An Analysis of the Ofgem and Rival Scenarios Aimed at Secure and Sustainable Electricity Supplies for the United Kingdom

A paper from PROSYMA RESEARCH LTD[1]

Submitted in response to the Office of Gas and Electricity Markets consultation paper "Project Discovery – Energy Market Scenarios" dated 9th October 2009

by

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1. Introduction

1.1 This paper has been written in response to Office of Gas and Electricity Markets (Ofgem) Project Discovery Consultation paper of 9th October 2009. The Ofgem paper defined four scenarios for different combinations of high or low economic growth with high or low levels of “Green” stimulus.

1.2 In the background section of the consultation paper, Ofgem gives a cogent summary of the failure of market driven energy policies pursued by successive United Kingdom governments for past quarter of century. We concur and would add our view that the long term maintenance of secure energy supplies clearly falls within the remit of a national government. Strangely, it is only within the United Kingdom where this view attracts controversy.

1.3 This paper is concerned primarily with electrical generation and the supply of electrical power. However, the United Kingdom consumes relatively less electrical power and thus burns more fossil fuel directly than most other comparable economies. Consideration has been given to the reduction in carbon dioxide emissions that could be achieved by replacing existing direct use of fossil fuel with electrical power derived principally from non fossil fuel sources.

1.4 All four Ofgem scenarios, “Green Transmission”, “Green Stimulus”, “Dash for Energy” and “Slow Growth”, were tested against our *Gridman* model to assess the capital cost, wholesale price, availability of power to meet the winter demand and the desire to reduce levels of carbon dioxide emission.

1.5 The National Grid “Gone Green” scenario and two alternative proposed scenarios, “Slow Nuclear” and “Fast Nuclear” were modelled, assessed also and the results and relative merits of all seven scenarios were compared.

1.6 The Ofgem paper models its proposed strategies only up to the year 2025 and, consequently, the long term implications for energy security and for the targets for the reduction of CO_2 emissions by the year 2050 have not been fully addressed. Such a policy also tends to minimise the impact of a new civil nuclear programme which cannot begin to have an impact until 2020. Consequently, for this study, the modelling of the two nuclear based scenarios was extended to the year 2050.

2. Electrical Generation Scenarios

2.1 The details of the proposed mix electrical power generation sources for the four Ofgem scenarios are clearly defined in Project Discovery Consultation Paper [1] and the National Grid "Gone Green" scenario is defined in detail in their "Gone Green" briefing note [2] and consultation paper of June 2009 [3].

2.2 Three of the Ofgem scenarios assume a near flat demand for annual electrical power but, in the case of "Dash for Energy" a slow increase is assumed, accompanied by a similar rise in peak demand. By contrast, the National Grid "Going Green" scenario assumes a rising demand for power but with a flat winter peak; this gives customers, both domestic and industrial, an incentive to stagger their periods of maximum demand throughout the day with a consequently flatter daily demand curve and a more efficient use of both generators and the grid.

2.3 Neither the Ofgem scenarios nor the National Grid "Gone Green" concept envisage more than a modest new civil nuclear programme. The authors consider that such a programme should be given serious consideration for the following reasons.

2.3.1 Wind turbines are effective in reducing the need to burn fossil fuel but provide power intermittently so, when the wind does not blow, back-up power is required. There are times when most of the UK is covered by a winter high pressure weather pattern and little wind blows, often for extended periods. The National Grid consultation paper [3] reported that the power from all UK wind farms fell to only 6% of the rated output at peak demand on 5 January 2009; two days later, the output fell to only about 1% of the total rated value, although fortunately not during peak demand. These assessments were substantiated by a recent assessment by Poyry [4] which confirmed that, for Britain, there are likely to be occasions, possibly lasting up to 3 days during periods of winter peak demand, when the total output from wind turbines may fall to below 5% of maximum rated capacity. In addition, a massive expansion of the national electricity grid network would be required, at a cost of many billions of pounds, to collect power from the large number of dispersed relatively low capacity power sources.

2.3.2 Three of the Ofgem scenarios assume some level of new coal fired plant fitted with carbon capture and storage (CCS). The authors believe that there are serious issues concerning the feasibility of CCS on the required scale. For example, the annual exhaust from the projected 1.6 GW Kingsnorth power station (working at maximum capacity) would consist of approximately 27 million tonnes of nitrogen and about 1.4 million tonnes of steam together with 8.5 million tonnes of CO_2 to be separated, probably by absorption in ethanolamine, in a process which would require large quantities of energy. In a liquid state, the resulting CO_2 would occupy a volume of about 7.5 million cubic metres at a pressure of 60 bar and at a temperature of 22 ^oC. The annual output would fill around 10,000 km of one metre diameter 10 mm mild steel pipe of total mass 2.5 million tons. These are literally incredible figures cannot be circumvented by even more improbable concepts of inserting liquid CO_2 into former oil bearing sedimentary rock.

2.3.3 Compared with our European neighbours, the consumption of electricity per capita in the UK is relatively low at around 6,400 kWh but the CO_2 per head of population is relatively high at around 11 tonnes pa. The figures for France and Germany are approximately 7,900 kWh / 6.7 tonnes CO_2 and 6,850 kWh / 9.7 tonnes CO_2respectively. This would indicate that, by making better use of controlled and directed electrical power, CO_2 emissions from the UK could be very significantly reduced. In France the high consumption of electrical power and low level of CO_2 emissions reflects the widespread use of nuclear power.

2.3.4 The EU Large Combustion Plant Directive requires some 8 MW of generation plant in the UK to be taken out of service by 2015. Simple calculations indicate that such a course of action will inevitably lead to power cuts in the UK from around 2015.

2.4 Consequently, two alternative scenarios were devised to be tested, modelled and compared with those devised by National Grid and Ofgem. These scenarios, named “Slow Nuclear” and “Fast Nuclear”, suppose expanded civil nuclear programmes. The principles behind these nuclear scenarios are given below.

2.4.1 Since even the fastest nuclear programme will have little impact upon the available power until 2020, derogation from the EU Large Combustion Plant Directive will be required to keep the obsolete coal fired plant open for until approximately 2025. The environmental impact of this the can be kept to a minimum by arranging for these old stations to be very low in the merit order and thus employed only for short periods in winter at times of peak demand.

2.4.2 It assumed, for both of the nuclear scenarios, that further development of renewable energy supplies is halted from 2015 and that, during this time, an increase in gas fired generating capacity is undertaken sufficient to meet the peak load demands together with the replacement of some 8 GW of coal fired plant of modern efficient supercritical design but not fitted with carbon capture and storage; ultimately, these would be the only remaining coal fired power stations in the UK. If necessary, the coal they require could be provided from indigenous supplies.

2.4.3 The Slow Nuclear Scenario assumes a relatively modest new civil nuclear power plant programme with the first new station connected to the grid in the year 2020 and future stations available at the rate of one reactor a year to 2025, rising to two per year during the following decade before falling back to about one a year up to 2050. The reactor types are assumed to be a mix of the Areva 1.6 GW(e) EPWR and Westinghouse 1.1 GW(e) AP 1000 designs.

2.4.5 The Fast Nuclear Scenario assumes a more aggressive civil nuclear programme to meet an increased demand for electrical power to displace other sources of energy. The first rector comes on line in 2020 but, thereafter the rate of build increases to two stations per year until the early 2040s; provision is made for a revived fast breeder programme with the first prototype available in 2025 and the first production fast breeder plant come into service in the late 2030s, building up to a rate of one per year in the mid 2040s. The nation’s power generating capacity is expanded to generate some 700 TWh by 2050 with an ability to handle a peak demand of 88 GW. In this way, a greatly expanded proportion of the nation’s total energy would come from electrical power with consequential reductions in the emission of CO_2.

2.5 The generation capacities for seven scenarios described above are compared in Table 1 for the year 2025 and reproduced in more detail in Tables 2A to 2G together with the Slow and Fast Nuclear Scenarios. The requirements for each in terms of peak winter load and annual generation are shown in Table 3.

