	**0.75**	**0.75**
CHP Type	Talbott's BG100	Talbott's BG100	Biomass ST	Biomass ST	Biomass ST large	Biomass ST large
Avg Site CHP electric capacity (MW)	0.00	0.00	1.26	12.07	26.82	151.40
Avg Site CHP heat capacity (MW)	0.00	0.00	1.69	7.38	11.68	65.95
Demand H:P	#DIV/0!	#DIV/0!	1.34	0.61	0.44	0.44
CHEMICLS resins	**0.00**	**0.00**	**0.75**	**0.75**	**0.75**	**0.75**
CHP Type	Talbott's BG100	Talbott's BG100	Talbott's BG100	Talbott's BG100	Biomass ST	Biomass ST large
Avg Site CHP electric capacity (MW)	0.00	0.00	0.00	0.00	3.01	6.75
Avg Site CHP heat capacity (MW)	0.00	0.00	0.00	0.00	1.84	2.94
Demand H:P	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.61	0.44
CHEMICLS soap	**0.00**	**0.00**	**0.75**	**0.75**	**0.75**	**0.75**
CHP Type	Talbott's BG100	Talbott's BG100	Biomass ST	Biomass ST	Biomass ST	Biomass ST
Avg Site CHP electric capacity (MW)	0.00	0.00	0.00	7.01	10.38	16.53
Avg Site CHP heat capacity (MW)	0.00	0.00	0.00	4.28	6.34	10.11
Demand H:P	#DIV/0!	#DIV/0!	#DIV/0!	0.61	0.61	0.61
CHEMICLS pharms	**0.00**	**0.00**	**0.50**	**0.75**	**0.75**	**0.75**
CHP Type	Talbott's BG100	Talbott's BG100	Biomass ST	Biomass ST	Biomass ST	Biomass ST large
Avg Site CHP electric capacity (MW)	0.00	0.00	1.93	3.51	6.11	11.21
Avg Site CHP heat capacity (MW)	0.00	0.00	1.18	2.15	3.74	4.88
Demand H:P	#DIV/0!	#DIV/0!	0.61	0.61	0.61	0.44
CHEMICLS organics	**0.00**	**0.00**	**0.75**	**1.00**	**1.00**	**1.00**
CHP Type	Talbott's BG100	Talbott's BG100	Biomass ST	Biomass ST larg	Biomass ST large	Biomass ST large
Avg Site CHP electric capacity (MW)	0.00	0.00	2.40	32.61	212.02	1136.06
Avg Site CHP heat capacity (MW)	0.00	0.00	3.21	14.21	92.36	494.89
Demand H:P	#DIV/0!	#DIV/0!	1.34	0.44	0.44	0.44
CHEMICLS syn fibres	**0.00**	**0.00**	**1.00**	**1.00**	**1.00**	**1.00**
CHP Type	Talbott's BG100	Talbott's BG100	Talbott's BG100	Biomass ST	Biomass ST large	Biomass ST large
Avg Site CHP electric capacity (MW)	0.00	0.00	0.00	12.87	64.33	151.09
Avg Site CHP heat capacity (MW)	0.00	0.00	0.00	7.87	28.02	65.82
Demand H:P	#DIV/0!	#DIV/0!	#DIV/0!	0.61	0.44	0.44
CHEMICLS dyes and pigs	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
CHP Type	Talbott's BG100	Talbott's BG100	Talbott's BG100	Talbott's BG100	Talbott's BG100	Biomass ST large
Avg Site CHP electric capacity (MW)	0.00	0.00	0.00	0.00	0.00	3.46
Avg Site CHP heat capacity (MW)	0.00	0.00	0.00	0.00	0.00	1.51
Demand H:P	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.44
CHEMICLS inorganics	**0.00**	**0.00**	**1.00**	**1.00**	**1.00**	**1.00**
CHP Type	Talbott's BG100	Talbott's BG100	Biomass ST	Biomass ST larg	Biomass ST large	Biomass ST large
Avg Site CHP electric capacity (MW)	0.00	0.00	0.00	32.44	83.45	268.76
Avg Site CHP heat capacity (MW)	0.00	0.00	0.00	14.13	36.35	117.08
Demand H:P	#DIV/0!	#DIV/0!	#DIV/0!	0.44	0.44	0.44
ENGINEER mechanical	**0.00**	**0.00**	**0.50**	**0.50**	**0.50**	**0.50**
CHP Type	Talbott's BG100	Talbott's BG100	Biomass ST	Biomass ST	Biomass ST	Biomass ST large
Avg Site CHP electric capacity (MW)	0.00	0.00	4.91	8.12	10.38	22.29
Avg Site CHP heat capacity (MW)	0.00	0.00	6.58	4.96	6.35	9.71
Demand H:P	#DIV/0!	#DIV/0!	1.34	0.61	0.61	0.44
ENGINEER electric	**0.00**	**0.00**	**0.50**	**0.50**	**0.50**	**0.50**
CHP Type	Talbott's BG100	Talbott's BG100	Talbott's BG100	Talbott's BG100	Biomass ST	Biomass ST
Avg Site CHP electric capacity (MW)	0.00	0.00	0.00	3.72	5.43	11.07
Avg Site CHP heat capacity (MW)	0.00	0.00	0.00	8.27	7.28	6.77
Demand H:P	#DIV/0!	#DIV/0!	#DIV/0!	2.22	1.34	0.61
ENGINEER vehicles	**0.00**	**0.00**	**0.50**	**0.50**	**0.50**	**0.50**
CHP Type	Talbott's BG100	Talbott's BG100	Biomass ST	Biomass ST	Biomass ST	Biomass ST large
Avg Site CHP electric capacity (MW)	0.00	0.00	3.23	6.07	8.35	21.16
Avg Site CHP heat capacity (MW)	0.00	0.00	4.33	3.71	5.11	9.22
Demand H:P	#DIV/0!	#DIV/0!	1.34	0.61	0.61	0.44

The above table shows how we have applied the restrictions to renewable CHP in the larger (EU ETS listed) sites. The different tranches represent different site energy demand ranges, as shown by the average site electricity and heat capacities meeting the site demands. The appropriate CHP technology is also shown. The fraction figures shown in the subsector named row i.e. the 0.75 for tranche 6 in the chemicals rubber polymer subsector (first row) indicates that we have restricted the probability of introducing renewable CHP in such sites to at maximum 75%. In practice, this figure is not likely to be reached, because competition with conventional CHP, which in he majority of cases is more financially attracting, and therefore more likely to be the option actually taken up. The 0.75 limiting figure is therefore an absolute upper bound rather than the actual uptake figure.

Description of scenarios Modelled

Phase 1

Scenario 1R – With the current Renewable Obligation (RO) Policy in place, Steam Turbine CHP is assumed to be sized based on either the site heat or power demand and operated to achieve a QI of 100 (both heat and power led sizing are tried and the most cost-effective selected). A practical biomass CHP growth restriction is applied.

Scenario 2R – It is assumed that the Renewable Heat Incentive (RHI) will award £40/MWh of renewable heat but the current preferential treatment by the RO of CHP over power only generation will be removed. Steam turbine CHP is assumed to be designed to match the heat and power demands of the site which is just physically possible in the case of refineries that have a large heat to power demand ratio. A practical biomass CHP growth restriction is applied.

Scenario 3R – It is assumed that the Renewable Heat Incentive (RHI) will award £20/MWh of renewable heat but the current preferential treatment by the RO of CHP over power only generation will be removed. Steam turbine CHP is assumed to be designed to match the heat and power demands of the site which is just physically possible in the case of refineries that have a large heat to power demand ratio. A practical biomass CHP growth restriction is applied.

Scenario 1U – As scenario 1R But with the practical biomass CHP growth restriction removed.

Scenario 2U – As scenario 2R But with the practical biomass CHP growth restriction removed.

Phase 2

Scenarios 1R and 1U. Same as Phase 1 Scenarios 1R and 2R but with updated central fuel and carbon price projections

Scenarios 2R and 2U Same as Phase 1 but with an RHI of £25/MWh, updated central fuel and carbon price projections and sensitivities round these. Each of the above two scenarios are used with the five sets of price scenarios described previously (high, central and low biomass prices and high-high, central and low fossil fuel and electricity prices) to provide projections of both renewable and convention CHP separately.

Phase 1 Results Summary

Overview

This section describes the results form Phases 1 and 2 of the modelling. Phase 2 results have been incorporated in the RHI consultation analysis and the accompanying analytical report[6].

The main conclusions from the **first phase** are

- With a restriction on biomass CHP industry growth assumed, were the current RO policy to continue as it is without introducing RHI (Scenario 1R), the projected renewable Good Quality CHP electrical capacity by 2020 is 1.65 GWe and this would be operated to generate in the order of 6.9 TWh/Yr of renewable heat

- Assuming an RHI policy were introduced awarding £40/MWh of renewable heat but at the same time the RO were revised to award all renewable power generating plant 1.5 ROCs/MWhe regardless of whether they were CHP or not (Scenario 2R), a large increase in the projected renewable heat generation from CHP (to 15.3 TWh/Yr) is anticipated with the same volume of electrical capacity (to 1.67GWe) as a result of schemes generally being sized based on site heat demands (heat led approach)

- Without the practical growth restrictions mentioned above and under the current RO policy (Scenario 1U) the projected renewable Good Quality CHP electrical capacity by 2020 increases to 2.7 GWe generating in the order 23.1 TWh heat/Yr. Under the proposed RHI (Scenario 2U) the projected Good Quality renewable CHP capacity is 3.0GWe of generating 41.1 TWh/Yr of renewable heat. Thus in the unrestricted scenario a very modest increase in renewable electricity generation from CHP is expected together with a very substantial increase in renewable heat generation

- Renewable CHP growth will compete with conventional CHP growth for sites, resulting in an overall reduction in CHP electrical capacity growth as compared to a CHP growth scenario without renewable CHP. This is because, for a given site, its most cost-effective electrical capacity and operating electrical output is typically lower than that of conventional CHP. Furthermore, the proposed RHI will tend to encourage a renewable steam turbine CHP to be designed to operate near maximum heat capability whereas the current RO policy tends to encourage renewable CHP to be designed to operate to maximise the entitlement to ROCs which occurs below the maximum heat capacity. Therefore for a given site heat load, the proposed RHI will tend to encourage a renewable steam turbine CHP with a lower power capacity than the current RO policy does

- The projected total (renewable + conventional) Good Quality CHP electrical capacity by 2020 with biomass growth restrictions are 17.3GWe under the current RO policy, 17.0GWe with an RHI of £40/MWh and 17.2GWe with an RHI of £20/MWh, the last being higher than the second due to suppressed competition from renewable CHP for sites. This compares with a projection of 17.8GWe in a scenario where no renewable CHP is built

- Overall the replacing of the current RO policy with the proposed RHI policy is expected to result in a reduced projection of CHP electrical capacity and output, it is anticipated that a marginal long term increase in overall CO2 saving from CHP would occur by 2020. However before 2020 the CO2 saving may in fact be lower at times as indicated for 2017 because the carbon saving from displacing electricity is higher than that from displacing heat. Furthermore, the results of phase 2 (as described below) indicate the long term carbon saving under an RHI may in fact be lower than with the current RO policy unless more renewable electricity from power only plant is produced elsewhere. The degree to which this happens is outside the scope of this report

[6] NERA 2009: The UK supply curve for renewable heat and NERA 2010: NERA 2010: Design of the Renewable Heat Incentive

- Under an RHI of only £20/MWh rather than £40/MWh the CO2 saving would be even more marginal. However it is clear that the projected CO2 saving from conventional CHP alone would be significantly lower so policy support for renewable CHP in whichever form is environmentally beneficial.

Table 1A: Projection results summary –Renewable CHP Heat Output

	*Actual 2008	2013	2017	2020
CHP Renewable Heat output (TWh)				
Renewable CHP Under **Scenario 1R** (Current RO Policy, ST heat extraction for QI = 100, practical biomass CHP growth restriction)	0.626	1.923	4.785	6.920
Renewable CHP Under **Scenario 2R** (Proposed RHI £40/MWh, ST designed to match site heat and power loads, practical biomass CHP growth restriction)	0.626	3.912	8.114	15.275
Renewable CHP Under **Scenario 3R** (Proposed RHI £20/MWh, ST designed to match site heat and power loads, practical biomass CHP growth restriction)	0.626	3.029	6.361	11.896
Renewable CHP Under **Scenario 1U** (As Scenario 1R but practical biomass CHP growth restriction removed)	0.626	5.700	15.677	23.148
Renewable CHP Under **Scenario 2U** (As Scenario 2R but practical biomass CHP growth restriction removed)	0.626	7.162	14.750	41.085

Graph A1 - Growth scenarios of Renewable CHP heat

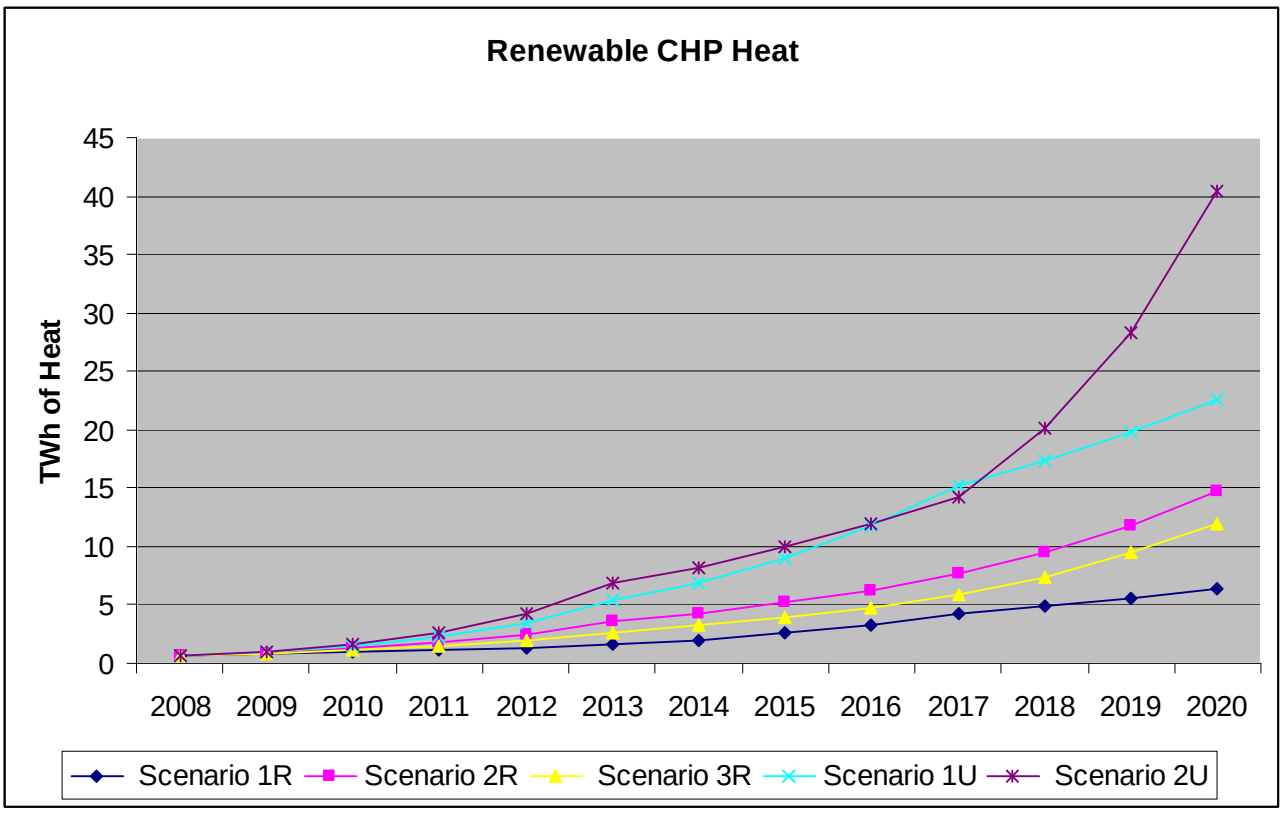


Table 1B: Projection results summary –CHP Elec Capacity

	*Actual 2008	2013	2017	2020
Elec Capacity in CHP Mode (MWe)				
Renewable CHP Under Scenario 1R	49	451	1,138	1,653
Conventional CHP Under Scenario 1R	5,420	9,245	12,017	15,622
Total CHP (Renewable + conventional under scenario 1R)	5,469	9,696	13,155	17,275
Renewable CHP Under Scenario 2R	49	420	878	1,670
Conventional CHP Under Scenario 2R	5,420	9,155	11,844	15,378
Total CHP (Renewable + conventional under scenario 2R)	5,469	9,574	12,722	17,049
Renewable CHP Under Scenario 3R	49	333	694	1,310
Conventional CHP Under Scenario 3R	5,420	9,446	12,268	15,897
Total CHP (Renewable + conventional under scenario 3R)	5,469	9,779	12,962	17,207
Renewable CHP Under Scenario 1U	49	670	1,811	2,665
Conventional CHP Under Scenario 1U	5,420	9,004	11,290	13,869
Total CHP (Renewable + conventional under scenario 1U)	5,469	9,674	13,101	16,534
Renewable CHP Under Scenario 2U	49	541	1,148	2,993
Conventional CHP Under Scenario 2U	5,420	8,880	11,170	14,002
Total CHP (Renewable + conventional under scenario 2U)	5,469	9,422	12,318	16,996
Compare previous study Conventional CHP Only (Central energy price)	5,474	10,470	13,789	17,754

Note: The average annual growth in renewable CHP capacity (MWe) in the early years 2008 to 2013 is 56% under current RO policy, 54% for the restricted £40/MWh RHI case and 47% with an RHI of £20/MWh. Between 2007 and 2020 the average annual growth is 13% with current RHO, 24% for restricted RHI at both £40/MWh and £20/MWh, being higher under the RHI due to the slower growth in earlier years.

Table 1C: Projection results summary –CHP Annual Elec Output

CHP Elec Output (TWh/Yr)	*Actual 2008	2013	2017	2020
Renewable CHP Under Scenario 1R	0.397	3.647	9.214	13.378
Conventional CHP Under Scenario 1R	43.869	74.831	97.266	126.446
Total CHP (Renewable + conventional under scenario 1R)	44.265	78.479	106.480	139.824
Renewable CHP Under Scenario 2R	0.397	3.396	7.105	13.520
Conventional CHP Under Scenario 2R	43.869	74.098	95.864	124.471
Total CHP (Renewable + conventional under scenario 2R)	44.265	77.494	102.969	137.991
Renewable CHP Under Scenario 3R	0.397	2.697	5.614	10.606
Conventional CHP Under Scenario 3R	43.869	76.454	99.300	128.668
Total CHP (Renewable + conventional under scenario 3R)	44.265	79.151	104.914	139.273
Renewable CHP Under Scenario 1U	0.397	5.422	14.655	21.570
Conventional CHP Under Scenario 1U	43.869	72.878	91.384	112.257
Total CHP (Renewable + conventional under scenario 1U)	44.265	78.300	106.039	133.827
Renewable CHP Under Scenario 2U	0.397	4.379	9.290	24.228
Conventional CHP Under Scenario 2U	43.869	71.879	90.410	113.336
Total CHP (Renewable + conventional under scenario 2U)	44.265	76.258	99.699	137.564
Compare previous study Conventional CHP Only (Central energy price)	43.868	84.743	111.604	143.702

The effect on CO2 savings

For these calculations, we have used the following emissions factors.

CO2 factors (tCO2/MWh)	
CHP fuel (gas)	0.190
Elect	0.430

Projected Total Carbon Savings (from Electricity and Heat) MtCO2/Yr

Carbon Savings from Renewable and Conventional CHP MtCO2/Yr	2013	2017	2020
Renewable CHP Under Scenario 1R	2.056	5.174	7.506
Conventional CHP Under Scenario 1R	13.993	16.981	20.264
Total CHP (Renewable + conventional under scenario 1R)	16.048	22.155	27.769
Renewable CHP Under Scenario 2R	2.451	5.111	9.683
Conventional CHP Under Scenario 2R	13.757	16.536	19.632
Total CHP (Renewable + conventional under scenario 2R)	16.208	21.646	29.315
Renewable CHP Under Scenario 3R	1.927	4.026	7.574
Conventional CHP Under Scenario 3R	14.282	17.204	20.405
Total CHP (Renewable + conventional under scenario 3R)	16.209	21.229	27.979
Conventional CHP Only Projection	15.737	19.260	22.679

Under the proposed RHI and RO policy revision, the balance of changes in overall carbon saving resulting from increased renewable heat, decreased heat and power from conventional CHP and either a modest increase or decrease in renewable electricity from CHP, is complex. It is concluded that the projected total carbon savings from renewable and conventional CHP are likely to be higher in the long term under the RHI than under the current RO policy but may be lower at times, for example in 2017.

In phase 2 as reported later, the long term carbon saving may be slightly lower overall for CHP (conventional + renewable) under an RHI than the existing RO.

However even under an RHI policy the total volume of renewable energy (heat and power) increases whilst offering a clear increase in carbon saving compared to a scenario of no renewable CHP. In addition, the reduction in renewable electricity from CHP may coincide with an increase in generation by renewable power only plant but this is outside the scope of this report.

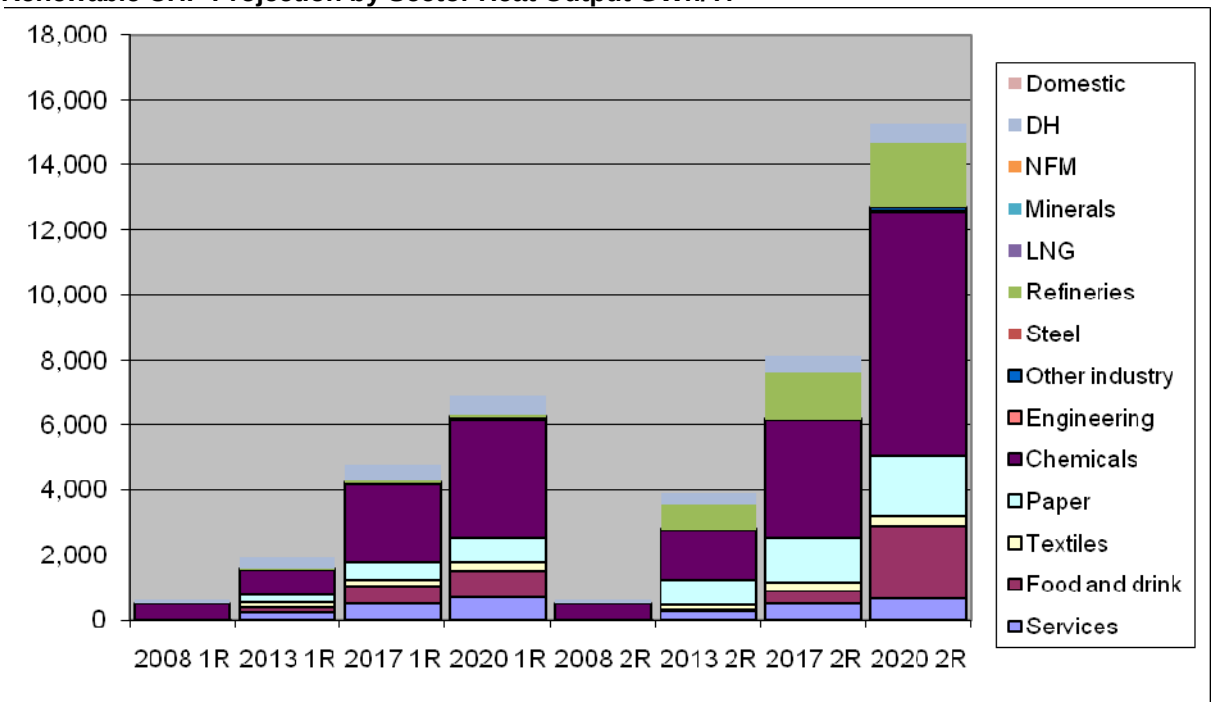
Detailed sector and technology results

Graphical Phase 1 Sector Results Summary

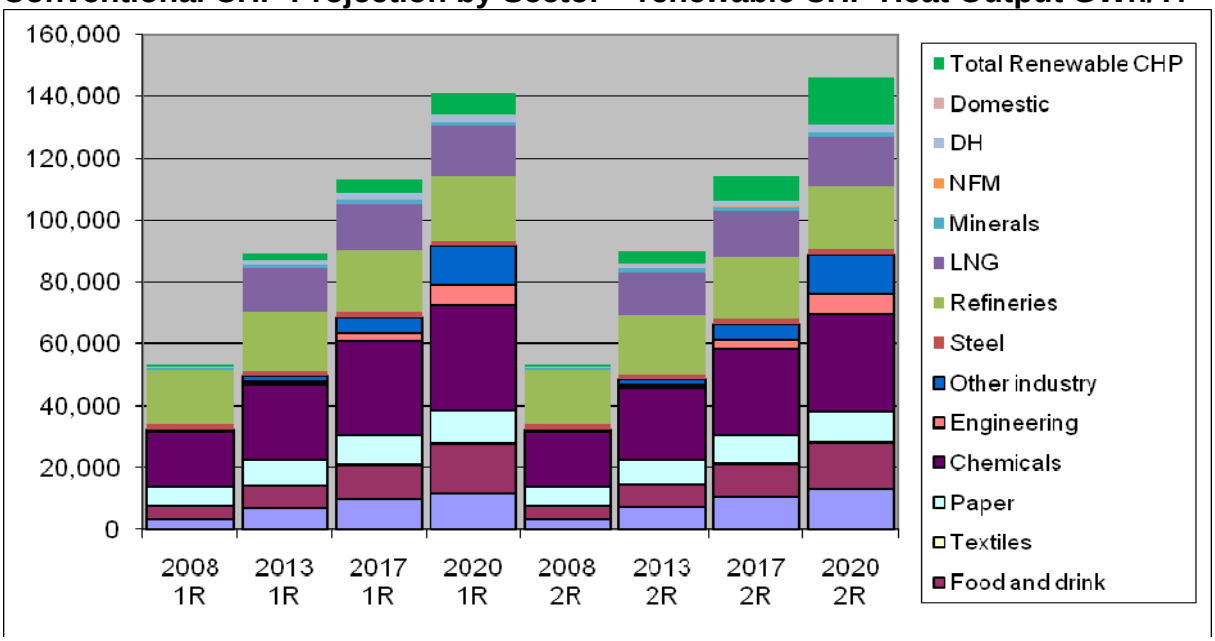
Scenario 1R = With existing RO policy, CHP designed and operated to maximise ROCs

Scenario 2R = With Proposed RHI = £40/MWh, CHP designed to follow site heat and power loads where possible with steam turbine technology

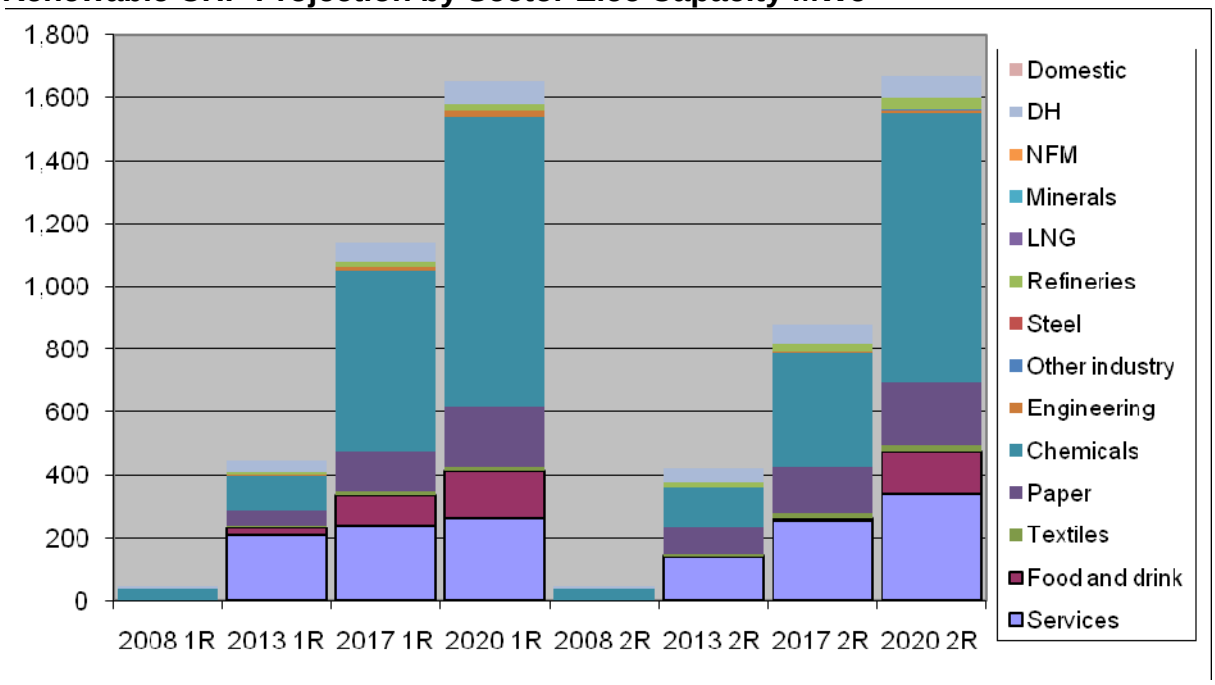
Renewable CHP Projection by Sector Heat Output GWh/Yr