3. Modelling Assumptions and Techniques

3.1 The model "*Gridman*" was employed assess the capital cost, maximum winter peak load & capacity margins, generator loadings to deliver the annual power requirements, mean wholesale costs and CO_2 emissions for each of the seven scenarios. "Gridman" is a relatively simple, labour intensive but easily auditable Excel based tool which builds upon the expertise the authors have acquired during many years of experience in the power generation and process industries.

3.2 Table 4 sets out the assumptions made for the characterisation of each generator type, in terms of capital cost, generation cost and annual escalation of this, CO_2 emissions, load factor and winter availability. In addition, provision was made for the costing of a greatly expanded grid that would be required for the "Green" scenarios.

3.3 To assess the ability to achieve the required peak load it is necessary to take into account the requirement for a Short Term Operating Requirement (STORR). The need for a STORR is explained in some detail in the National Grid consultation paper [3] and it is essential to provide cover for the sudden loss of generation capacity for whatever reason. The calculation of the STORR made by National Grid is based on complex statistical data and thus variable, depending upon the circumstances. Such a calculation is beyond the scope of *Gridman* so the value has been set at a fixed value of 4GW for all scenarios. The STORR currently costs National Grid some £115m pa and this figure has input into Gridman, escalating at 2.5% pa. As far as we can ascertain, the Ofgem consultation paper [1] omitted the need for the STORR and thus overestimates the maximum available winter load for all four of its scenarios by some 4GW.

3.4 As explained in Paragraph 2.3.1, there will be times when the power available from all the wind turbines in the country falls to as low as 5% of their combined rated capacity. Thus, it has been assumed that only 5% of rated power from wind turbines, wave and tidal generators may be available to meet the winter peak demand.

3.5 In the modelling of scenarios, a merit order has been assumed which minimises the emissions of CO_2 rather than minimises generating costs, as has traditionally been the case. The merit order modelled thus gives renewables and nuclear power the highest priority, followed by closed circuit gas turbines, then coal fired plant and the interconnectors with open circuit gas turbines and oil fired plant at the lowest priority.

3.6 The modelling of generation costs and CO_2 emissions by "Gridman" is relatively crude and covers only the direct costs of the generating companies and National. No allowance has been made for additional EU or government imposed taxes and penalties such as carbon trading or penalties that might be imposed for Renewable Obligation Certification requirements.

3.7 The National Grid "Gone Green" Scenario and the four scenarios proposed by Ofgem run only until 2025 so cannot be modelled beyond that date. The "Slow Nuclear" and "Fast Nuclear" scenarios and have been modelled up to 2050.

4. Results of Modelling and Analysis

4.1 The assessments of capital costs for each scenario are given in the final columns in Tables 2A to 2G and a graphical representation of the cumulative costs is given in Figure 1.

4.2 The Gone Green, Green Transition and Green Stimulus all require investments of in the region of £100bn to £110bn by the year 2025 or about £7bn per year. The Dash for Energy strategy would require annual investment in the region of £4.5bn to £5bn, the Slow Growth just over £3.5bn. The Slow and Fast Nuclear strategies would require annual investments of about £3.2bn and £4bn respectively, with investment continuing at approximately these rates to 2050.

4.3 The targets for annual generation and peak supply set by the originators for each scenario are shown in Figures 2A and 2B. The peak supply target for the Slow Nuclear scenario follows that set by National Grid for Gone Green whilst that for the Fast Nuclear Scenario is the same as for the Ofgem Dash for Growth.

4.4 In all cases the targets for annual generation are achieved. Figure 3A shows the maximum achievable winter peak load for each case whilst Figure 3B shows the capacity margin for each. The latter indicates clearly that all three of the “Green” scenarios will fail to meet their required capacity long before 2025 and, in the case of the two Ofgem “Green” scenarios, there would be winter power cuts from 2015, if not before. The authors believe that both National Grid and Ofgem have failed fully to take into account the need for back up generation when the winter conditions are such that the output from the entire fleet of wind farms may fall as low as 5% of their total rated value. Ofgem have also apparently failed the account for the need for a STORR. The trends in these figures indicate that none of the “Green” scenarios will be viable in the long term.

4.5 All four Ofgem scenarios show peak power shortfalls from around 2015 because, in all cases, it has been assumed that EU’s large Combustion Plant Directive has been implemented. Both the nuclear scenarios assume that derogation has been achieved thus securing security of supply for the immediate future.

4.6 The annual generation by each different type of supply for each of the scenarios is shown in Figures 4A to 4G. It can be seen that, in all cases, there remains a significant need for natural gas fuel, even for each of the three “Green” scenarios. The reason is that the wind farms can provide only an average of some 30% of their rated value over a complete year and require nearly 100% back up power from fossil fuel generators. The two “nuclear” scenarios lessen the reliance upon natural gas from 2025 onwards. This dependence on natural gas could be reduced somewhat by placing the remaining coal fired plant higher in the merit order and reduced further by building coal fired plant. However, since coal fired powered plant is inherently less efficient than gas, there would be an increase in CO_2 emissions.

4.7 Figure 5A shows the total CO_2 emitted for each scenario, assuming the generation usages given in Figures 4A to 4G. Figure 5B shows the CO_2 emitted per TWh of electricity generated for each scenario. All three “Green” scenarios initially achieve a large reduction in emissions because the virtually emission free wind farms displace power that would otherwise have been generated by fossil fired plant. However, as has been demonstrated in the foregoing, these “Green” scenarios lead to severe winter power shortages well before the year 2025. The Dash for Energy and the Slow Growth scenarios achieve some useful reductions in emissions in the early years but the curve is virtually flat by 2025 after which the ability to replace fossil fired generation with renewables is limited. The nuclear scenarios show an initial increase in CO_2 emissions as the existing nuclear plant is taken out of service and because the older coal fired plant is kept, assuming derogation for the Large Combustion Plant Directive.

4.8 In the long term, both the nuclear scenarios show significant reductions in emissions as the new nuclear plant displaces the fossil fired capacity. By the year 2050, the Slow Nuclear case indicates emissions of 0.22 million tonnes CO_2 per TWh, which is lower than that achieved by with any of the non-nuclear scenarios. The Fast Nuclear scenario results in CO_2 emissions of only 0.14 million tonnes per generated TWh.

4.9 The CO_2 emitted per TWh for the Fast Nuclear scenario is less than that from gas fired space heating or process plant (about 0.25 million tonnes per TWh, assuming 80% efficiency) and very much less than that from vehicles powered with internal combustion engines (about 0.75 million tonnes CO_2 per TWh of useful power). Thus, by employinmg electrical energy instead of gas and petroleum fuel, it would be possible to reduce, very significantly, the Uk's emissions of carbon dioxide.

4.10 Current total emissions from the UK are in the region of 550 – 600 million tonnes of CO_2. Of this, some 160 comes from electrical generation and, for the same total power generated and employed, this could be reduced by 60% to about 65 million tonnes. The additional electrical power available could displace fossil fuels; assuming 75% were to displace space heating and process plant and 25% to displace vehicle fuel, the additional emissions saved would be about 25 and 50 million tonnes respectively, leading to a total reduction in emissions of about 170 million tonnes or around 35%. To this must be added the further efficiency gains that can be achieved for better controlled and directed electrical power and other energy saving techniques. Thus the target of a 50% reduction from 1990 levels seems achievable even though the 80% target lacks credibility.

5. Security of Energy Supplies

5.1 The security of supplies off fossil fuels has been addressed by Ofgem in the consultation paper. The authors have no particular expertise in this area and further consideration of this matter is outside the scope of this study.

5.2 Two scenarios based on expanded programmes of civil nuclear power have been considered in this study. The opponents of nuclear power sometimes suggest that supplies of Uranium ore are as likely to be interrupted as supplies of oil or natural gas. The authors believe that, for the reasons set out below, supplies of nuclear fuel are likely to be secure for foreseeable future.