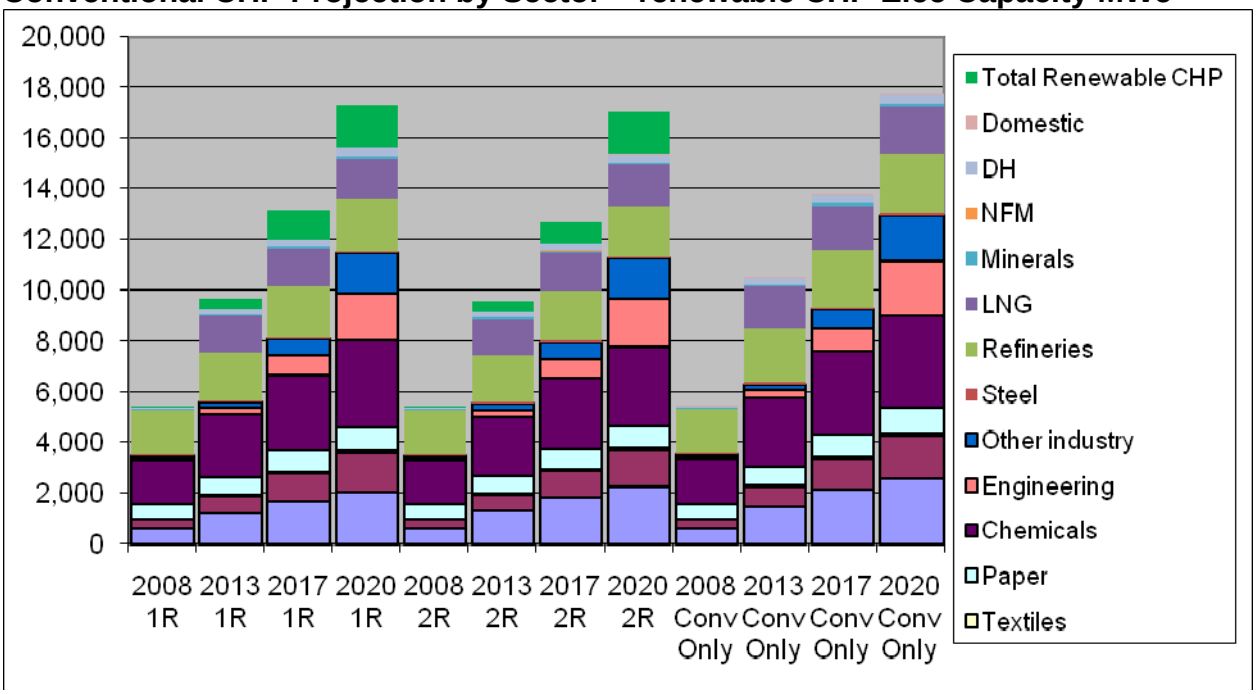
Conventional CHP Projection by Sector + renewable CHP Heat Output GWh/Yr



Renewable CHP Projection by Sector Elec Capacity MWe



Conventional CHP Projection by Sector + renewable CHP Elec Capacity MWe



The following sets of tables and figures summarise the individual sector projections for both renewable and conventional CHP. Results cover both electrical capacity projections and heat output projections.

Results for the sectors in the lower section of the tables are not modelled (with the exception of refineries); these sector projections have been made qualitatively.

The CHP uptake projection model considers the competitive interactions between renewable CHP and conventional CHP, so that the effect of changes in the specification of the renewable CHP technology will change the conventional CHP uptake. The following tables and figures show the effects of the renewable CHP scenarios on conventional CHP projections.

Renewable CHP results by Sector

Scenario 1R - (CHP Heat Output GWh/Yr) with practical biomass CHP growth restriction with Current RO Policy and CHP designed and operated to achieve QI=100

Biomass CHP projection

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	-	257.9	518.2	713.5
Food and drink	4	148.9	506.8	775.3
Textiles	-	146.5	215.4	267.15
Paper	27	212.4	523.3	756.475
Chemicals	491	762.2	2403.9	3635.25
Engineering	-	10.8	49.1	77.825
Other industry	-	1.4	5.9	9.275
Sub-total	522.0	1,540.1	4,222.6	6,234.8
Steel	-	-	-	-
Refineries	-	26.6	58.3	82
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**1,923.3**	**4,784.8**	**6,919.5**

Conventional CHP projection and Total

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3,571.80	7,142.00	9,998.10	12,140.30
Food and drink	4,076.80	7,053.80	10,937.40	15,453.70
Textiles	6.2	190.6	338.1	448.8
Paper	6,421.20	8,174.90	9,577.90	10,630.10
Chemicals	17,775.70	24,518.90	29,913.40	33,959.30
Engineering	243	922.2	2,679.90	6,510.80
Other industry	459.8	1,768.80	5,197.40	12,753.30
Sub-total	32,554.5	49,771.2	68,642.2	91,896.3
Steel	1,640.50	1,739.90	1,739.90	1,739.90
Refineries	17,713.20	18,972.20	19,979.30	20,734.70
LNG	-	14,065.40	15,070.10	16,200.40
Minerals	645.7	1,271.20	1,271.20	1,271.20
NFM	22.3	20.8	20.8	20.8
DH	404.4	1,386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	56.8
Total Conventional CHP	**53,005.1**	**87,266.6**	**108,733.8**	**134,263.9**
Total Renewable CHP	**626.0**	**1,923.3**	**4,784.8**	**6,919.5**
Total CHP	**53,631.1**	**89,189.9**	**113,518.6**	**141,183.4**

Scenario 2R - (CHP Heat Output GWh/Yr) with practical biomass CHP growth restriction with Proposed RHI Policy and CHP designed and operated to match site heat and power loads

Biomass CHP projection

GWh heat output	Actual 2008	2013	2017	2020
Services	-	282.2	508	677.275
Food and drink	4	49.8	374.3	2203.85
Textiles	-	144.1	259.3	345.775
Paper	27	775.6	1,374.50	1823.675
Chemicals	491	1488.6	3615.2	7488.8
Engineering	0	0.3	5.1	62.55
Other industry	0	0.4	7.8	115.875
Sub-total	522.0	2,741.0	6,144.2	12,717.8
Steel	-	-	-	-
Refineries	-	814.2	1,465.50	1,954.05
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**3,911.8**	**8,113.6**	**15,274.6**

Conventional CHP projection and Total

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3571.8	7578.1	10783.2	13,187.00
Food and drink	4076.8	6921.9	10,571.80	14,752.80
Textiles	6.2	189.6	336.3	446.3
Paper	6421.2	7946.9	9167.5	10083
Chemicals	17775.7	23327.8	27769.4	31,100.70
Engineering	243	925.2	2695.6	6,564.30
Other industry	459.8	1767.8	5,192.20	12,735.30
Sub-total	32,554.5	48,657.3	66,516.0	88,869.4
Steel	1640.5	1739.9	1739.9	1739.9
Refineries	17713.2	18841.8	19744.7	20421.9
LNG	-	14065.4	15070.1	16200.4
Minerals	645.7	1271.2	1271.2	1271.2
NFM	22.3	20.8	20.8	20.8
DH	404.4	1386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	56.8
Total Conventional CHP	**53,005.1**	**86,022.3**	**106,373.0**	**130,924.2**
Total Renewable CHP	**626.0**	**3,911.8**	**8,113.6**	**15,274.6**
Total CHP	**53,631.1**	**89,934.1**	**114,486.6**	**146,198.8**

Scenario 1U (CHP Heat Output GWh/Yr) without practical biomass CHP growth restriction with Current RO Policy Assuming CHP would be designed and operated to achieve QI=100

Biomass CHP projection

GWh heat output	Actual 2008	2013	2017	2020
Services	-	917	2,497.70	3,683.20
Food and drink	4	1,251.10	3,781.80	5,679.80
Textiles	-	345.8	583.9	762.4
Paper	27	212.4	523.3	756.5
Chemicals	491	769.6	2,494.60	3,788.40
Engineering	-	731.8	2,324.00	3,518.20
Other industry	-	1,079.70	2,878.50	4,227.60
Sub-total	522.0	5,307.4	15,083.8	22,416.1
Steel	-	-	-	-
Refineries	-	35.5	89.1	129.2
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**5,699.5**	**15,676.8**	**23,148.0**

Conventional CHP projection and Total

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3,571.80	6,781.10	9,348.50	11,274.10
Food and drink	4,076.80	6,368.20	9,098.80	12,024.70
Textiles	6.2	111.6	196	259.2
Paper	6,421.20	8,174.90	9,577.90	10,630.10
Chemicals	17,775.70	24,426.40	29,746.90	33,737.40
Engineering	243	816.7	2,153.60	4,797.70
Other industry	459.8	1,410.40	3,457.60	7,221.60
Sub-total	32,554.5	48,089.3	63,579.3	79,944.8
Steel	1,640.50	1,739.90	1,739.90	1,739.90
Refineries	17,713.20	18,836.30	19,734.80	20,408.70
LNG	-	14,065.40	15,070.10	16,200.40
Minerals	645.7	1,271.20	1,271.20	1,271.20
NFM	22.3	20.8	20.8	20.8
DH	404.4	1,386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	56.8
Total Conventional CHP	**53,005.1**	**85,448.8**	**103,426.4**	**121,986.4**
Total Renewable CHP	**626.0**	**5,699.5**	**15,676.8**	**23,148.0**
Total CHP	**53,631.1**	**91,148.3**	**119,103.2**	**145,134.4**

Case 2U - (CHP Heat Output GWh/Yr) without practical biomass CHP growth restriction with Proposed RHI Policy Assuming CHP designed and operated to match site heat and power loads

Biomass CHP projection

GWh heat output	Actual 2008	2013	2017	2020
Services	-	2,732.70	4,918.90	6,558.50
Food and drink	4	79.1	861.6	7,252.00
Textiles	-	414.5	746.1	994.8
Paper	27	775.6	1,374.50	1,823.70
Chemicals	491	1,533.70	3,814.70	8,069.90
Engineering	0	2.1	155.3	8,528.30
Other industry	0	1.6	95.3	4,215.30
Sub-total	522.0	5,539.3	11,966.4	37,442.5
Steel	-	-	-	-
Refineries	-	1,266.40	2,279.50	3,039.30
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**7,162.3**	**14,749.8**	**41,084.5**

Conventional CHP projection and Total

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3,571.8	6,803.7	9,389.2	11,328.3
Food and drink	4,076.8	6,321.6	8,979.1	11,810.1
Textiles	6.2	93.7	163.7	216.2
Paper	6,421.2	7,946.9	9,167.5	10,083.0
Chemicals	17,775.7	23,214.6	27,565.7	30,829.0
Engineering	243.0	828.2	2,208.5	4,969.1
Other industry	459.8	1,671.0	4,691.3	11,051.3
Sub-total	32,554.5	46,879.7	62,165.0	80,287.0
Steel	1,640.5	1,739.9	1,739.9	1,739.9
Refineries	17,713.2	18,700.7	19,490.6	20,083.1
LNG	-	14,065.4	15,070.1	16,200.4
Minerals	645.7	1,271.2	1,271.2	1,271.2
NFM	22.3	20.8	20.8	20.8
DH	404.4	1,386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	56.8
Total Conventional CHP	**53,005.1**	**84,103.6**	**101,767.9**	**122,003.0**
Total Renewable CHP	**626.0**	**7,162.3**	**14,749.8**	**41,084.5**
Total CHP	**53,631.1**	**91,265.9**	**116,517.7**	**163,087.5**

Case 1R - (CHP Mode Elec Capacity MWe) with practical biomass CHP growth restriction with Current RO, CHP designed and operated to achieve QI=100.

Biomass CHP projection

MW electrical capacity	Actual 2008	2013	2017	2020
Services	-	208.9	241.1	265.3
Food and drink	-	26.6	96	148.1
Textiles	-	8.1	12	14.9
Paper	3	44.5	128.1	190.9
Chemicals	34	109.9	571.7	918
Engineering	-	2.6	11.8	18.7
Other industry	-	0.3	1.5	2.3
Sub-total	37.0	400.9	1,062.2	1,558.2
Steel	-	-	-	-
Refineries	-	7.5	16.5	23.3
LNG	-	-	-	-
Minerals	-		-	-
NFM	-	-	-	-
DH	12.0	42.2	59.6	71.3
Total Renewable CHP	**49.0**	**450.6**	**1,138.3**	**1,652.8**

Conventional CHP Projection and Total

MW electrical capacity	Actual 2008	2013	2017	2020
Services	610.40	1,220.50	1,708.70	2,074.80
Food and drink	404.30	699.50	1,084.60	1,532.40
Textiles	1.1	34.3	60.8	80.7
Paper	553.50	704.70	825.60	916.40
Chemicals	1,788.50	2,467.00	3,009.70	3,416.80
Engineering	69.1	262.3	762.40	1,852.30
Other industry	57.3	220.60	648.10	1,590.30
Sub-total	3,484.2	5,608.9	8,099.9	11,463.7
Steel	66.60	70.70	70.70	70.70
Refineries	1,763.10	1,888.40	1,988.60	2,063.80
LNG	-	1,400.00	1,500.00	1,612.50
Minerals	35	69.00	69.00	69.00
NFM	11.3	10.5	10.5	10.5
DH	53.4	187.8	265.4	317.5
Domestic	6.3	10	13	14.5
Total Conventional CHP	**5,419.9**	**9,245.3**	**12,017.1**	**15,622.2**
Total Renewable CHP	**49.0**	**450.6**	**1,138.3**	**1,652.8**
Total CHP	**5,468.9**	**9,695.9**	**13,155.4**	**17,275.0**

Case 2R - with practical biomass CHP growth restriction with Proposed RHI Policy
Assuming CHP designed and operated to match site heat and power loads

Biomass CHP projection

MW electrical capacity	Actual 2008	2013	2017	2020
Services	-	142.9	257.2	342.9
Food and drink	0	0.4	8.7	134.8
Textiles	-	8.1	14.5	19.4
Paper	3	84.7	150.1	199.2
Chemicals	34	125.8	358.2	854.5
Engineering	0	0.1	1.1	6.6
Other industry	0	0.1	0.8	4.8
Sub-total	37.0	362.1	790.6	1,562.2
Steel	-	-	-	-
Refineries	-	15.3	27.6	36.8
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	12.0	42.2	59.6	71.3
Total Renewable CHP	**49.0**	**419.6**	**877.8**	**1,670.3**

Conventional CHP projection and Total

MW electrical capacity	Actual 2008	2013	2017	2020
Services	610.4	1,295.10	1,842.80	2,253.70
Food and drink	404.3	686.4	1,048.30	1,462.90
Textiles	1.1	34.1	60.4	80.2
Paper	553.5	685	790.2	869.2
Chemicals	1,788.50	2,347.10	2,794.00	3,129.20
Engineering	69.1	263.2	766.9	1,867.50
Other industry	57.3	220.4	647.4	1,588.10
Sub-total	3,484.2	5,531.3	7,950.0	11,250.8
Steel	66.6	70.7	70.7	70.7
Refineries	1,763.10	1,875.40	1,965.30	2,032.70
LNG	-	1,400.00	1,500.00	1,612.50
Minerals	35	69	69	69
NFM	11.3	10.5	10.5	10.5
DH	53.4	187.8	265.4	317.5
Domestic	6.3	10	13	14.5
Total Conventional CHP	**5,419.9**	**9,154.7**	**11,843.9**	**15,378.2**
Total Renewable CHP	**49.0**	**419.6**	**877.8**	**1,670.3**
Total CHP	**5,468.9**	**9,574.3**	**12,721.7**	**17,048.5**

Case 1U - without practical biomass CHP growth restriction with Current RO policy where it is assumed CHP would be designed and operated to achieve a QI of 100.