5.3 Uranium ore is found in various countries but the principal producers are Canada, Australia and Kazakhstan, each of which supplies about 20% of the total world output, and Namibia, which supplies about 10%. According to the IAEA [5], in 2005, the total identified world stocks of uranium ore were 4.7 million tonnes and the annual demand was about 55,000 tonnes. The current world installed nuclear capacity is 370 GW(e) and this is expected to rise to between 450GWe and 530GWe by 2025, leading to an increased in annual world demand to somewhere between 80,000 and

100,000 tonnes. The identified reserves in Australia alone have since been estimated as 2 million tonnes [6].

5.4 The spot price of uranium ore increased from $40/Kg(u) to $200/Kg(u) between 2000 and 2004 but has since fallen back to about $165Kg(u). The increased demand for uranium ore is expected to stimulate prospecting and supply and the total easily available world supplies of ore available for mining at current prices are thought to exceed 35 million tonnes [5]. Consequently, we are not likely to "run out" of uranium ore for a further two or three centuries.

5.5 Currently only a small quantity of nuclear fuel is recycled and the foregoing assumes most uranium ore is used in a nuclear reactor only once. Two or three times as much energy could be extracted from each tonne of ore by recycling and reuse in a PWR type of reactor. Use in fast breeder reactor could increase the energy extracted by a factor around 50. Recycling and reuse has the added advantage of greatly reducing the high active waste from fuel.

5.6 Neither of the two candidate pressurised water reactor designs (Areva's EPWR and Westinghouse's AP1000) are of British origin but British industry retains much expertise and capability in the nuclear field residing in such companies as Rolls Royce (which is responsible for UK submarine nuclear propulsion plant), Babcock international, Amec and Sheffield Forgemasters whilst Euenco and BNFL have a dominant role in the nuclear fuel supply sector. These companies and others would be well placed to benefit from a revived UK civil nuclear programme which, if properly managed, could stimulate a much needed revival of British engineering expertise.

5.7 Using uranium ore only once in a reactor gives world uranium supplies sufficient for about 200 years, recycling through a conventional PWR would extend this to 500 years and use in a breeder reactor would extent this to several thousands of years; extraction from seawater would give a virtually infinite resource. For the present, and in contrast to oil and natural gas, about half the world's supplies of uranium ore are mined in friendly stable democracies.

6. Responses Questions from the Ofgem Consultation Paper

6.1 The question posed by Ofgem are considered here and answered in the light of the content contained in this paper

6.2 Questions in Chapter 2, Approach and Assumptions

9.2.1 Q1: *Please provide comments on our approach of using scenarios and stress tests to explore future uncertainty, and as a basis for evaluating policy responses.* A1: We believe that the Ofgem approach is fundamentally sound but that there have been some shortcomings in its implementation; these are described later.

6.2.2 Q2: *Are there other techniques for analysing uncertainty that we should consider?* A2: We believe that the Ofgem approach to electrical energy security needs to take better account of the intermittency of electricity supply from wind turbines and we have outlined our approach in this paper.

6.2.3 Q3: *Are there other techniques for analysing uncertainty that we should consider?* A3: We believe that Ofgem has omitted the requirement for the Short Term Operating Requirement (STORR) required by the operators of National Grid to assure the maintenance of electrical supplies during times of peak demand.

6.2.4 Q4: *Do you agree with our key scenario drivers and choice of scenarios?* A4: We believe that Ofgem should have considered the long term (post 2025) implications of its proposed scenarios and scenarios involving a major new civil nuclear programme should have been included. For this reason, we have proposed the Slow Nuclear and Fast Nuclear scenarios.

6.2.5 Q5: *Do you believe our scenarios sufficiently cover the range of uncertainty facing the market, and hence cover the areas where future policy responses may be required?* A5: We believe that the issues surrounding nuclear power should have been considered in more detail and we have attempted to address these in this paper.

6.2.6 Q6: *Do you have any specific comments on scenario assumptions, and their internal consistency?* A6: We consider that the assumptions concerning wind variability, and in particular, the possibility that, during periods of high winter demand the supply available from the entire UK wind turbine fleet may fall to as low as 5% of the rated value, has not been adequately taken into account .

6.2.7 Q7: *Do you agree with our methodology for modelling gas and electricity supply/demand balances?* A7: We believe that Ofgem has not fully considered the possibility that, by replacing largely gas fuel used for space heating and process plant with electrical power, the total national emissions of carbon dioxide could be very significantly reduced.

6.2.8 Q8: *Do you agree that LNG is the likely medium-long term source of "swing gas" for the European market?* A8: The question is outside the scope of our study.

6.3 Questions in Chapter 3, Scenario Analysis Approach and Assumptions

6.3.1 Q1: *Do you have any observations or comments on the scenario results?* A1: As previously explained, the authors of this report believe that the Ofgem study have underestimated the effects of wind variability on the ability of to meat the peak load demand and also neglected to take into account the need for National Grid to maintain a STORR of about 4 MW to allow the supplies to recover from a sudden loss of supply.

6.3.2 Q2: *Do you agree with our assessment of what the key messages of the scenario analysis are?* A2: We believe that Ofgem has omitted two key messages. The first is that, if the UK does not seek derogation from the EU’s Large Combustion Plant Directive then winter power cuts are inevitable from 2015. The second is that electrical energy supply strategies based largely on wind power will inevitably lead to unreliable power unless there is some 90% to 95% back up supplies from fossil fuel generators and, for this reason, wind derived electrical energy has only limited potential to reduce carbon dioxide emissions.

6.3.3 Q3: *Are there other issues relating to secure and sustainable energy supplies that our scenarios are not showing?* A3: As previously explained, the possibility of a large new civil nuclear programme should be considered in detail; we have attempted to address this in our study. There is also the issue of carbon capture and storage for coal fired plant. In this study we have explained why we doubt that such technology is feasible; even if it is, on Ofgem's own figures, the capital cost of new coal fire plant is similar to that of new nuclear plant but with very much higher fuel costs.

6.3.4 Q4: *To what extent do you believe that innovations on the demand side could increase the scope for voluntary demand side response in the future?* A4: we believe that there is tremendous scope for displacing high carbon dioxide emitting process plant, space heating and also vehicle power sources with more efficient and inherently cleaner electrical power. This already occurs, to an extent, in France and if the UK could emulate France in this matter, particularly with a large nuclear power programme, we would be well on our way to reducing our national emissions of CO_2 by 50%.

6.4 Questions in Chapter 4, Stress Tests.

6.4.1 The authors of this study believe that their criticisms of the stress testing techniques employed by Ofgem have been identified in the foregoing. The principal criticisms concern inadequate consideration of wind variability and requirement of the National Grid to maintain a Short Term Operating Requirement.

7. Conclusions

7.1 It has been established that the Ofgem "Green Stimulus" and "Green Transition" scenarios will be difficult if not impossible to achieve as will National Grid's "Gone Green" scenario. If implemented, these would pose significant risks to the nation's supply of electrical energy during the winter peak period of December to March and the cost of electrical generation would be likely to rise by well over 50% by the year 2025 at constant prices.

7.2 In addition to the above, there will almost inevitably be winter power cuts if the EU's Large Combustions Plant Directive is implemented in the UK. It is essential that steps to secure derogation from this are put in hand in the near future. Since the plant thus preserved would be near the bottom of the merit order and only used only at times of peak demand, the additional pollution released would be minimal.

7.3 A major new civil nuclear programme would cost very much less than any of the "Green" strategies proposed, would go far in securing the nation's energy supplies and would offer the possibility of significant reductions in UK's emissions of carbon dioxide both in the generation of electrical power and by replacing oil, gas and petroleum energy sources in the process industries, for space heating and for transport.