Biomass CHP Projection

MW electrical capacity	Actual 2008	2013	2017	2020
Services	-	249.4	373.8	467.1
Food and drink	-	87.9	278	420.7
Textiles	-	19.2	32.5	42.4
Paper	3	44.5	128.1	190.9
Chemicals	34	111.6	594.7	957
Engineering	-	44.7	156.8	240.9
Other industry	-	60.4	161.9	238
Sub-total	37.0	617.7	1,725.8	2,557.0
Steel	-	-	-	-
Refineries	-	10	25.2	36.6
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	12.0	42.2	59.6	71.3
Total Renewable CHP	**49.0**	**669.9**	**1,810.6**	**2,664.9**

Conventional CHP

MW electrical capacity	Actual 2008	2013	2017	2020
Services	610.4	1,158.90	1,597.60	1,926.70
Food and drink	404.3	631.5	902.3	1,192.40
Textiles	1.1	20.1	35.2	46.6
Paper	553.5	704.7	825.6	916.4
Chemicals	1,788.50	2,457.60	2,993.00	3,394.50
Engineering	69.1	232.3	612.7	1,364.90
Other industry	57.3	175.9	431.1	900.5
Sub-total	3,484.2	5,381.0	7,397.5	9,742.0
Steel	66.6	70.7	70.7	70.7
Refineries	1,763.10	1,874.90	1,964.30	2,032.50
LNG	-	1,400.00	1,500.00	1,612.50
Minerals	35	69	69	69
NFM	11.3	10.5	10.5	10.5
DH	53.4	187.8	265.4	317.5
Domestic	6.3	10	13	14.5
Total Conventional CHP	**5,419.9**	**9,003.9**	**11,290.4**	**13,869.2**
Total Renewable CHP	**49.0**	**669.9**	**1,810.6**	**2,664.9**
Total CHP	**5,468.9**	**9,673.8**	**13,101.0**	**16,534.1**

Scenario - 2U without practical biomass CHP growth restriction with Proposed RHI, CHP designed and operated to match site heat and power loads

Biomass CHP projection

MW electrical capacity	Actual 2008	2013	2017	2020
Services	-	236.2	425.2	567
Food and drink	0	0.7	18.9	411.2
Textiles	-	23.1	41.6	55.5
Paper	3	84.7	150.1	199.2
Chemicals	34	129.1	375.3	912.1
Engineering	0	0.7	21.3	486.3
Other industry	0	0.5	12.8	233.5
Sub-total	37.0	475.0	1,045.2	2,864.8
Steel	-	-	-	-
Refineries	-	23.8	42.9	57.2
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	12.0	42.2	59.6	71.3
Total Renewable CHP	**49.0**	**541.0**	**1,147.7**	**2,993.3**

Conventional

MW electrical capacity	Actual 2008	2013	2017	2020
Services	610.4	1,162.70	1,604.60	1,936.00
Food and drink	404.3	626.9	890.4	1,171.10
Textiles	1.1	16.8	29.4	38.9
Paper	553.5	685	790.2	869.2
Chemicals	1,788.50	2,335.70	2,773.50	3,101.90
Engineering	69.1	235.6	628.3	1,413.60
Other industry	57.3	208.4	585	1,378.10
Sub-total	3,484.2	5,271.1	7,301.4	9,908.8
Steel	66.6	70.7	70.7	70.7
Refineries	1,763.10	1,861.40	1,940.00	1,999.00
LNG	-	1,400.00	1,500.00	1,612.50
Minerals	35	69	69	69
NFM	11.3	10.5	10.5	10.5
DH	53.4	187.8	265.4	317.5
Domestic	6.3	10	13	14.5
Total Conventional CHP	**5,419.9**	**8,880.5**	**11,170.0**	**14,002.5**
Total Renewable CHP	**49.0**	**541.0**	**1,147.7**	**2,993.3**
Total CHP	**5,468.9**	**9,421.5**	**12,317.7**	**16,995.8**

Conventional gas CHP projection with no renewable option

The results under the various scenarios considered can be compared directly with the results (total renewable plus fossil fuel CHP). As pointed out earlier, the effect of introducing renewable CHP as an option is to reduce the overall projected total CHP capacity as a result of the difference in the capacities chosen for the two competing technologies at the same sites.

Projection of total fossil fuel CHP (with no renewable options) by sector (MW electrical capacity)

MW electrical capacity	Actual 2008	2013	2017	2020
Services	610.4	1,479.0	2,142.8	2,598.5
Food and drink	404.3	783.8	1,219.0	1,686.8
Textiles	1.1	38.9	70.2	92.5
Paper	553.5	782.2	918.8	1,002.2
Chemicals	1,788.5	2,680.3	3,248.9	3,608.0
Engineering	69.1	300.6	891.8	2,153.2
Other industry	57.3	251.7	752.8	1,831.1
Sub-total	3,484.2	6,316.6	9,244.3	12,972.3
Steel	66.6	80.7	82.2	81.5
Refineries	1,763.1	2,141.6	2,285.3	2,343.8
LNG	0.0	1,598.8	1,744.2	1,859.3
Minerals	35.0	78.8	80.2	79.6
NFM	11.3	12.0	12.2	12.1
DH	53.4	230.0	325.0	388.8
Domestic	**6.3**	**11.4**	**15.1**	**16.7**
Total Conventional CHP	**5,419.9**	**10,469.9**	**13,788.5**	**17,754.1**

Scenario 3 RHI £20/MWh

Scenario 3R Biomass CHP projection with practical biomass CHP growth restriction with Proposed RHI reduced to £20/MWh heat, CHP designed and operated to match site heat and power loads

CHP Heat Output Capacity GWh/Yr	Actual 2008	2013	2017	2020
Biomass CHP Projection under Scenario 3R (Heat to power matches site demands, restricted growth)	626	3,029	6,361	11,896
Conventional CHP Projection under Scenario 3R	53,005	89,103	110,483	135,776
Total CHP Projection under Scenario 3R	53,631	92,132	116,844	147,672

Power Capacity in CHP mode MWe	Actual 2008	2013	2017	2020
Biomass CHP Projection under Scenario 3R (Heat to power matches site demands, restricted growth)	49	417	814	1,452
Conventional CHP Projection under Scenario 3R	5,420	9,362	12,148	15,755
Total CHP Projection under Scenario 3R	5,469	9,779	12,962	17,207

Under this scenario renewable power and heat generation is projected to be lower. It is projected that some of the sites, which would take up renewable CHP at an RHI of £40/MWh, would not do so at an RHI of £20/MWh. This is the principal cause of reduced power and heat generation as is still assumed those that would still take up CHP would still size the CHP according to site heat and power load and therefore the sizing and operation strategy change would be small.

It is projected that some sites that would select renewable CHP under an RHI of £40/MWh would select conventional CHP under an RHI of £20/MWh.

Phase 2 results summary

Overview

The main conclusions from the **second phase** are

- The projection is that renewable heat generated by CHP will be between 2 and 35 TWh/Yr depending on the growth and energy price sensitivity scenariobetween 2 and 16 TWh/Yr in the restricted scenario and between 3 and 35 TWh/Yr in the unrestricted scenario

- Based on the central energy and carbon price scenarios, the revised renewable CHP heat generation projections are 7.4 TWh/Yr by 2020 for the 'restricted' scenario, and 15.8 TWh/Yr in the 'unrestricted' case. This compares with the phase 1 projections at an RHI of £40/MWh of 15.3 TWh/Yr at the restricted growth case and 41 TWh/Yr at the unrestricted growth case, and 11.9TWh/Yr at an RHI of £20/MWh with the practical growth restriction. The revised projections for renewable CHP are thus lower under the revised central scenario set of energy and carbon prices and assumed RHI value of £25/MWh. This is essentially due to much higher revised biomass price projections

- An RHI of £25/MWh is projected to encourage the growth of renewable heat from CHP but at the expense of total CHP electrical output and also of renewable electricity in the short term (prior to 2020). As a result, based on the central fuel price scenarios, the projected total carbon savings from renewable and conventional CHP are projected to be slightly lower (24.2MtCO2/Yr) in the long term (by 2020) than the savings under the current RO policy (24.9MtCO2/Yr). Under an RHI policy, renewable CHP still appears to offer a clear increase in carbon saving compared to a scenario with no biomass CHP (18.5MtCO2/Yr) so it's support for renewable CHP it still environmentally beneficial, at least in CHP, just not as much as the existing RO. However it is possible this may be mitigated elsewhere by increased growth of non CHP renewable power generation making up the shortfall in renewable CHP electricity generation. A study of this effect is outside the scope of this report

- By 2020, the low biomass fuel price scenario results in an increase to 11.9 TWh/Yr for the 'restricted' scenario and to 22.8 TWh/Yr in the 'unrestricted' case; similar to the Phase 1 projection with RHI £20/MWh for the restricted scenario but lower than the phase 1 for the unrestricted scenario. The low biomass fuel price scenario results in a decrease to 3.4 TWh/Yr for the 'restricted' scenario and to 9.6 TWh/Yr in the 'unrestricted' case

- A further key sensitivity is the effects of the fossil fuel price scenarios on renewable CHP take-up, compared with conventional CHP. The latter is also affected very significantly by the fossil fuel price scenario used. The 'high-high' fossil fuel and carbon price scenario, results in an increase to 15.7 TWh/Yr for the 'restricted' scenario, and to 35.0 TWh/Yr in the 'unrestricted' case. The 'low' fossil fuel and carbon price scenario reduces heat output to 2.0 TWh/Yr for the 'restricted' scenario, and to 2.7 TWh/Yr in the 'unrestricted' case. It is therefore concluded that the fossil fuel price effects (within the range of the assumption made about 'high-high' and 'low' price scenario differences) are much more pronounced than the effects of the biomass price scenario range of assumptions

- The effect of the fossil fuel and electricity price on conventional CHP capacity is also apparent. For the biomass CHP growth restricted case, the central price scenario level of conventional CHP is 15.0 GWe by 2020, and this increases only slightly to 15.3GWe in competition with increased biomass CHP under the high-high fossil fuel and electricity price scenario. However, under the low fossil fuel price scenario, there is a significant reduction to 13.3 GWe of conventional CHP capacity and the biomass CHP also reduces.

Table 1: Projection results summary –Renewable CHP Heat Output – Scenario R (with practical biomass CHP growth restriction)

	*Actual 2008	2013	2017	2020
CHP Renewable Heat output (TWh/Yr)				
1R BAU Current RO policy Central biomass price scenario with central fossil fuel and electricity price scenario	0.626	1.279	3.077	4.415
2R RHI £25/MWh Central biomass price scenario with central fossil fuel and electricity price scenario	0.626	2.460	4.493	7.358
2R RHI £25/MWh High biomass price scenario with central fossil fuel and electricity price scenario	0.626	1.551	2.387	3.405
2R RHI £25/MWh Low biomass price scenario with central fossil fuel and electricity price scenario)	0.626	3.397	6.774	11.869
2R RHI £25/MWh Central biomass price scenario with high-high fossil fuel and electricity price scenario	0.626	3.955	8.350	15.700
2R RHI £25/MWh Central biomass price scenario with low fossil fuel and electricity price scenario	0.626	1.128	1.535	1.962

Table 2: Projection results summary –Renewable CHP Heat Output – Scenario U (with growth restriction removed)

	*Actual 2008	2013	2017	2020
CHP Renewable Heat output (TWh/Yr)				
1U BAU Current RO policy Central biomass price scenario with central fossil fuel and electricity price scenario	0.626	3.242	8.794	12.947
2U RHI £25/MWh Central biomass price scenario with central fossil fuel and electricity price scenario	0.626	3.447	6.843	15.820
2U RHI £25/MWh High biomass price scenario with central fossil fuel and electricity price scenario	0.626	2.398	4.403	9.629
2U RHI £25/MWh Low biomass price scenario with central fossil fuel and electricity price scenario)	0.626	4.476	9.394	22.805
2U RHI £25/MWh Central biomass price scenario with high-high fossil fuel and electricity price scenario	0.626	5.099	11.317	35.045
2U RHI £25/MWh Central biomass price scenario with low fossil fuel and electricity price scenario	0.626	1.334	1.953	2.701

Note the significant increase in the combined 'renewable + conventional CHP' totals with the 'high-high' fossil fuel and electricity price scenario compared with the central scenario projections and the very large reduction when using the 'low' price scenario. This is a direct result of the relative fossil fuel and electricity price effects. The impact of the high and low biomass price scenarios is lower.

Table 3: Projection results summary –CHP Elec Capacity – Scenario R (with practical biomass CHP growth restriction)

	*Actual 2008	2013	2017	2020
Elec Capacity in CHP Mode (MWe)				
1R Renewable CHP under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	49	224	638	947
1R Conventional CHP	5420	9076	12403	14967
1R Total CHP (Renewable + conventional) under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	5469	9300	13041	15915
2R Renewable CHP under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	49	305	557	873
2R Conventional CHP	5420	8811	11360	15021
2R Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	5469	9117	11917	15894
Renewable CHP under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	49	224	363	496
Conventional CHP	5420	9000	11714	15556
Total CHP (Renewable + conventional) under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	5469	9224	12078	16052
Renewable CHP under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	49	387	768	1322
Conventional CHP	5420	8709	11170	14737
Total CHP (Renewable + conventional) under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	5469	9097	11938	16059
Renewable CHP under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	49	448	944	1759
Conventional CHP	5420	8717	11309	15253
Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	5469	9165	12253	17012
Renewable CHP under RHI £25/MWh central biomass price scenario with low fossil fuel and electricity price scenario	49	187	291	376
Conventional CHP	5420	8617	10664	13260
2R Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with low fossil fuel and electricity price scenario	5469	8804	10956	13636
Conventional CHP Only (Central energy price)	5,420	9,914	13,023	16,883

Table 4: Projection results summary –CHP Elec Capacity – Scenario U (with growth restriction removed)

	*Actual 2008	2013	2017	2020
Elec Capacity in CHP Mode (MWe)				
1R Renewable CHP under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	49	334	982	1467
Conventional CHP	5420	8854	11412	13399
Total CHP (Renewable + conventional) under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	5469	9187	12394	14866
Renewable CHP under central biomass price scenario with central fossil fuel and electricity price scenario	49	368	698	1371
Conventional CHP	5420	8697	11074	14467
	5469	9065	11772	15839
Renewable CHP under high biomass price scenario with central fossil fuel and electricity price scenario	49	276	477	858
Conventional CHP	5420	8917	11521	15210
	5469	9193	11998	16069
Renewable CHP under low biomass price scenario with central fossil fuel and electricity price scenario	49	457	933	1970
Conventional CHP	5420	8581	10833	14053
	5469	9038	11766	16024
Renewable CHP under central biomass price scenario with high-high fossil fuel and electricity price scenario	49	756	1847	2930
Conventional CHP	5420	8442	10430	13177
	5469	9198	12277	16108
Renewable CHP under central biomass price scenario with low fossil fuel and electricity price scenario	49	200	318	422
Conventional CHP	5420	8597	10624	13199
	5469	8797	10942	13622
Compare				
(Central energy price)	5,420	9,914	13,023	16,883

Average annual Renewable CHP Capacity Growth Rates

Table 5 Projected Growth in Renewable CHP Electrical Capacity under restricted growth scenario	2008-2013	2013-2017	2017-2020
1R Renewable CHP under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	36%	23%	8%
2R Renewable CHP under central biomass price scenario with central fossil fuel and electricity price scenario	44%	13%	9%
Renewable CHP under high biomass price scenario with central fossil fuel and electricity price scenario	35%	10%	6%
Renewable CHP under low biomass price scenario with central fossil fuel and electricity price scenario	51%	15%	11%
Renewable CHP under central biomass price scenario with high-high fossil fuel and electricity price scenario	56%	16%	13%
Renewable CHP under central biomass price scenario with low fossil fuel and electricity price scenario	31%	9%	5%

Table 6 Projected Growth in Renewable CHP Electrical Capacity under unrestricted growth scenario	2008-2013	2013-2017	2017-2020
1U Renewable CHP under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	47%	24%	8%
2U Renewable CHP under central biomass price scenario with central fossil fuel and electricity price scenario	50%	14%	14%
Renewable CHP under high biomass price scenario with central fossil fuel and electricity price scenario	41%	12%	12%
Renewable CHP under low biomass price scenario with central fossil fuel and electricity price scenario	56%	15%	16%
Renewable CHP under central biomass price scenario with high-high fossil fuel and electricity price scenario	73%	20%	10%
Renewable CHP under central biomass price scenario with low fossil fuel and electricity price scenario	33%	10%	6%

For the central fuel price scenarios it can be seen that an RHI would accelerate the growth in renewable CHP capacity in early years but in later years the growth rate would then be slower, primarily due to a higher level of market saturation.

Table 7: Projection results summary –CHP Annual Elec Output – Scenario R (with practical biomass CHP growth restriction)

	*Actual 2008	2013	2017	2020
Annual Elec Output (TWh/Yr)				
1R Renewable CHP under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	0.397	1.812	5.165	7.668
1R Conventional CHP	43.869	73.461	100.392	121.147
1R Total CHP (Renewable + conventional) under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	44.265	75.273	105.557	128.814
2R Renewable CHP under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	0.397	2.472	4.509	7.069
2R Conventional CHP	43.869	71.319	91.944	121.578
2R Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	44.265	73.791	96.454	128.647
Renewable CHP under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	0.397	1.811	2.941	4.017
Conventional CHP	43.869	72.847	94.816	125.907
Total CHP (Renewable + conventional) under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	44.265	74.657	97.757	129.923
Renewable CHP under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	0.397	3.133	6.219	10.702
Conventional CHP	43.869	70.495	90.406	119.280
Total CHP (Renewable + conventional) under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	44.265	73.628	96.625	129.982
Renewable CHP under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	0.397	3.622	7.639	14.240
Conventional CHP	43.869	70.558	91.533	123.457
Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	44.265	74.180	99.173	137.698
Renewable CHP under RHI £25/MWh central biomass price scenario with low fossil fuel and electricity price scenario	0.397	1.511	2.359	3.040
Conventional CHP	43.869	69.748	86.317	107.329
2R Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with low fossil fuel and electricity price scenario	44.265	71.260	88.675	110.368
Conventional CHP Only (Central energy price)	43.869	80.245	105.409	136.653

Table 8: Projection results summary –CHP Annual Elec Output – Scenario U (with growth restriction removed)

	*Actual 2008	2013	2017	2020
Annual Elec Output (TWh/Yr)				
1R Renewable CHP under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	0.397	2.702	7.949	11.874
1R Conventional CHP	43.869	71.661	92.365	108.449
1R Total CHP (Renewable + conventional) under BAU Current RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	44.265	74.363	100.315	120.323
2R Renewable CHP under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	0.397	2.980	5.647	11.100
2R Conventional CHP	43.869	70.392	89.636	117.100
2R Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	44.265	73.372	95.283	128.199
Renewable CHP under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	0.397	2.236	3.858	6.947
Conventional CHP	43.869	72.173	93.254	123.113
Total CHP (Renewable + conventional) under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	44.265	74.408	97.112	130.061
Renewable CHP under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	0.397	3.701	7.549	15.948
Conventional CHP	43.869	69.453	87.685	113.749
Total CHP (Renewable + conventional) under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	44.265	73.154	95.234	129.697
Renewable CHP under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	0.397	6.121	14.947	23.718
Conventional CHP	43.869	68.328	84.423	106.658
Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	44.265	74.449	99.370	130.377
Renewable CHP under RHI £25/MWh central biomass price scenario with low fossil fuel and electricity price scenario	0.397	1.620	2.571	3.418
Conventional CHP	43.869	69.582	85.994	106.836
2R Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with low fossil fuel and electricity price scenario	44.265	71.203	88.565	110.255
Conventional CHP Only (Central energy price)	43.869	80.245	105.409	136.653

The following table shows the associated carbon savings from the above projections. As with phase 1, for these calculations, we have used the following emissions factors.

CO2 factors (tCO2/MWh)	
CHP fuel (gas)	0.190
Elect	0.430

Table 9: Projection results summary –Total Carbon Savings (from Electricity and Heat) MtCO2/Yr – Scenario R (with practical biomass CHP growth restriction)

	2013	2017	2020
Carbon Savings from Renewable and Conventional CHP MtCO2/Yr			
1R Renewable CHP under BAU RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	1.103	3.000	4.415
Conventional CHP	14.157	17.706	20.460
Total CHP (Renewable + conventional) under BAU RO Policy central biomass price scenario with central fossil fuel and electricity price scenario	15.261	20.706	24.875
2R Renewable CHP under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	1.686	3.077	4.904
Conventional CHP	13.667	16.223	19.332
Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with central fossil fuel and electricity price scenario	15.353	19.300	24.235
2R Renewable CHP under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	1.171	1.869	2.590
Conventional CHP	13.984	16.811	20.201
Total CHP (Renewable + conventional) under RHI £25/MWh high biomass price scenario with central fossil fuel and electricity price scenario	15.156	18.680	22.790
2R Renewable CHP under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	2.208	4.390	7.609
Conventional CHP	13.494	15.904	18.861
Total CHP (Renewable + conventional) under RHI £25/MWh low biomass price scenario with central fossil fuel and electricity price scenario	15.702	20.294	26.470
2R Renewable CHP under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	2.559	5.400	10.101
Conventional CHP	13.455	15.910	19.024
Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with high-high fossil fuel and electricity price scenario	16.014	21.310	29.125
2R Renewable CHP under central biomass price scenario with low fossil fuel and electricity price scenario	0.936	1.403	1.804
Conventional CHP	13.679	16.029	18.695
Total CHP (Renewable + conventional) under RHI £25/MWh central biomass price scenario with low fossil fuel and electricity price scenario	14.614	17.432	20.500
Conventional CHP Only (Central energy price)	13.303	15.703	18.504

Under the proposed RHI and RO policy revision, the balance of changes in overall carbon saving resulting from increased renewable heat, decreased heat and power from conventional CHP and either a modest increase or decrease in renewable electricity from CHP, is complex.

It is concluded that, in the central fossil fuel and renewable fuel price projections, the projected total carbon savings from renewable and conventional CHP may be slightly lower in the long term than the savings under the current RO policy.

However even under an RHI policy the total volume of renewable energy (heat and power) increases whilst offering a clear increase in carbon saving compared to a scenario of no renewable CHP. In addition, the reduction in renewable electricity from CHP may coincide with an increase in generation by renewable power only plant but this is outside the scope of this report.

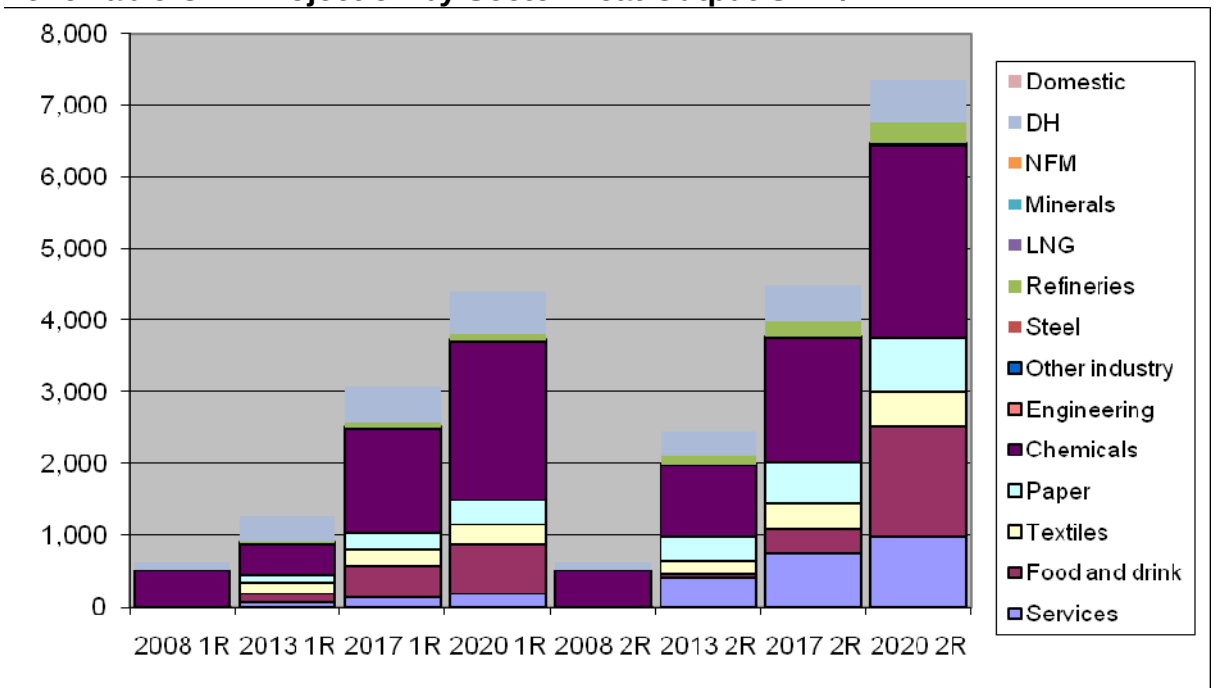
Detailed sector and technology results

Graphical Phase 2 Sector Results Summary for central fuel price scenarios

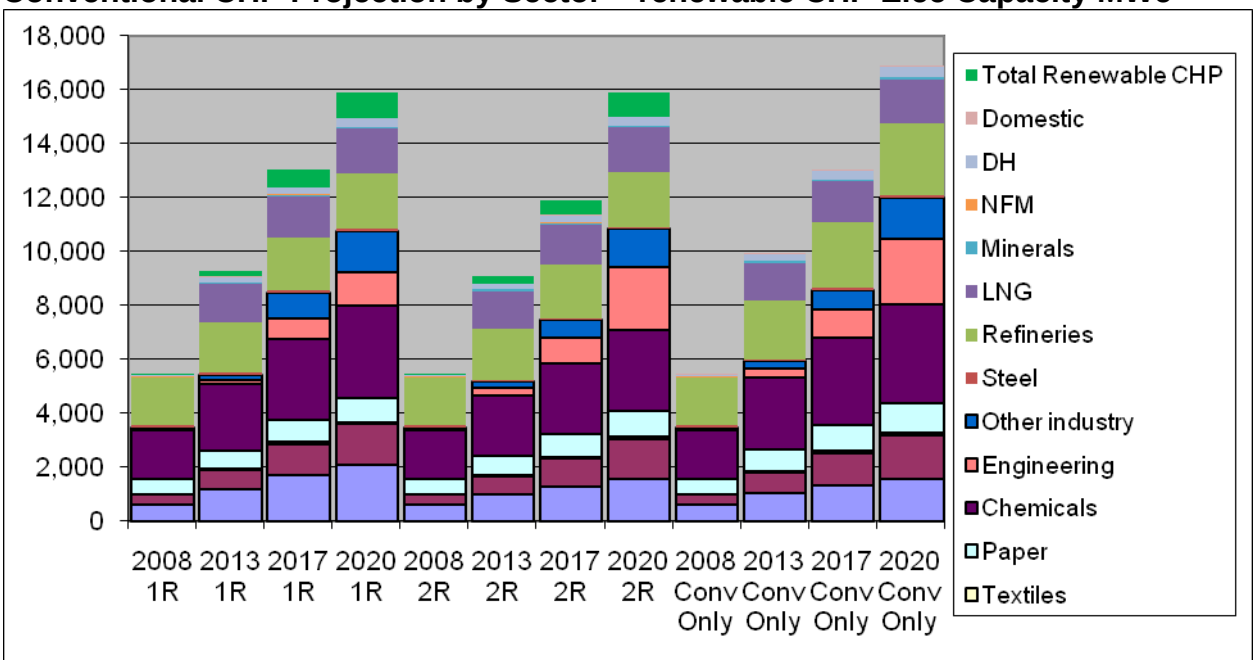
Scenario 1R = With existing RO policy, CHP designed and operated to maximise ROCs

Scenario 2R = With Proposed RHI = £25/MWh, CHP designed to follow site heat and power loads where possible with steam turbine technology

Renewable CHP Projection by Sector Heat Output GWh/Yr



Conventional CHP Projection by Sector + renewable CHP Elec Capacity MWe



The following sets of tables and figures summarise the individual sector projections for both renewable and conventional CHP. Results cover both electrical capacity projections and heat output projections.

The CHP uptake projection model considers the competitive interactions between renewable CHP and conventional CHP, so that the effect of changes in the specification of the renewable CHP technology will change the conventional CHP uptake. The following tables and figures show the effects of the renewable CHP scenarios on conventional CHP projections.

The following results cover the central biomass price with central fossil fuel and electric price scenario only. Further results covering the following four scenarios are provide in Appendix 2 of this report:

- High and low biomass price scenarios with the central fossil fuel and electricity price scenario;
- Central biomass price scenario with high-high and low fossil fuel and electricity price scenarios.