8 References

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Table 1: Comparison of Generation Sources (GW) at 2025								
Generating Source	Current (2010)	Gone Green	Green Transition	Green Stimulus	Dash for Energy	Slow Growth	Slow Nuclear	Fast Nuclear
On Shore Wind	2.0	18.1	16.9	16.1	9.0	8.2	5.0	5.0
Off Shore Wind	1.2	16.1	16.9	16.1	9.0	8.2	5.0	5.0
Wave & Tidal	0.0	2.4	1.2	1.1	0.9	0.7	0.0	0.0
Biomass	0.1	1.1	2.0	1.9	1.1	1.0	0.8	0.8
Open Circuit Gas Turbine	0.8	0.2	0.2	0.2	0.2	0.2	1.5	1.5
CC Gas Turbine (inc CHP)	29.7	31.3	31.0	31.0	58.6	52.2	35.0	40.0
Coal	28.4	13.9	18.4	15.5	13.2	11.2	21.0	28.0
Hydro power	1.1	1.1	1.4	1.4	1.4	1.4	1.1	1.1
Pumped Storage	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
Oil	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nuclear	9.4	9.7	7.6	7.6	4.4	2.8	8.2	10.9
Interconnectors	2.0	4.2	3.5	3.5	2.5	2.5	2.5	2.5
Total	80.8	100.8	101.8	97.1	103.0	91.1	82.8	97.5

Table 2A: Generator Mix for "Gone Green" Scenario to 2025

Generating Source	2010	2015	2020	2025	New Plant capital cost (£bn)
On Shore Wind	2.0	6.2	15.6	18.1	19.3
Off Shore Wind	1.2	5.1	13.8	16.1	41.7
Wave & Tidal	0.0	0.0	1.4	2.4	9.6
Biomass	0.1	0.8	0.8	1.1	2.5
Open Circuit Gas Turbine	0.8	0.4	0.3	0.2	0.0
CC Gas Turbine (inc CHP)	29.7	34.2	34.6	31.3	2.9
Coal *	28.4	23.1	19.8	13.9	5.8
Hydro power	1.1	1.1	1.1	1.1	0.0
Pumped Storage	2.7	2.7	2.7	2.7	0.0
Oil	3.4	0.0	0.0	0.0	0.0
Nuclear	9.4	9.4	6.9	9.7	20.2
Interconnectors	2.0	3.7	4.2	4.2	1.1
Grid	-	-	-	-	7.0
Total (GW)	80.8	86.7	101.2	100.8	110.1

*Note: 1.6 GW of supercritical coal plant (without CCS?) becomes available in each of 2015, 2020 and 2025.

Table 2B: Generator Mix for "Green Transition " Scenario to 2025					
Generating Source	2010	2015	2020	2025	New Plant capital cost (£bn)
On Shore Wind	2.0	6.7	14.3	16.9	17.9
Off Shore Wind	1.2	6.7	14.3	16.9	44.0
Wave & Tidal	0.0	0.2	0.6	1.2	4.8
Biomass	0.1	0.8	1.3	2.0	4.8
Open Circuit Gas Turbine	0.8	0.4	0.3	0.2	0.0
CC Gas Turbine (inc CHP)	29.7	33.0	31.5	31.0	2.0
Coal *	28.4	21.7	21.8	18.4	12.3
Hydro power	1.1	1.1	1.3	1.4	1.2
Pumped Storage	2.7	2.7	2.7	2.7	0.0
Oil	3.4	0.0	0.0	0.0	0.0
Nuclear	9.4	9.4	9.3	7.6	12.8
Interconnectors	2.0	2.5	3.5	3.5	0.8
Grid	-	-	-	-	7.0
Total	80.8	85.2	100.9	101.8	107.4
*Note: 4 GW of supercritical coal plant with CCS becomes available in 2020 and a further 3.2 GW by 2025.					

Table 2C: Generator Mix for "Green Stimulus" Scenario to 2025					
Generating Source	2010	2015	2020	2025	New Plant capital cost (£bn)
On Shore Wind	2.0	6.4	13.6	16.1	16.9
Off Shore Wind	1.2	6.4	13.6	16.1	41.7
Wave & Tidal	0.0	0.2	0.5	1.1	4.4
Biomass	0.1	0.8	0.8	1.9	4.5
Open Circuit Gas Turbine	0.8	0.4	0.3	0.2	0.0
CC Gas Turbine (inc CHP)	29.7	33.4	31.5	31.0	2.2
Coal *	28.4	22.2	17.0	15.5	13.2
Hydro power	1.1	1.2	1.3	1.4	1.2
Pumped Storage	2.7	2.7	2.7	2.7	0.0
Oil	3.4	0.0	0.0	0.0	0.0
Nuclear	9.4	9.4	9.3	7.6	12.8
Interconnectors	2.0	2.5	3.5	3.5	0.8
Grid	-	-	-	-	7.0
Total	80.8	85.6	94.1	97.1	104.7

*Note: 4.4 GW of supercritical coal plant with CCS becomes available in 2020 and a further 3.2 GW by 2025.

Table 2D: Generator Mix for "Dash for Energy" Scenario to 2025					
Generating Source	2010	2015	2020	2025	New Plant capital cost (£bn)
On Shore Wind	2.0	4.4	7.1	9.0	8.4
Off Shore Wind	1.2	4.4	7.1	9.0	21.8
Wave & Tidal	0.0	0.1	0.5	0.9	3.6
Biomass	0.1	0.3	0.7	1.1	2.5
Open Circuit Gas Turbine	0.8	0.4	0.3	0.2	0.0
CC Gas Turbine (inc CHP)	29.7	42.8	48.7	58.6	17.3
Coal *	28.4	21.4	20.5	13.2	7.9
Hydro power	1.1	1.2	1.3	1.4	1.2
Pumped Storage	2.7	2.7	2.7	2.7	0.0
Oil	3.4	0.0	0.0	0.0	0.0
Nuclear	9.4	9.4	3.7	4.4	6.4
Interconnectors	2.0	2.5	2.5	2.5	0.3
Grid	-	-	-	-	3.5
Total	80.8	89.6	95.1	103.0	73.0
*Note: 0.4 GW of supercritical coal plant with CCS becomes available in 2020 and a further 3.2 GW by 2025.					

Table 2E: Generator Mix for "Slow Growth" Scenario to 2025					
Generating Source	2010	2015	2020	2025	New Plant capital cost (£bn)
On Shore Wind	2.0	4.0	6.5	8.2	7.4
Off Shore Wind	1.2	4.0	6.5	8.2	19.6
Wave & Tidal	0.0	0.1	0.4	0.7	2.8
Biomass	0.1	0.3	0.7	1.0	2.3
Open Circuit Gas Turbine	0.8	0.4	0.3	0.2	0.0
CC Gas Turbine (inc CHP)	29.7	33.0	39.5	52.2	13.5
Coal *	28.4	21.4	20.2	11.2	0.0
Hydro power	1.1	1.2	1.3	1.4	1.2
Pumped Storage	2.7	2.7	2.7	2.7	0.0
Oil	3.4	0.0	0.0	0.0	0.0
Nuclear	9.4	9.4	3.7	2.8	3.2
Interconnectors	2.0	2.5	2.5	2.5	0.3
Grid	-				3.5
Total	80.8	79.0	84.3	91.1	53.7
*Note: No new supercritical coal plant and none with CCS.					

Table 2F: Generator Mix for “Slow Nuclear” Scenario to 2050											
Generating Source	2010	2015	2020	2025	2030	2035	2040	2045	2050	New Plant capital cost to 2025 (£Bn)	New Plant capital cost to 2050 (£Bn)
On Shore Wind	2.0	4.4	5.0	5.0	5.0	5.0	5.0	5.0	5.0	3.6	3.6
Off Shore Wind	1.2	4.4	5.0	5.0	5.0	5.0	5.0	5.0	5.0	10.6	10.6
Wave & Tidal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biomass	0.1	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.8	1.8
OCGT	0.8	0.8	1.0	1.5	1.5	1.5	1.5	1.5	1.5	0.0	0.0
CCG T (inc CHP)	29.7	34.0	36.0	35.0	33.0	30.0	27.0	25.0	23.0	3.8	3.8
Coal *	28.4	24.0	22.0	21.0	12.0	10.0	8.0	8.0	8.0	9.6	9.6
Hydro power	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.0	0.0
Pumped Storage	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.0	0.0
Oil	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nuclear	9.4	9.4	7.4	8.2	21.7	28.7	35.6	39.4	43.2	15.5	94.8
Interconnectors	2.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0.3	0.3
Grid	-	-	-	-	-	-	-	-	-	2.5	3.8
Total	80.8	84.1	83.5	82.8	85.3	87.3	89.2	91.0	92.8	47.6	128.2
*Note: First new supercritical 1.6 GW coal plan available by 2015, two further plants by 2020 and tow more by 2025; none fitted with CCS											