Renewable and conventional CHP results by sector for the central biomass price scenario with central fossil fuel and electricity price scenario

Scenario 1R Central - (CHP Heat Output GWh/Yr) with practical biomass CHP growth restriction with existing RO and CHP designed and operated to maximise ROCs

Biomass CHP projection

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	-	65.5	136.1	189.1
Food and drink	4	129.7	452.0	693.7
Textiles	-	146.5	215.4	267.2
Paper	27	99.0	243.9	352.6
Chemicals	491	450.0	1443.7	2189.0
Engineering	0	5.0	22.5	35.7
Other industry	0	0.4	1.6	2.5
Sub-total	522.0	896.0	2515.3	3729.8
Steel	-	-	-	-
Refineries	-	26.6	58.3	82.0
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**1,279.2**	**3,077.5**	**4,414.5**

Conventional CHP projection

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3,571.80	7,002.75	9935.6	12,135.31
Food and drink	4,076.80	7,053.80	11853.7	15,453.70
Textiles	6.2	190.6	338.1	448.8
Paper	6,421.20	8,174.90	9579.0	10,632.05
Chemicals	17,775.70	24,518.90	29913.4	33,959.30
Engineering	243	453.04	2703.3	4,390.99
Other industry	459.8	1,673.27	7,751.22	12,309.68
Sub-total	32,554.5	49,067.3	72,074.4	89,329.8
Steel	1,640.50	1,739.90	1,739.90	1,739.90
Refineries	17,713.20	18,972.2	19979.3	20,734.7
LNG	-	14,065.40	15,070.10	16,577.10
Minerals	645.7	1,271.20	1,271.20	1,271.20
NFM	22.3	20.8	20.8	20.8
DH	404.4	1,386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	58.8
Total Conventional CHP	**53,005.1**	**86,562.6**	**112,166.1**	**132,076.1**
Total Renewable CHP	**626.0**	**1,279.2**	**3,077.5**	**4,414.5**
Total CHP	**53,631.1**	**87,841.8**	**115,243.5**	**136,490.6**

Scenario 1U Central - (CHP Heat Output GWh/Yr) without practical biomass CHP growth restriction with existing RO and CHP designed and operated to maximise ROCs

Biomass CHP projection

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	-	232.7	657.6	976.3
Food and drink	4	1089.8	3371.3	5082.3
Textiles	-	345.8	583.9	762.4
Paper	27	99.0	243.9	352.6
Chemicals	491	454.4	1498.3	2281.2
Engineering	0	336.2	1066.7	1614.7
Other industry	0	292.5	779.8	1145.3
Sub-total	522.0	2850.3	8201.4	12214.8
Steel	-	-	-	-
Refineries	-	35.5	89.0	129.2
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**3,242.5**	**8,794.4**	**12,946.7**

Conventional CHP projection

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3,571.80	6,648.89	9289.2	11,269.47
Food and drink	4,076.80	6,368.20	9600.5	12,024.70
Textiles	6.2	111.6	195.9	259.2
Paper	6,421.20	8,174.90	9579.0	10,632.05
Chemicals	17,775.70	24,426.40	29747.0	33,737.40
Engineering	243	401.21	2020.9	3,235.65
Other industry	459.8	1,334.23	4,554.90	6,970.40
Sub-total	32,554.5	47,465.4	64,987.4	78,128.9
Steel	1,640.50	1,739.90	1,739.90	1,739.90
Refineries	17,713.20	18,836.3	19734.8	20,408.7
LNG	-	14,065.40	15,070.10	16,577.10
Minerals	645.7	1,271.20	1,271.20	1,271.20
NFM	22.3	20.8	20.8	20.8
DH	404.4	1,386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	58.8
Total Conventional CHP	**53,005.1**	**84,824.9**	**104,834.5**	**120,549.1**
Total Renewable CHP	**626.0**	**3,242.5**	**8,794.4**	**12,946.7**
Total CHP	**53,631.1**	**88,067.4**	**113,628.9**	**133,495.8**

Scenario 1R Central - Biomass CHP projection (CHP Mode Elec Capacity MWe) with practical biomass CHP growth restriction with existing RO policy assuming CHP designed and operated to maximise ROCs under central biomass price scenario with central fossil fuel and electricity price scenario

MW electrical capacity	Actual 2008	2013	2017	2020
Services	-	62.8	79.2	91.4
Food and drink	0	18.2	68.4	106.0
Textiles	-	8.1	12.0	14.9
Paper	3	19.7	56.6	84.3
Chemicals	34	63.9	339.2	545.7
Engineering	0	1.3	6.1	9.7
Other industry	0	0.1	0.5	0.7
Sub-total	37.0	174.2	561.9	852.7
Steel	-	-	-	-
Refineries	-	7.5	16.5	23.3
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	12.0	42.2	59.6	71.3
Total Renewable CHP	**49.0**	**223.9**	**638.1**	**947.3**

Conventional CHP

MW electrical capacity	Actual 2008	2013	2017	2020
Services	610.4	1,197.66	1697.2	2,071.78
Food and drink	404.3	699.50	1175.4	1,532.40
Textiles	1.1	34.3	60.8	80.7
Paper	553.5	704.70	809.4	887.97
Chemicals	1,788.50	2,467.00	3009.7	3,416.80
Engineering	69.1	128.50	769.2	1,249.70
Other industry	57.3	207.95	964.36	1,531.66
Sub-total	3,484.2	5,439.6	8,486.1	10,771.0
Steel	66.6	70.7	70.7	70.7
Refineries	1,763.10	1,888.4	1988.6	2,063.8
LNG	-	1,400.00	1,500.00	1,650.00
Minerals	35	69	69	69
NFM	11.3	10.5	10.5	10.5
DH	53.4	187.8	265.4	317.5
Domestic	6.3	10	13	15
Total Conventional CHP	**5,419.9**	**9,076.0**	**12,403.3**	**14,967.5**
Total Renewable CHP	**49.0**	**223.9**	**638.1**	**947.3**
Total CHP	**5,468.9**	**9,299.9**	**13,041.4**	**15,914.8**

Scenario 2R Central - (CHP Heat Output GWh/Yr) with practical biomass CHP growth restriction with proposed RHI and CHP designed and operated to match site heat and power loads

Biomass CHP projection

GWh heat output	Actual 2008	2013	2017	2020
Services	-	414.1	745.3	993.7
Food and drink	4	47.8	347.7	1,540.50
Textiles	-	192.2	345.9	461.2
Paper	27	338.3	587.3	774.1
Chemicals	491	993.4	1745.7	2,664.50
Engineering	0	0.2	2.3	14.3
Other industry	0	0.3	3.6	25.9
Sub-total	522.0	1,986.3	3,777.8	6,474.2
Steel	-	-	-	-
Refineries	-	117.2	210.9	281.2
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**2,460.1**	**4,492.6**	**7,358.1**

Conventional CHP projection

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3,571.80	5,707.90	7,416.80	9,125.70
Food and drink	4,076.80	7,014.30	10,827.20	14,993.90
Textiles	6.2	182.7	323.8	465
Paper	6,421.20	8,169.70	9,568.50	10,967.30
Chemicals	17,775.70	22,499.20	26,278.00	30,056.70
Engineering	243	1,048.30	3,375.20	8,112.80
Other industry	459.8	1,755.40	5,126.80	11,453.60
Sub-total	32,554.5	46,377.5	62,916.3	85,175.0
Steel	1,640.50	1,739.90	1,739.90	1,739.90
Refineries	17,713.20	18,831.10	19,725.50	20,619.80
LNG	-	14,065.40	15,070.10	16,577.10
Minerals	645.7	1,271.20	1,271.20	1,271.20
NFM	22.3	20.8	20.8	20.8
DH	404.4	1,386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	58.8
Total Conventional CHP	**53,005.1**	**83,731.8**	**102,754.1**	**127,806.4**
Total Renewable CHP	**626.0**	**2,460.1**	**4,492.6**	**7,358.1**
Total CHP	**53,631.1**	**86,191.9**	**107,246.7**	**135,164.5**

Scenario 2U Central - (CHP Heat Output GWh/Yr) without practical biomass CHP growth restriction with proposed RHI and CHP designed and operated to match site heat and power loads

Biomass CHP projection

GWh heat output	Actual 2008	2013	2017	2020
Services	-	850.1	1,530.10	2,040.10
Food and drink	4	76.9	819.4	4,830.00
Textiles	-	619.6	1,115.20	1,487.00
Paper	27	338.3	587.3	774.1
Chemicals	491	1021	1833.8	2,845.10
Engineering	0	1.8	120.4	2,760.70
Other industry	0	0.3	5.3	42.9
Sub-total	522.0	2,908.0	6,011.5	14,779.9
Steel	-	-	-	-
Refineries	-	182.2	328	437.3
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**3,446.8**	**6,843.4**	**15,819.9**

Conventional CHP projection

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3,571.80	5,568.50	7,165.80	8,763.20
Food and drink	4,076.80	6,580.20	9,651.10	12,862.60
Textiles	6.2	74.7	129.6	184.4
Paper	6,421.20	8,169.70	9,568.50	10,967.30
Chemicals	17,775.70	22,457.40	26,202.70	29,948.00
Engineering	243	1,020.30	3,215.10	7,603.70
Other industry	459.8	1,736.00	5,025.00	11,151.30
Sub-total	32,554.5	45,606.8	60,957.8	81,480.5
Steel	1,640.50	1,739.90	1,739.90	1,739.90
Refineries	17,713.20	18,691.80	19,474.70	20,257.60
LNG	-	14,065.40	15,070.10	16,577.10
Minerals	645.7	1,271.20	1,271.20	1,271.20
NFM	22.3	20.8	20.8	20.8
DH	404.4	1,386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	58.8
Total Conventional CHP	**53,005.1**	**82,821.8**	**100,544.8**	**123,749.7**
Total Renewable CHP	**626.0**	**3,446.8**	**6,843.4**	**15,819.9**
Total CHP	**53,631.1**	**86,268.6**	**107,388.2**	**139,569.6**

Scenario 2R Central - Biomass CHP projection (CHP Mode Elec Capacity MWe) with practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **central biomass price scenario with central fossil fuel and electricity price scenario**

MW electrical capacity	Actual 2008	2013	2017	2020
Services	-	115.3	207.5	276.6
Food and drink	0	0.5	9.5	92.8
Textiles	-	10.8	19.4	25.9
Paper	3	37.3	64.8	85.4
Chemicals	34	81.3	163.4	275.8
Engineering	0	0.1	0.5	1.7
Other industry	0	0.1	0.3	1
Sub-total	37.0	245.4	465.4	759.2
Steel	-	-	-	-
Refineries	-	17.8	32.1	42.8
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	12.0	42.2	59.6	71.3
Total Renewable CHP	**49.0**	**305.4**	**557.1**	**873.3**

Conventional CHP

MW electrical capacity	Actual 2008	2013	2017	2020
Services	610.4	975.5	1,267.50	1,559.60
Food and drink	404.3	695.6	1,073.70	1,486.80
Textiles	1.1	32.8	58.2	83.6
Paper	553.5	704.2	824.8	945.4
Chemicals	1,788.50	2,263.70	2,643.90	3,024.10
Engineering	69.1	298.2	960.2	2,308.00
Other industry	57.3	218.9	639.3	1,428.20
Sub-total	3,484.2	5,188.9	7,467.6	10,835.7
Steel	66.6	70.7	70.7	70.7
Refineries	1,763.10	1,874.40	1,963.40	2,052.40
LNG	-	1,400.00	1,500.00	1,650.00
Minerals	35	69	69	69
NFM	11.3	10.5	10.5	10.5
DH	53.4	187.8	265.4	317.5
Domestic	6.3	10	13	15
Total Conventional CHP	**5,419.9**	**8,811.3**	**11,359.6**	**15,020.8**
Total Renewable CHP	**49.0**	**305.4**	**557.1**	**873.3**
Total CHP	**5,468.9**	**9,116.7**	**11,916.7**	**15,894.1**

Conventional gas CHP results with no renewable option

The results under the various scenarios considered (total renewable plus fossil fuel CHP) can be compared directly with the results for conventional CHP with no renewable option. As pointed out earlier, the effect of introducing renewable CHP is to reduce the overall projected total CHP capacity as a result of the difference in the capacities chosen for the two competing technologies at the same sites.

The following tables and figures compare the total fossil fuel CHP capacity projections with no renewable option for the three fossil fuel and electricity price cases – central, high-high and low.

Projections of total fossil fuel CHP (with no renewable options) by sector (MW electrical capacity) – central fossil fuel and electricity price case

MW electrical capacity	Actual 2008	2013	2017	2020
Services	601.8	1,047.1	1,344.0	1,566.6
Food and drink	407.9	774.0	1,186.2	1,634.0
Textiles	1.1	48.7	80.3	104.1
Paper	536.2	792.9	964.1	1,092.5
Chemicals	1,847.4	2,674.6	3,226.0	3,639.6
Engineering	65.6	349.0	1,063.4	2,452.4
Other industry	57.0	259.7	713.6	1,523.1
Sub-total	3,517.0	5,946.0	8,577.6	12,012.3
Steel	68.9	66.7	66.7	66.7
Refineries	1,762.7	2,181.9	2,461.3	2,670.9
LNG	-	1,400.0	1,500.0	1,650.0
Minerals	38.4	69.0	69.0	69.0
NFM	10.5	10.5	10.5	10.5
DH	65.4	230.0	325.0	388.8
Domestic	**6.0**	**10.0**	**13.0**	**15.0**
Total Conventional CHP	**5,468.9**	**9,914.1**	**13,023.1**	**16,883.2**

Projections of total fossil fuel CHP (with no renewable options) by sector (MW electrical capacity) – High-high fossil fuel and electricity price case

MW electrical capacity	Actual 2008	2013	2017	2020
Services	601.8	1,074.80	1,390.20	1,626.70
Food and drink	407.9	779.4	1200.1	1,658.90
Textiles	1.1	49.9	82.4	106.8
Paper	536.2	807	987.5	1,122.90
Chemicals	1,847.40	2,688.30	3,248.90	3,669.30
Engineering	65.6	365.9	1150.8	2,717.90
Other industry	57	269.7	760.2	1,653.60
Sub-total	3,517.0	6,035.0	8,820.1	12,556.1
Steel	68.9	66.7	66.7	66.7
Refineries	1,762.70	2,193.50	2,480.70	2,696.10
LNG	-	1,400.00	1,500.00	1,650.00
Minerals	38.4	69	69	69
NFM	10.5	10.5	10.5	10.5
DH	65.4	230.0	325.0	388.8
Domestic	**6.0**	**10.0**	**13.0**	**15.0**
Total Conventional CHP	**5,468.9**	**10,014.7**	**13,285.0**	**17,452.2**

Projections of total fossil fuel CHP (with no renewable options) by sector (MW electrical capacity) – low fossil fuel and electricity price case

MW electrical capacity	Actual 2008	2013	2017	2020
Services	601.8	936.9	1,160.30	1,327.80
Food and drink	407.9	704.8	1014.9	1,334.00
Textiles	1.1	40.9	67.4	87.3
Paper	536.2	641.8	712.2	765
Chemicals	1,847.40	2,507.60	2,947.70	3,277.90
Engineering	65.6	271.2	698.4	1,419.90
Other industry	57	204.7	479.8	909
Sub-total	3,517.0	5,307.9	7,080.7	9,120.9
Steel	68.9	66.7	66.7	66.7
Refineries	1,762.70	2,146.10	2,401.70	2,593.40
LNG	-	1,400.00	1,500.00	1,650.00
Minerals	38.4	69	69	69
NFM	10.5	10.5	10.5	10.5
DH	65.4	230.0	325.0	388.8
Domestic	**6.0**	**10.0**	**13.0**	**15.0**
Total Conventional CHP	**5,468.9**	**9,240.2**	**11,466.6**	**13,914.3**

Appendix 1. Delivered fossil fuel and electricity price scenarios used in the CHP modelling work

Central scenario

£ per MWh (Excl Carbon, CCL, ROCs, RHI etc.) (2009 real terms)	2008	2012	2013	2020
GasPrice(SMALL)	30.87	32.49	32.89	35.63
GasPrice(MEDIUM)	30.87	32.49	32.89	35.63
GasPrice(LARGE)	26.68	28.08	28.42	30.79
DisplacedGasPrice(SMALL)	30.39	31.98	32.36	35.07
DisplacedGasPrice(MEDIUM)	30.39	31.98	32.36	35.07
DisplacedGasPrice(LARGE)	30.39	31.98	32.36	35.07
TopUpPowerPrice(SMALL)	118.20	100.43	101.50	113.11
TopUpPowerPrice(MEDIUM)	99.79	84.79	85.69	95.49
TopUpPowerPrice(LARGE)	99.79	84.79	85.69	95.49
PowerExpPrice(SMALL)	80.74	68.60	69.33	77.26
PowerExpPrice(MEDIUM)	80.74	68.60	69.33	77.26
PowerExpPrice(LARGE)	80.74	68.60	69.33	77.26