Table 2G: Generator Mix for "Fast Nuclear" Scenario to 2050											
Generating Source	2010	2015	2020	2025	2030	2035	2040	2045	2050	New Plant capital cost to 2025 (£Bn)	New Plant capital cost to 2050 (£Bn)
On Shore Wind	2.0	2.0	4.4	5.0	5.0	5.0	5.0	5.0	5.0	3.6	3.6
Off Shore Wind	1.2	1.2	4.4	5.0	5.0	5.0	5.0	5.0	5.0	10.6	10.6
Wave & Tidal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biomass	0.1	0.1	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.8	1.8
OCGT	0.8	0.8	0.8	1.0	1.5	1.8	2.0	2.0	2.0	0.0	0.0
CCG T (inc CHP)	29.7	29.7	36.0	40.0	40.0	35.0	35.0	29.0	26.0	6.2	6.2
Coal *	28.4	28.4	28.0	28.0	28.0	23.0	13.0	8.0	8.0	9.6	9.6
Hydro power	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.0	0.0
Pumped Storage	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.0	0.0
Oil	3.4	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nuclear *	9.4	9.4	9.4	7.4	10.9	24.4	39.4	54.7	62.2	24.4	161.7
Interconnectors	2.0	2.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0.3	0.3
Grid	-	-	-	-	-	-	-	-	-	2.5	3.8
Total	80.8	80.8	90.1	93.5	97.5	101.3	106.5	110.8	115.3	58.9	197.4
*Note: New Coal plant as for Slow Nuclear Scenario. Nuclear plant is PWR design until 2040; after that the Fast Breeder Reactor starts to enter service.											

Table 3: Winter Peak Demand and Annual Generation Requirements for each Scenario										
Scenario		2010	2015	2020	2025	2030	2035	2040	2045	2050
Gone Green	Winter peak (GW)	59.4	60.4	59.6	58.7	-	-	-	-	-
	Annual Demand (TWh)	360	380	400	420	-	-	-	-	-
Green Transition	Winter peak (GW)	61.2	60.1	62.7	64.5	-	-	--	-	-
	Annual Demand (TWh)	344	337	357	372	-	-	-	-	-
Green Stimulus	Winter peak (GW)	60.3	56.9	59.3	61	-	-	-	-	-
	Annual Demand (TWh)	340	322	342	355	-	-	-	-	-
Dash for Energy	Winter peak (GW)	62.2	65.7	68.2	71.1	-	-	-	-	-
	Annual Demand (TWh)	353	370	385	401	-	-	-	-	-
Slow Growth	Winter peak (GW)	61.3	60.1	63	65.3	-	-	-	-	-
	Annual Demand (TWh)	348	344	355	368	-	-	-	-	-
Slow Nuclear	Winter peak (GW)	59.4	60.4	59.6	58.7	59.9	61.1	62.3	63.5	64.8
	Annual Demand (TWh)	359	384	408	436	457	480	504	529	556
Fast Nuclear	Winter peak (GW)	62.2	65.7	68.2	71.1	73.9	76.9	80.0	83.2	86.5
	Annual Demand (TWh)	359	384	408	449	494	543	597	657	700

Table 4: Assumptions for Capital Cost, Generation Cost and CO_2 Emissions for Each Generator Type						
Generating Source	Capital Cost per GW (£m at 2010 base)	Mean Cost of Power Generated (p/kWh 2010 base)	Annual Escalation of Generation costs (% for 2010 base)	CO2 Emissions (Mt TWh)	Maximum Annual Load Factor	Winter Generator Availability
On Shore Wind	1,200	4.50	0.0%	0.01	30%	95%
Off Shore Wind	2,800	8.00	1.0%	0.01	35%	85%
Wave & Tidal	4,000	8.00	1.0%	0.01	35%	85%
Biomass	2,500	4.00	5.0%	0.01	85%	95%
Open Circuit Gas Turbine	500	3.50	5.0%	0.704	97%	98%
CC Gas Turbine (inc CHP)	600	3.00	5.0%	0.369	95%	95%
Coal (existing)	N/A	3.75	2.5%	0.961	90%	95%
Coal (supercritical)	1,200	3.75	2.5%	0.747	90%	95%
Coal (superficial with CCS)	2.200	4.00	2.5%	0.01	90%	95%
Hydro power	4,000	2.80	0.0%	0.00	63%	95%
Pumped Storage	N/A	Fixed at £300m pa	0.0%	0.00	N/A	95%
Oil	1,000	4.00	5.0%	0.704	100%	95%
Nuclear (EPWR & AP1000)	2,000	4.00	1.0%	0.037	95%	84%
Nuclear (FBR)	2,500	4.00	1.0%	0.037	95%	84%
Interconnectors	500	4.00	2.5%	0.045	100%	100%

Figure 1: Cumulative Investment Costs for Each Scenario

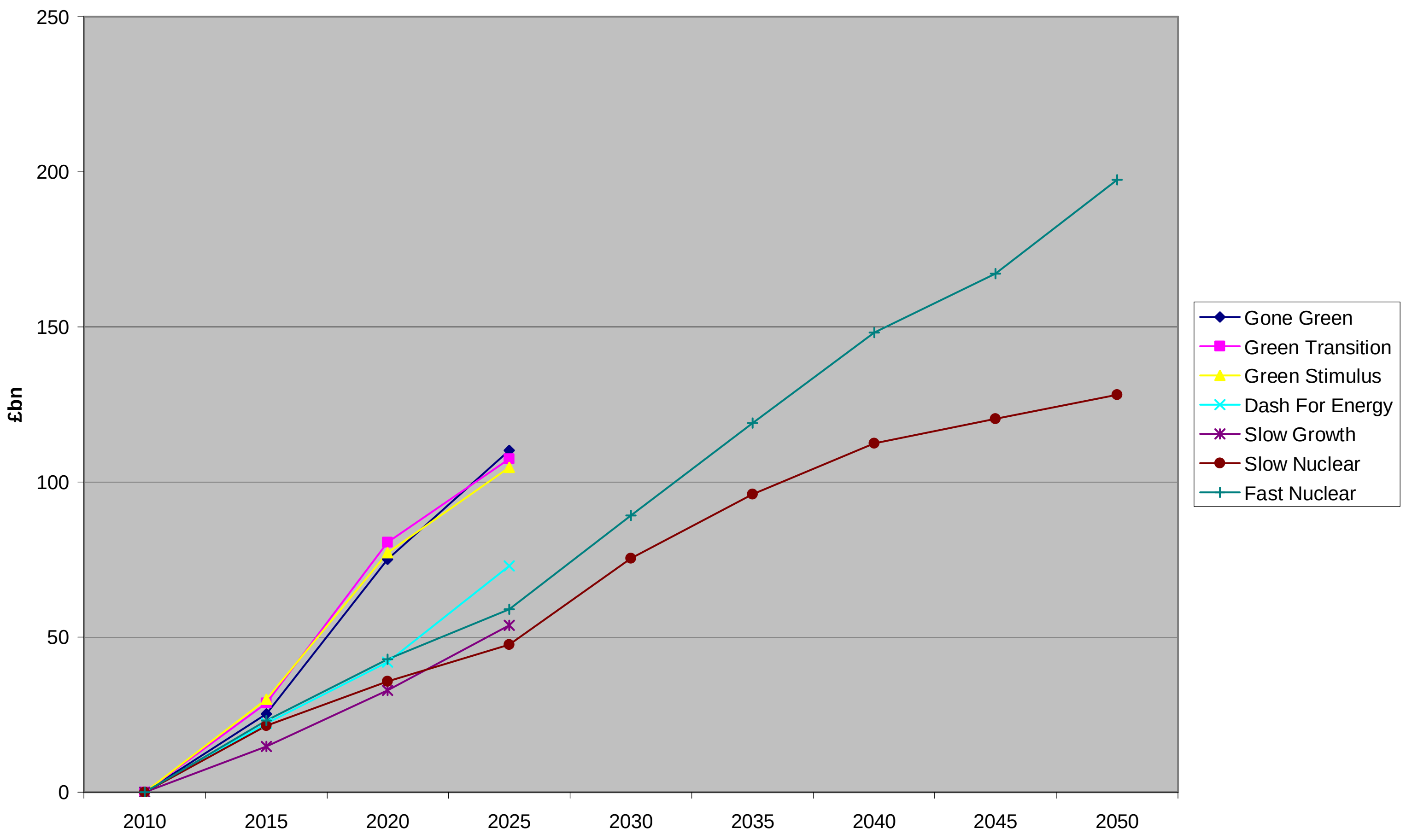

Figure 2A: Annual Generation Targets for Each Scenario

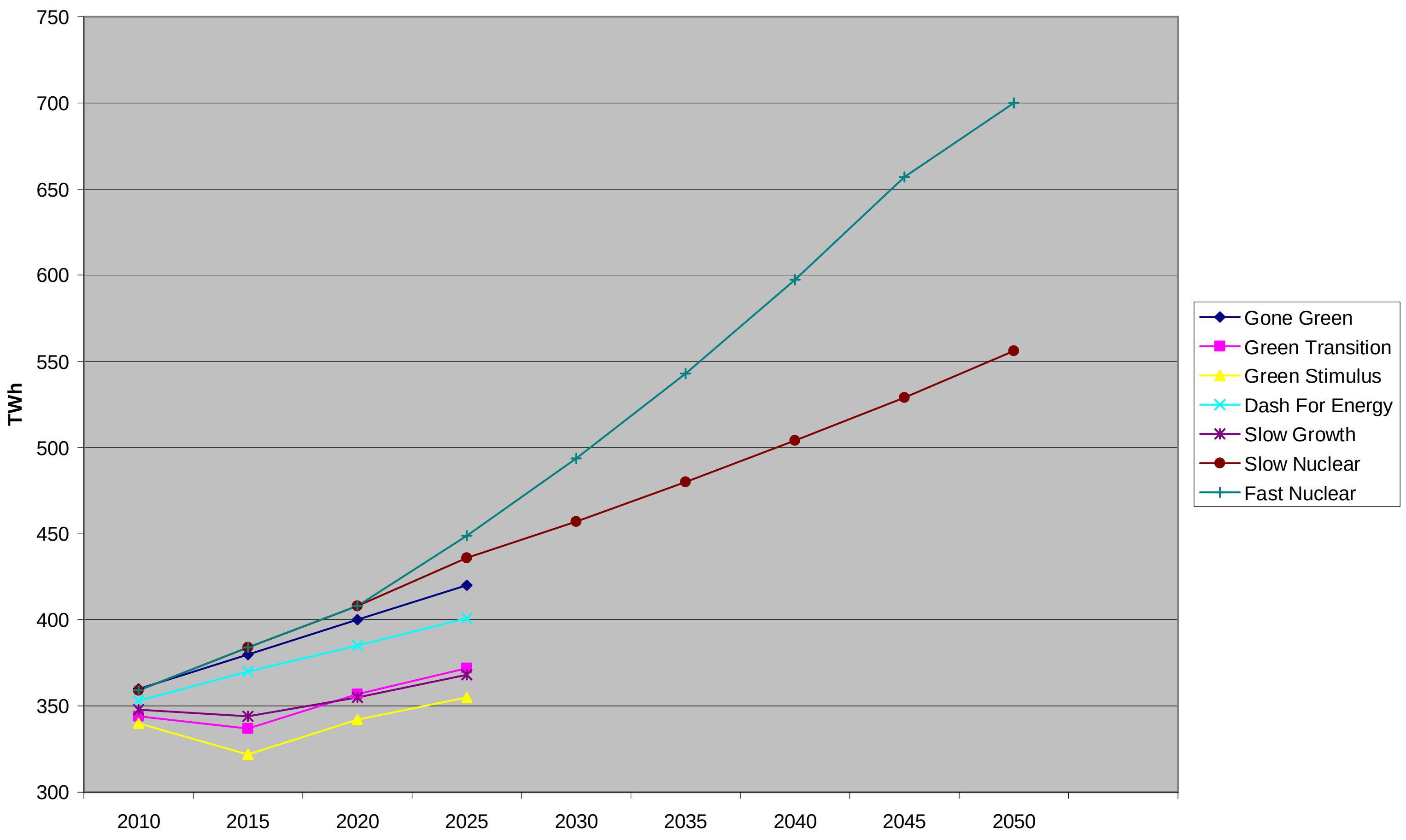

Figure 2B: Annual Winter Peak Supply Targets for Each Scenario (excluding STORR)