High-high price scenario

£ per MWh (Excl carbon, CCL, ROCs, RHI etc.) (2009 real terms)	2008	2012	2013	2020
CHPGasPrice(SMALL)	30.87	51.25	54.36	63.69
CHPGasPrice(MEDIUM)	30.87	51.25	54.36	63.69
CHPGasPrice(LARGE)	26.68	44.28	46.97	55.03
DisplacedGasPrice(SMALL)	30.39	50.44	53.50	62.68
DisplacedGasPrice(MEDIUM)	30.39	50.44	53.50	62.68
DisplacedGasPrice(LARGE)	30.39	50.44	53.50	62.68
TopUpPowerPrice(SMALL)	118.18	110.14	149.80	175.91
TopUpPowerPrice(MEDIUM)	99.78	92.99	126.47	148.52
TopUpPowerPrice(LARGE)	99.78	92.99	126.47	148.52
PowerExpPrice(SMALL)	80.74	75.74	103.01	120.96
PowerExpPrice(MEDIUM)	80.74	75.74	103.01	120.96
PowerExpPrice(LARGE)	80.74	75.74	103.01	120.96

Low price scenario

£ per MWh (Excl carbon, CCL, ROCs, RHI etc.) (2009 real terms)	2008	2012	2013	2020
GasPrice(SMALL)	30.87	17.68	17.73	18.09
GasPrice(MEDIUM)	30.87	17.68	17.73	18.09
GasPrice(LARGE)	26.68	15.28	15.32	15.63
DisplacedGasPrice(SMALL)	30.39	17.40	17.45	17.80
DisplacedGasPrice(MEDIUM)	30.39	17.40	17.45	17.80
DisplacedGasPrice(LARGE)	30.39	17.40	17.45	17.80
TopUpPowerPrice(SMALL)	118.18	61.54	58.38	59.52
TopUpPowerPrice(MEDIUM)	99.78	51.96	49.28	50.25
TopUpPowerPrice(LARGE)	99.78	51.96	49.28	50.25
PowerExpPrice(SMALL)	80.74	42.13	40.13	40.67
PowerExpPrice(MEDIUM)	80.74	42.13	40.13	40.67
PowerExpPrice(LARGE)	80.74	42.13	40.13	40.67

Sectors growth scenario indices – Central (DECC UEP38)

	2007-2010	2007-2013	2007-2020
Food, drink & tobacco	0.871	0.927	1.036
Textiles, leather & clothing	0.924	0.849	0.684
Pulp, paper, printing & publishing	1.001	1.054	1.136
Chemicals & chemical products	0.721	0.822	1.067
Engineering & vehicles	0.828	0.897	1.023
Construction & other industry	0.839	0.915	1.006
Refineries	1.0355	1.0512	1.0940
Services sector	0.984	1.041	1.233

Appendix 2. Detailed sector and technology results under the different biomass price and fossil fuel price scenarios – Phase 2 results only

The following results cover the following four scenarios.

- High and low biomass price scenarios with the central fossil fuel and electricity price scenario;
- Central biomass price scenario with high-high and low fossil fuel and electricity price scenarios.

The central biomass price scenarios with the central fossil fuel and electricity price scenario results are provide in the main report. All scenario results have also been summarised in the Summary of result section of the report.

Renewable and conventional CHP results by sector for the high biomass price scenario with central fossil fuel and electricity price scenario

Scenario 2R - Biomass CHP projection (CHP Heat Output GWh/Yr) with practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **high biomass price scenario with central fossil fuel and electricity price scenario**

GWh heat output	Actual 2008	2013	2017	2020
Services	-	216.5	389.7	519.6
Food and drink	4	34.3	191	692.7
Textiles	-	144	259.2	345.6
Paper	27	107.8	172.5	220.9
Chemicals	491	601.9	708.3	800.3
Engineering	0	0	0.1	0.3
Other industry	0	0.2	1.6	8.3
Sub-total	522.0	1,104.7	1,722.4	2,587.7
Steel	-	-	-	-
Refineries	-	89.2	160.6	214.2
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**1,550.5**	**2,386.9**	**3,404.6**

Scenario 2R - Conventional CHP projection by sector and total renewable (CHP Heat Output GWh/Yr) with practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **high biomass price scenario with central fossil fuel and electricity price scenario**

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3571.8	5735.1	7,465.70	9,196.40
Food and drink	4076.8	7125.6	11,138.50	15,571.50
Textiles	6.2	193.9	344	494.1
Paper	6421.2	8484.7	10135.4	11,786.20
Chemicals	17,775.70	23,847.80	28,705.40	33,563.10
Engineering	243	1051.3	3393	8,170.10
Other industry	459.8	1756.2	5130.9	11,465.80
Sub-total	32,554.5	48,194.6	66,312.9	90,247.2
Steel	1640.5	1739.9	1739.9	1739.9
Refineries	17,713.20	18,905.00	19,858.50	20,812.00
LNG	-	14,065.40	15,070.10	16,577.10
Minerals	645.7	1271.2	1271.2	1271.2
NFM	22.3	20.8	20.8	20.8
DH	404.4	1,386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	58.8
Total Conventional CHP	**53,005.1**	**85,622.8**	**106,283.7**	**133,070.8**
Total Renewable CHP	**626.0**	**1,550.5**	**2,386.9**	**3,404.6**
Total CHP	**53,631.1**	**87,173.3**	**108,670.6**	**136,475.4**

Case 2U - Biomass CHP projection (CHP Heat Output GWh/Yr) without practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **high biomass price scenario with central fossil fuel and electricity price scenario**

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	-	621.6	1,118.90	1,491.80
Food and drink	4	69.1	675.8	3,736.10
Textiles	-	484.6	872.3	1,163.00
Paper	27	107.8	172.5	220.9
Chemicals	491	616.1	738.7	846.5
Engineering	0	1.3	65.2	1,217.00
Other industry	0	0.2	2.3	14.2
Sub-total	522.0	1,900.7	3,645.7	8,689.5
Steel	-	-	-	-
Refineries	-	140.5	252.9	337.1
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**2,397.8**	**4,402.5**	**9,629.3**

Scenario 2U - Conventional CHP projection by sector and total renewable (CHP Heat Output GWh/Yr) without practical biomass CHP growth restriction with proposed RHI policy assuming REN CHP designed and operated to match site heat and power loads under **high biomass price scenario with central fossil fuel and electricity price scenario**

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3571.8	5627.6	7,272.20	8,916.80
Food and drink	4076.8	6818.1	10,288.20	14,007.20
Textiles	6.2	110.3	193.6	276.9
Paper	6421.2	8484.7	10135.4	11,786.20
Chemicals	17,775.70	23,821.70	28,658.50	33,495.20
Engineering	243	1039.8	3326.2	7,956.10
Other industry	459.8	1755.9	5129.5	11,461.70
Sub-total	32,554.5	47,658.1	65,003.6	87,900.1
Steel	1640.5	1739.9	1739.9	1739.9
Refineries	17,713.20	18,768.10	19,612.10	20,456.00
LNG	-	14,065.40	15,070.10	16,577.10
Minerals	645.7	1271.2	1271.2	1271.2
NFM	22.3	20.8	20.8	20.8
DH	404.4	1,386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	58.8
Total Conventional CHP	**53,005.1**	**84,949.4**	**104,728.0**	**130,367.7**
Total Renewable CHP	**626.0**	**2,397.8**	**4,402.5**	**9,629.3**
Total CHP	**53,631.1**	**87,347.2**	**109,130.5**	**139,997.0**

Scenario 2R - Biomass CHP projection (CHP Mode Elec Capacity MWe) with practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **high biomass price scenario with central fossil fuel and electricity price scenario**

MW electrical capacity	Actual 2008	2013	2017	2020
Services	-	103.4	186.1	248.1
Food and drink	0	0.3	4.7	36.1
Textiles	-	8	14.5	19.3
Paper	3	12	19.2	24.6
Chemicals	34	44.2	54.6	63.9
Engineering	0	0	0	0
Other industry	0	0	0.1	0.3
Sub-total	37.0	167.9	279.2	392.3
Steel	-	-	-	-
Refineries	-	13.6	24.5	32.6
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	12.0	42.2	59.6	71.3
Total Renewable CHP	**49.0**	**223.7**	**363.3**	**496.2**

Scenario 2R - Projection of Conventional CHP (by sector) and Total Renewable CHP Capacity (Elec Capacity in CHP Mode MWe) with practical biomass CHP growth restriction with proposed RHI, REN CHP designed and operated to match site heat and power loads under **high biomass price scenario with central fossil fuel and electricity price scenario**

MW electrical capacity	Actual 2008	2013	2017	2020
Services	610.4	980.1	1,275.90	1,571.60
Food and drink	404.3	706.6	1,104.50	1,544.10
Textiles	1.1	34.8	61.8	88.8
Paper	553.5	731.4	873.7	1,016.00
Chemicals	1,788.50	2,399.40	2,888.20	3,376.90
Engineering	69.1	299.1	965.3	2,324.30
Other industry	57.3	219	639.8	1,429.70
Sub-total	3,484.2	5,370.4	7,809.2	11,351.4
Steel	66.6	70.7	70.7	70.7
Refineries	1,763.10	1,881.70	1,976.60	2,071.50
LNG	-	1,400.00	1,500.00	1,650.00
Minerals	35	69	69	69
NFM	11.3	10.5	10.5	10.5
DH	53.4	187.8	265.4	317.5
Domestic	6.3	10	13	15
Total Conventional CHP	**5,419.9**	**9,000.1**	**11,714.4**	**15,555.6**
Total Renewable CHP	**49.0**	**223.7**	**363.3**	**496.2**
Total CHP	**5,468.9**	**9,223.8**	**12,077.7**	**16,051.8**

Renewable and conventional CHP results by sector for the low biomass price scenario with central fossil fuel and electricity price scenario

Scenario 2R - Biomass CHP projection (CHP Heat Output GWh/Yr) with practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **low biomass price scenario with central fossil fuel and electricity price scenario**

GWh heat output	Actual 2008	2013	2017	2020
Services	-	710	1,278.00	1,704.00
Food and drink	4	55.7	458.3	2,225.60
Textiles	-	202	363.6	484.9
Paper	27	671.5	1,187.00	1,573.70
Chemicals	491	1280.2	2755.6	4,897.00
Engineering	0	0.2	3.1	21.2
Other industry	0	0.4	7.7	71.1
Sub-total	522.0	2,920.0	6,053.3	10,977.5
Steel	-	-	-	-
Refineries	-	120.4	216.8	289
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**3,397.0**	**6,774.0**	**11,869.2**

Scenario 2R - Conventional CHP projection by sector and total renewable (CHP Heat Output GWh/Yr) with practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **low biomass price scenario with central fossil fuel and electricity price scenario**

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3,571.80	5,690.00	7,384.50	9,079.10
Food and drink	4,076.80	6,958.40	10,672.30	14,708.70
Textiles	6.2	180.8	320.5	460.2
Paper	6,421.20	7,972.90	9,214.20	10,455.60
Chemicals	17,775.70	21,756.80	24,941.70	28,126.60
Engineering	243	1,047.40	3,370.50	8,097.70
Other industry	459.8	1,754.40	5,121.70	11,438.40
Sub-total	32,554.5	45,360.7	61,025.4	82,366.3
Steel	1,640.50	1,739.90	1,739.90	1,739.90
Refineries	17,713.20	18,822.20	19,709.50	20,596.70
LNG	-	14,065.40	15,070.10	16,577.10
Minerals	645.7	1,271.20	1,271.20	1,271.20
NFM	22.3	20.8	20.8	20.8
DH	404.4	1,386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	58.8
Total Conventional CHP	**53,005.1**	**82,706.1**	**100,847.2**	**124,974.6**
Total Renewable CHP	**626.0**	**3,397.0**	**6,774.0**	**11,869.2**
Total CHP	**53,631.1**	**86,103.1**	**107,621.2**	**136,843.8**

Case 2U - Biomass CHP projection (CHP Heat Output GWh/Yr) without practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **low biomass price scenario with central fossil fuel and electricity price scenario**

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	-	1,173.90	2,112.90	2,817.30
Food and drink	4	82.2	923	5,661.30
Textiles	-	681.8	1,227.20	1,636.30
Paper	27	671.5	1,187.00	1,573.70
Chemicals	491	1320.5	2913.9	5,275.60
Engineering	0	2.3	178.8	4,675.10
Other industry	0	0.5	11	114.1
Sub-total	522.0	3,932.7	8,553.8	21,753.4
Steel	-	-	-	-
Refineries	-	187.1	336.7	448.9
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**4,476.4**	**9,394.4**	**22,805.0**

Scenario 2U - Conventional CHP projection by sector and total renewable (CHP Heat Output GWh/Yr) without practical biomass CHP growth restriction with proposed RHI policy assuming REN CHP designed and operated to match site heat and power loads under **low biomass price scenario with central fossil fuel and electricity price scenario**

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3,571.80	5,551.50	7,135.20	8,719.00
Food and drink	4,076.80	6,484.70	9,400.40	12,419.00
Textiles	6.2	56.7	97.1	137.5
Paper	6,421.20	7,972.90	9,214.20	10,455.60
Chemicals	17,775.70	21,697.30	24,834.60	27,971.90
Engineering	243	1,001.10	3,106.50	7,263.40
Other industry	459.8	1,729.60	4,991.60	11,052.70
Sub-total	32,554.5	44,493.8	58,779.6	78,019.1
Steel	1,640.50	1,739.90	1,739.90	1,739.90
Refineries	17,713.20	18,682.70	19,458.30	20,233.90
LNG	-	14,065.40	15,070.10	16,577.10
Minerals	645.7	1,271.20	1,271.20	1,271.20
NFM	22.3	20.8	20.8	20.8
DH	404.4	1,386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	58.8
Total Conventional CHP	**53,005.1**	**81,699.7**	**98,350.2**	**120,264.6**
Total Renewable CHP	**626.0**	**4,476.4**	**9,394.4**	**22,805.0**
Total CHP	**53,631.1**	**86,176.1**	**107,744.6**	**143,069.6**

Scenario 2R - Biomass CHP projection (CHP Mode Elec Capacity MWe) with practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **low biomass price scenario with central fossil fuel and electricity price scenario**

MW electrical capacity	Actual 2008	2013	2017	2020
Services	-	132.8	239.1	318.8
Food and drink	0	0.5	12.9	140.4
Textiles	-	11.4	20.5	27.3
Paper	3	74	130.8	173.4
Chemicals	34	107.7	271	541.3
Engineering	0	0.1	0.7	2.8
Other industry	0	0.1	0.7	2.9
Sub-total	37.0	326.6	675.7	1,206.9
Steel	-	-	-	-
Refineries	-	18.3	33	44
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	12.0	42.2	59.6	71.3
Total Renewable CHP	**49.0**	**387.1**	**768.3**	**1,322.2**

Scenario 2R - Projection of Conventional CHP (by sector) and Total Renewable CHP Capacity (Elec Capacity in CHP Mode MWe) with practical biomass CHP growth restriction with proposed RHI, REN CHP designed and operated to match site heat and power loads under **low biomass price scenario with central fossil fuel and electricity price scenario**

MW electrical capacity	Actual 2008	2013	2017	2020
Services	610.4	972.4	1,262.00	1,551.60
Food and drink	404.3	690	1,058.30	1,458.60
Textiles	1.1	32.5	57.6	82.7
Paper	553.5	687.3	794.3	901.3
Chemicals	1,788.50	2,189.00	2,509.50	2,829.90
Engineering	69.1	298	958.9	2,303.70
Other industry	57.3	218.8	638.6	1,426.30
Sub-total	3,484.2	5,088.0	7,279.2	10,554.1
Steel	66.6	70.7	70.7	70.7
Refineries	1,763.10	1,873.50	1,961.80	2,050.10
LNG	-	1,400.00	1,500.00	1,650.00
Minerals	35	69	69	69
NFM	11.3	10.5	10.5	10.5
DH	53.4	187.8	265.4	317.5
Domestic	6.3	10	13	15
Total Conventional CHP	**5,419.9**	**8,709.5**	**11,169.6**	**14,736.9**
Total Renewable CHP	**49.0**	**387.1**	**768.3**	**1,322.2**
Total CHP	**5,468.9**	**9,096.6**	**11,937.9**	**16,059.1**

Renewable and conventional CHP results by sector for the central biomass price scenario with high-high fossil fuel and electricity price scenario

Scenario 2R - Biomass CHP projection (CHP Heat Output GWh/Yr) with practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **central biomass price scenario with high-high fossil fuel and electricity price scenario**

GWh heat output	Actual 2008	2013	2017	2020
Services	-	774.4	1,393.90	1,858.60
Food and drink	4	61.3	544.2	2,799.20
Textiles	-	204.2	367.6	490.1
Paper	27	952.8	1,693.40	2,248.90
Chemicals	491	1484.2	3595.9	6,983.20
Engineering	0	0.7	22.8	299.5
Other industry	0	0.5	12.1	128.9
Sub-total	522.0	3,478.1	7,629.9	14,808.4
Steel	-	-	-	-
Refineries	-	120.3	216.6	288.8
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**3,955.0**	**8,350.4**	**15,699.9**

Scenario 2R - Conventional CHP projection by sector and total renewable (CHP Heat Output GWh/Yr) with practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **central biomass price scenario with high-high fossil fuel and electricity price scenario**

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3,571.80	5,788.40	7,561.80	9,335.10
Food and drink	4,076.80	6,960.30	10,677.60	14,718.30
Textiles	6.2	185.1	328.2	471.3
Paper	6,421.20	8,011.00	9,282.80	10,554.60
Chemicals	17,775.70	21,305.90	24,130.00	26,954.10
Engineering	243	1,112.30	3,755.40	9,353.50
Other industry	459.8	1,862.90	5,705.80	13,210.10
Sub-total	32,554.5	45,225.9	61,441.6	84,597.0
Steel	1,640.50	1,739.90	1,739.90	1,739.90
Refineries	17,713.20	18,824.70	19,713.90	20,603.10
LNG	-	14,065.40	15,070.10	16,577.10
Minerals	645.7	1,271.20	1,271.20	1,271.20
NFM	22.3	20.8	20.8	20.8
DH	404.4	1,386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	58.8
Total Conventional CHP	**53,005.1**	**82,573.8**	**101,267.8**	**127,211.7**
Total Renewable CHP	**626.0**	**3,955.0**	**8,350.4**	**15,699.9**
Total CHP	**53,631.1**	**86,528.8**	**109,618.2**	**142,911.6**

Case 2U - Biomass CHP projection (CHP Heat Output GWh/Yr) without practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **central biomass price scenario with high-high fossil fuel and electricity price scenario**

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	-	1,284.60	2,312.30	3,083.10
Food and drink	4	85.8	997.4	6,278.10
Textiles	-	690.7	1,243.20	1,657.70
Paper	27	952.8	1,693.40	2,248.90
Chemicals	491	1537.2	3830.3	7,596.60
Engineering	0	3.5	383.4	12,928.10
Other industry	0	0.6	16.9	201.3
Sub-total	522.0	4,555.2	10,476.9	33,993.8
Steel	-	-	-	-
Refineries	-	186.9	336.5	448.6
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**5,098.7**	**11,317.3**	**35,045.1**

Scenario 2U - Conventional CHP projection by sector and total renewable (CHP Heat Output GWh/Yr) without practical biomass CHP growth restriction with proposed RHI policy assuming REN CHP designed and operated to match site heat and power loads under **central biomass price scenario with high-high fossil fuel and electricity price scenario**

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3,571.80	5,481.20	7,008.70	8,536.30
Food and drink	4,076.80	6,034.60	8,258.80	10,450.00
Textiles	6.2	58.9	101.1	143.3
Paper	6,421.20	8,011.00	9,282.80	10,554.60
Chemicals	17,775.70	21,235.60	24,003.60	26,771.50
Engineering	243	997.5	3,086.80	7,201.80
Other industry	459.8	1,418.90	3,495.20	6,872.50
Sub-total	32,554.5	43,237.7	55,237.0	70,530.0
Steel	1,640.50	1,739.90	1,739.90	1,739.90
Refineries	17,713.20	18,685.00	19,462.40	20,239.80
LNG	-	14,065.40	15,070.10	16,577.10
Minerals	645.7	1,271.20	1,271.20	1,271.20
NFM	22.3	20.8	20.8	20.8
DH	404.4	1,386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	58.8
Total Conventional CHP	**53,005.1**	**80,445.9**	**94,811.7**	**112,781.4**
Total Renewable CHP	**626.0**	**5,098.7**	**11,317.3**	**35,045.1**
Total CHP	**53,631.1**	**85,544.6**	**106,129.0**	**147,826.5**

Scenario 2R - Biomass CHP projection (CHP Mode Elec Capacity MWe) with practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **central biomass price scenario with high-high fossil fuel and electricity price scenario**

MW electrical capacity	Actual 2008	2013	2017	2020
Services	-	143	257.4	343.2
Food and drink	0	0.6	15.3	176.1
Textiles	-	11.5	20.7	27.6
Paper	3	103.8	184.5	244.9
Chemicals	34	127.7	367.8	813.6
Engineering	0	0.3	4.4	33.4
Other industry	0	0.1	1.1	5.2
Sub-total	37.0	387.0	851.2	1,644.0
Steel	-	-	-	-
Refineries	-	18.3	33	44
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	12.0	42.2	59.6	71.3
Total Renewable CHP	**49.0**	**447.5**	**943.8**	**1,759.3**

Scenario 2R - Projection of Conventional CHP (by sector) and Total Renewable CHP Capacity (Elec Capacity in CHP Mode MWe) with practical biomass CHP growth restriction with proposed RHI, REN CHP designed and operated to match site heat and power loads under **central biomass price scenario with high-high fossil fuel and electricity price scenario**

MW electrical capacity	Actual 2008	2013	2017	2020
Services	610.4	989.2	1,292.30	1,595.40
Food and drink	404.3	690.2	1,058.80	1,459.50
Textiles	1.1	33.3	59	84.7
Paper	553.5	690.5	800.2	909.8
Chemicals	1,788.50	2,143.70	2,427.80	2,712.00
Engineering	69.1	316.4	1,068.40	2,661.00
Other industry	57.3	232.3	711.5	1,647.20
Sub-total	3,484.2	5,095.6	7,418.0	11,069.6
Steel	66.6	70.7	70.7	70.7
Refineries	1,763.10	1,873.70	1,962.20	2,050.70
LNG	-	1,400.00	1,500.00	1,650.00
Minerals	35	69	69	69
NFM	11.3	10.5	10.5	10.5
DH	53.4	187.8	265.4	317.5
Domestic	6.3	10	13	15
Total Conventional CHP	**5,419.9**	**8,717.3**	**11,308.8**	**15,253.0**
Total Renewable CHP	**49.0**	**447.5**	**943.8**	**1,759.3**
Total CHP	**5,468.9**	**9,164.8**	**12,252.6**	**17,012.3**

Renewable and conventional CHP results by sector for the central biomass price scenario with low fossil fuel and electricity price scenario

Scenario 2R - Biomass CHP projection (CHP Heat Output GWh/Yr) with practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **central biomass price scenario with low fossil fuel and electricity price scenario**

GWh heat output	Actual 2008	2013	2017	2020
Services	-	140.8	253.4	337.8
Food and drink	4	23.7	98.2	285.5
Textiles	-	40.7	73.3	97.7
Paper	27	27.5	28	28.3
Chemicals	491	500.1	507.5	513.1
Engineering	0	0	0	-
Other industry	0	0.1	1	4.5
Sub-total	522.0	732.9	961.4	1,266.9
Steel	-	-	-	-
Refineries	-	38.4	69.2	92.2
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**1,127.9**	**1,534.5**	**1,961.8**

Scenario 2R - Conventional CHP projection by sector and total renewable (CHP Heat Output GWh/Yr) with practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **central biomass price scenario with low fossil fuel and electricity price scenario**

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3,571.80	5,192.30	6,488.70	7,785.10
Food and drink	4,076.80	6,619.60	9,755.30	13,048.10
Textiles	6.2	181.8	322.4	462.9
Paper	6,421.20	7,430.70	8,238.30	9,046.00
Chemicals	17,775.70	23,214.50	27,565.50	31,916.50
Engineering	243	857.1	2,349.00	5,003.60
Other industry	459.8	1,453.60	3,650.70	7,283.10
Sub-total	32,554.5	44,949.6	58,369.9	74,545.3
Steel	1,640.50	1,739.90	1,739.90	1,739.90
Refineries	17,713.20	19,004.10	20,036.80	21,069.50
LNG	-	14,065.40	15,070.10	16,577.10
Minerals	645.7	1,271.20	1,271.20	1,271.20
NFM	22.3	20.8	20.8	20.8
DH	404.4	1,386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	58.8
Total Conventional CHP	**53,005.1**	**82,476.9**	**98,519.0**	**117,626.4**
Total Renewable CHP	**626.0**	**1,127.9**	**1,534.5**	**1,961.8**
Total CHP	**53,631.1**	**83,604.8**	**100,053.5**	**119,588.2**

Case 2U - Biomass CHP projection (CHP Heat Output GWh/Yr) without practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **central biomass price scenario with low fossil fuel and electricity price scenario**

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	-	189.1	340.4	453.8
Food and drink	4	31	159.4	544.7
Textiles	-	160.7	289.3	385.8
Paper	27	27.5	28	28.3
Chemicals	491	506.3	518.9	528.6
Engineering	0	0	0	-
Other industry	0	0.2	1.5	7.7
Sub-total	522.0	914.8	1,337.5	1,948.9
Steel	-	-	-	-
Refineries	-	62.2	112	149.4
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	104.0	356.6	503.9	602.7
Total Renewable CHP	**626.0**	**1,333.6**	**1,953.4**	**2,701.0**

Scenario 2U - Conventional CHP projection by sector and total renewable (CHP Heat Output GWh/Yr) without practical biomass CHP growth restriction with proposed RHI policy assuming REN CHP designed and operated to match site heat and power loads under **central biomass price scenario with low fossil fuel and electricity price scenario**

GWh/Yr heat output	Actual 2008	2013	2017	2020
Services	3,571.80	5,180.50	6,467.50	7,754.50
Food and drink	4,076.80	6,592.90	9,684.60	12,922.30
Textiles	6.2	155.5	275	394.4
Paper	6,421.20	7,430.70	8,238.30	9,046.00
Chemicals	17,775.70	23,210.40	27,558.10	31,905.80
Engineering	243	857.1	2,349.00	5,003.60
Other industry	459.8	1,453.40	3,649.70	7,280.40
Sub-total	32,554.5	44,880.5	58,222.2	74,307.0
Steel	1,640.50	1,739.90	1,739.90	1,739.90
Refineries	17,713.20	18,892.90	19,836.60	20,780.40
LNG	-	14,065.40	15,070.10	16,577.10
Minerals	645.7	1,271.20	1,271.20	1,271.20
NFM	22.3	20.8	20.8	20.8
DH	404.4	1,386.7	1,959.4	2,343.8
Domestic	24.5	39.2	50.9	58.8
Total Conventional CHP	**53,005.1**	**82,296.6**	**98,171.1**	**117,099.0**
Total Renewable CHP	**626.0**	**1,333.6**	**1,953.4**	**2,701.0**
Total CHP	**53,631.1**	**83,630.2**	**100,124.5**	**119,800.0**

Scenario 2R - Biomass CHP projection (CHP Mode Elec Capacity MWe) with practical biomass CHP growth restriction with proposed RHI policy assuming CHP designed and operated to match site heat and power loads under **central biomass price scenario with low fossil fuel and electricity price scenario**

MW electrical capacity	Actual 2008	2013	2017	2020
Services	-	98.4	177.1	236.2
Food and drink	0	0.2	1.8	9.8
Textiles	-	2.3	4.1	5.5
Paper	3	3.1	3.1	3.1
Chemicals	34	34.6	35.1	35.4
Engineering	0	0	0	-
Other industry	0	0	0.1	0.2
Sub-total	37.0	138.6	221.3	290.2
Steel	-	-	-	-
Refineries	-	5.9	10.5	14
LNG	-	-	-	-
Minerals	-	-	-	-
NFM	-	-	-	-
DH	12.0	42.2	59.6	71.3
Total Renewable CHP	**49.0**	**186.7**	**291.4**	**375.5**

Scenario 2R - Projection of Conventional CHP (by sector) and Total Renewable CHP Capacity (Elec Capacity in CHP Mode MWe) with practical biomass CHP growth restriction with proposed RHI, REN CHP designed and operated to match site heat and power loads under **central biomass price scenario with low fossil fuel and electricity price scenario**

MW electrical capacity	Actual 2008	2013	2017	2020
Services	610.4	887.3	1,108.90	1,330.50
Food and drink	404.3	656.4	967.4	1,293.90
Textiles	1.1	32.7	57.9	83.2
Paper	553.5	640.5	710.1	779.8
Chemicals	1,788.50	2,335.70	2,773.50	3,211.30
Engineering	69.1	243.8	668.3	1,423.50
Other industry	57.3	181.3	455.2	908.2
Sub-total	3,484.2	4,977.7	6,741.3	9,030.4
Steel	66.6	70.7	70.7	70.7
Refineries	1,763.10	1,891.60	1,994.40	2,097.20
LNG	-	1,400.00	1,500.00	1,650.00
Minerals	35	69	69	69
NFM	11.3	10.5	10.5	10.5
DH	53.4	187.8	265.4	317.5
Domestic	6.3	10	13	15
Total Conventional CHP	**5,419.9**	**8,617.3**	**10,664.3**	**13,260.3**
Total Renewable CHP	**49.0**	**186.7**	**291.4**	**375.5**
Total CHP	**5,468.9**	**8,804.0**	**10,955.7**	**13,635.8**