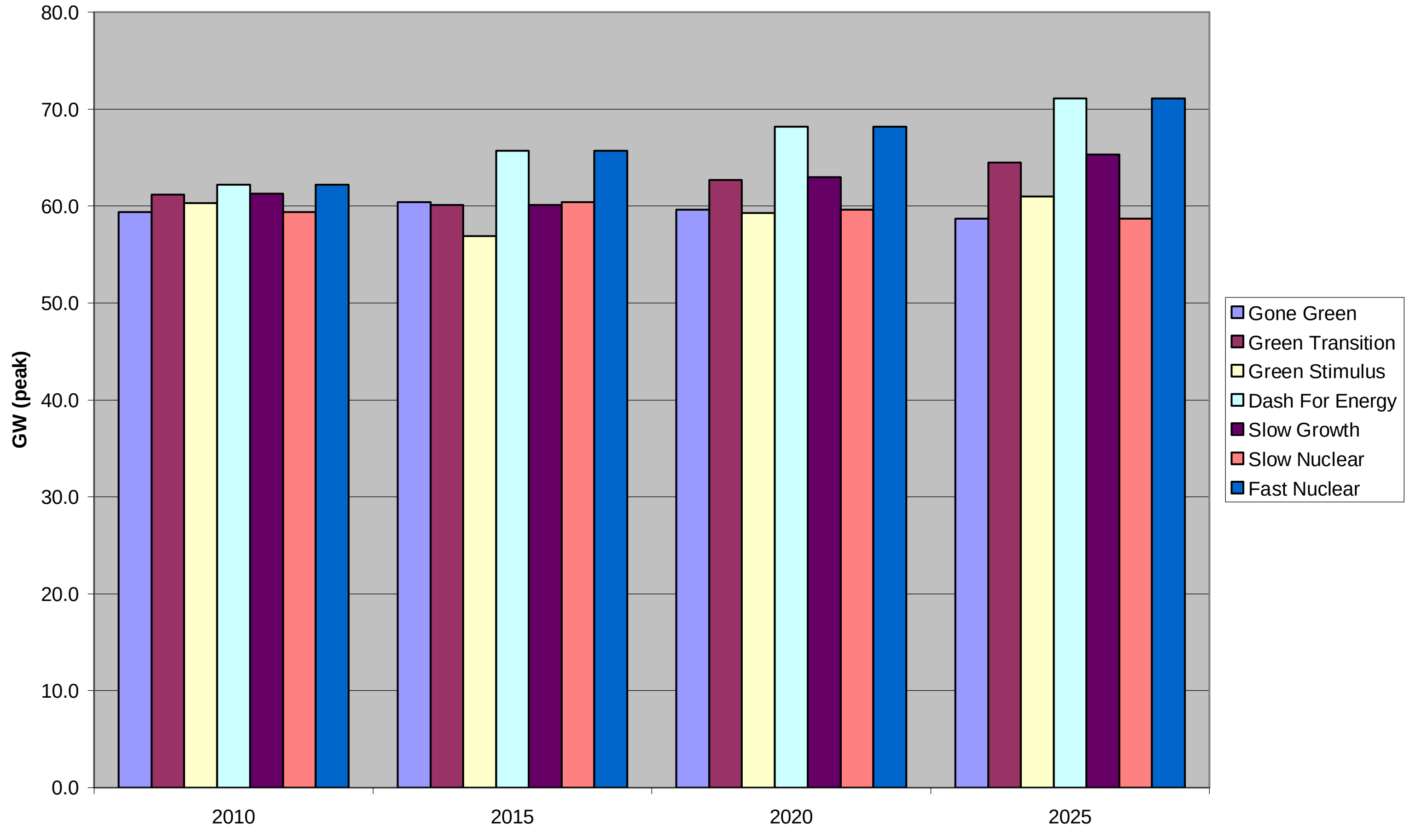

Figure 3A: Maximum Winter Peak Availability for Each Scenario

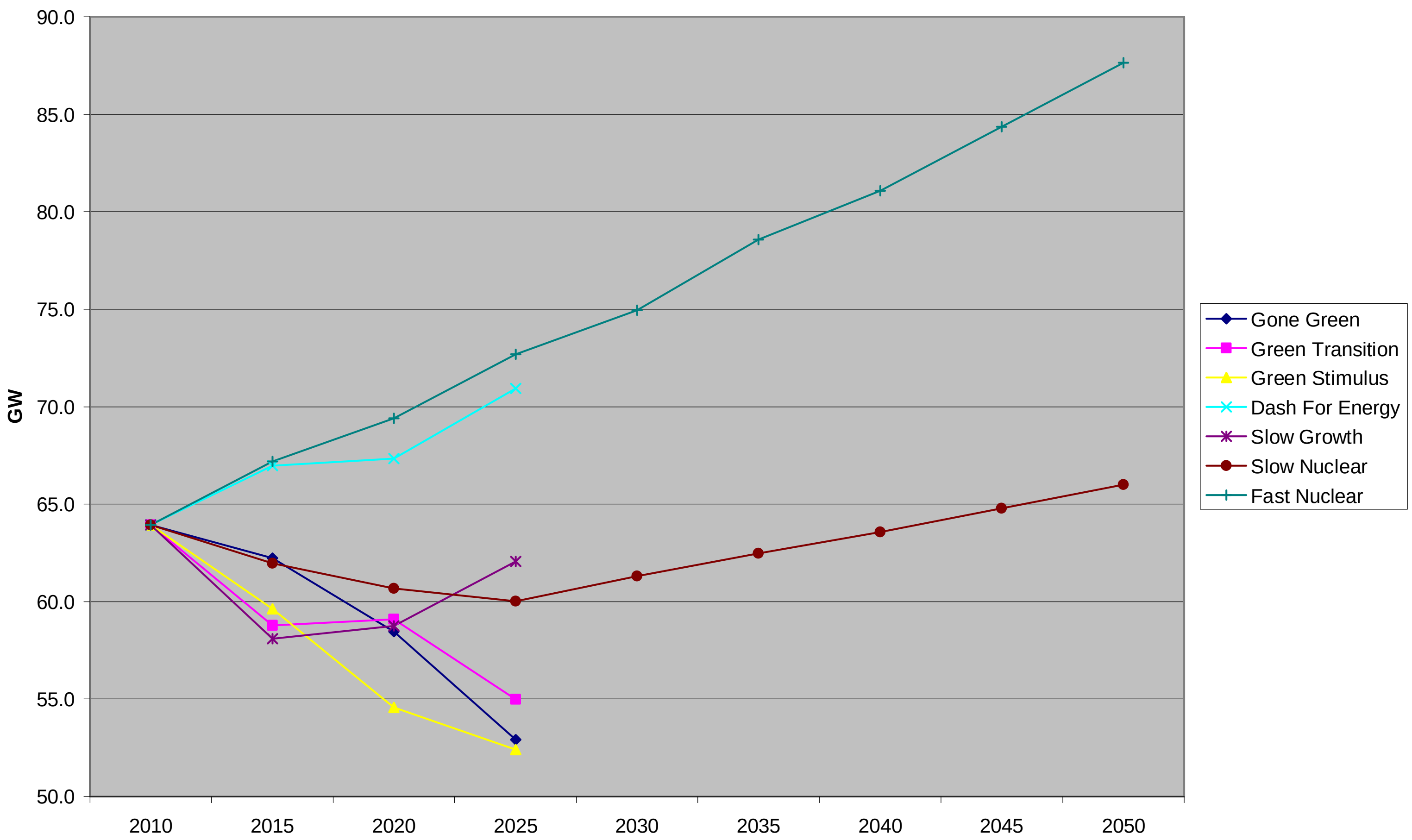

Figure 3B: Capacity Margin for Each Scenario

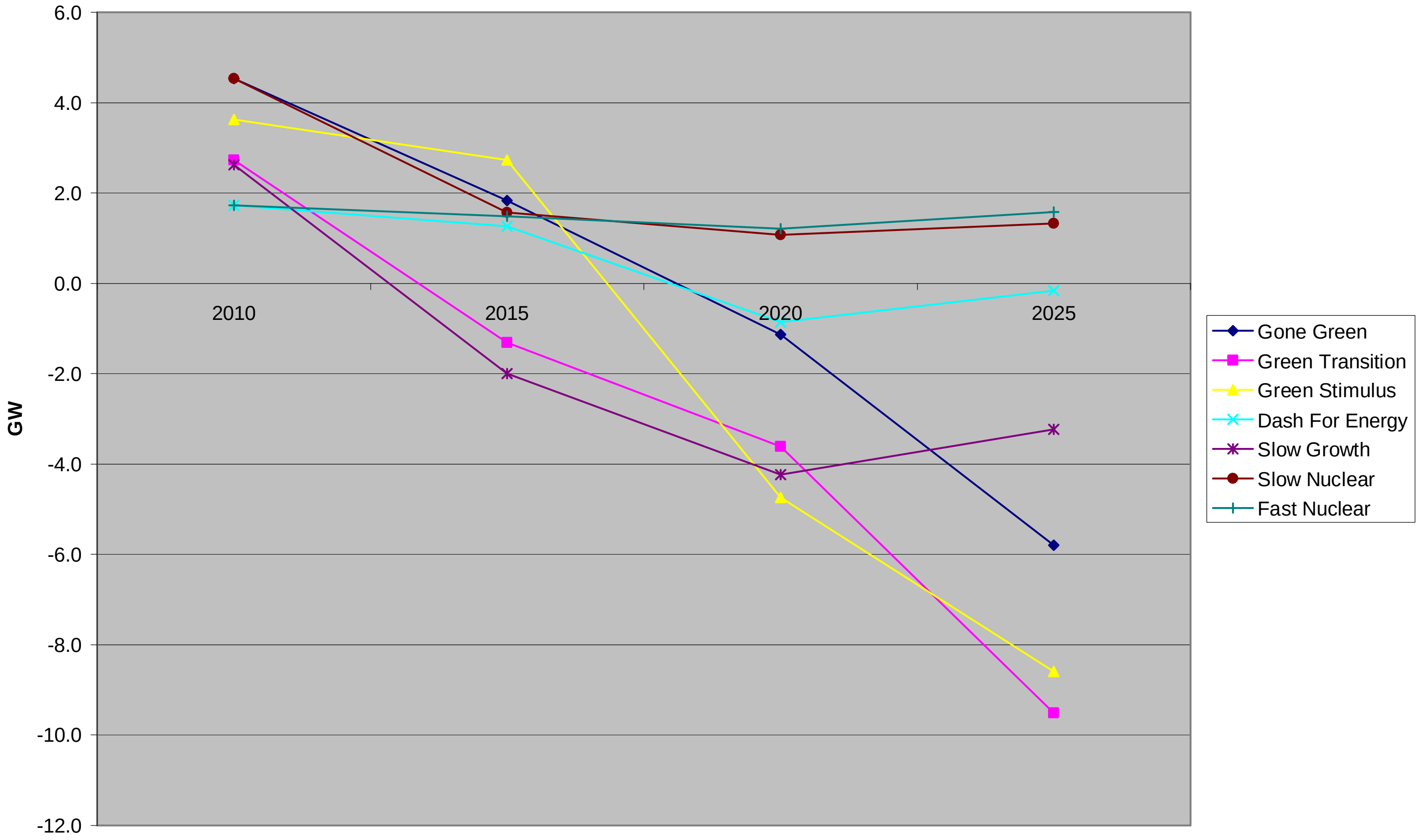

Figure 4A: Generation by Generator Type for the National Grid "Gone Green" Scenario

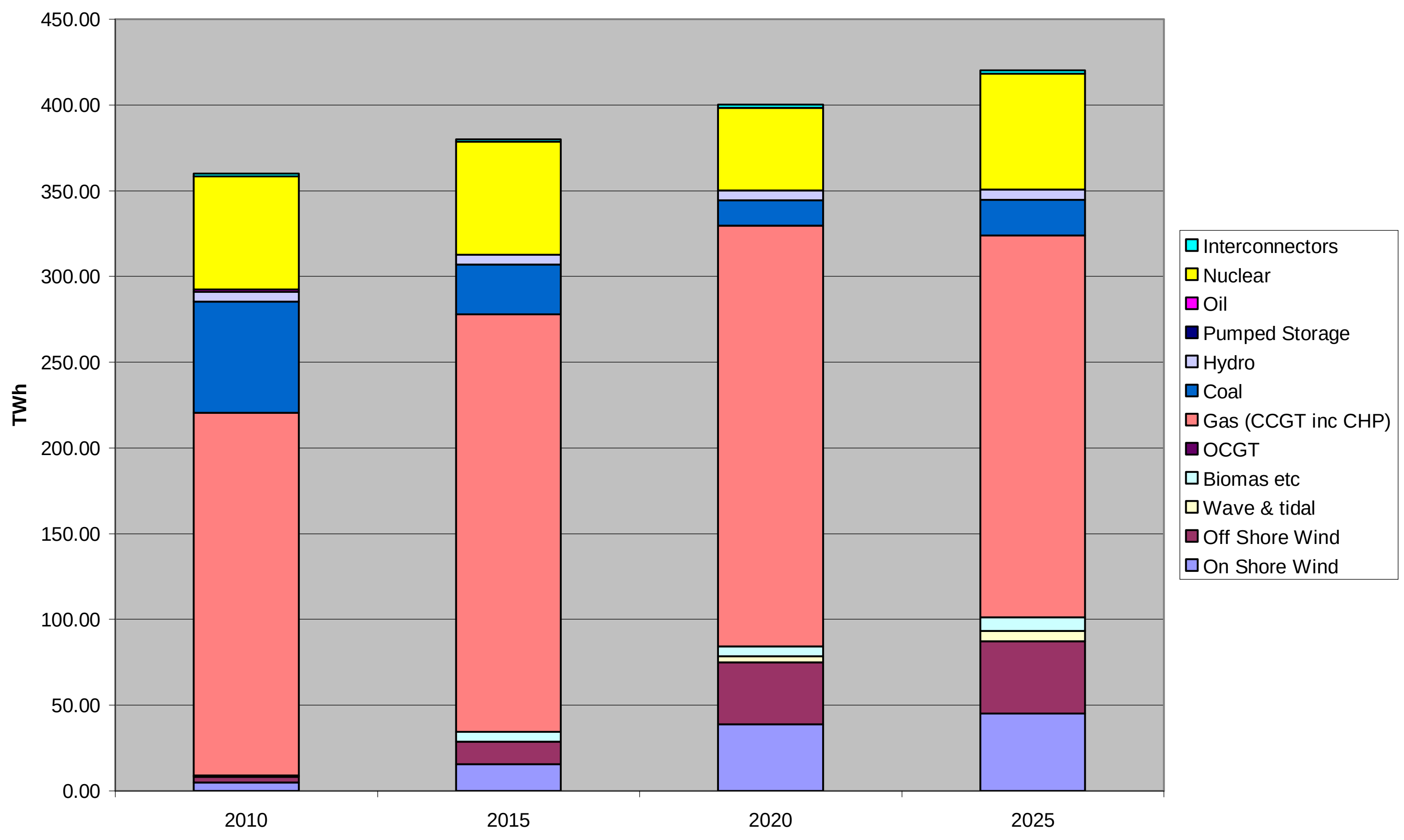

Figure 4B: Generation by Generator Type for the Ofgem "Green Transition" Scenario

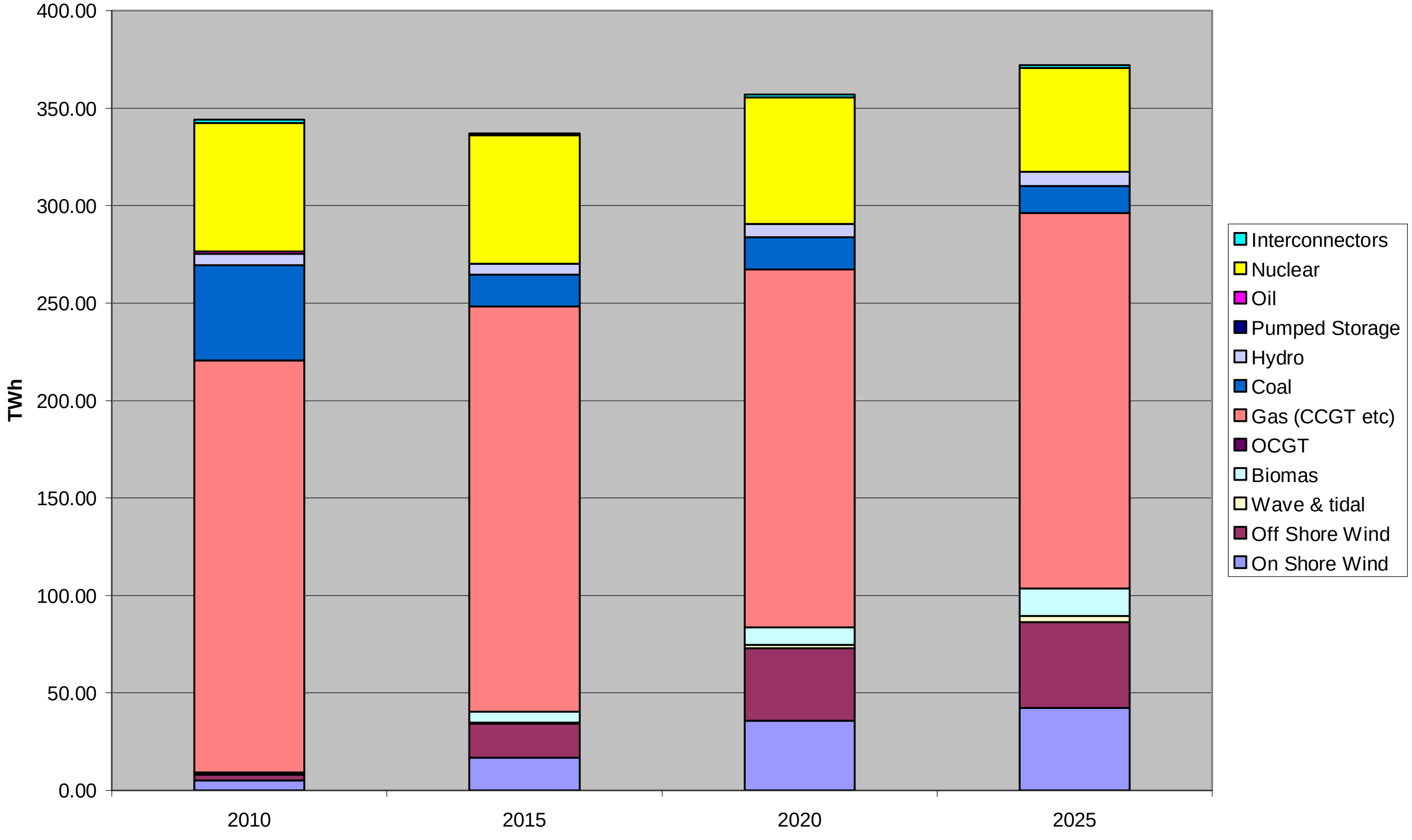

Figure 4C: Generation by Generator Type for the Ofgem "Green Stimulus" Scenario

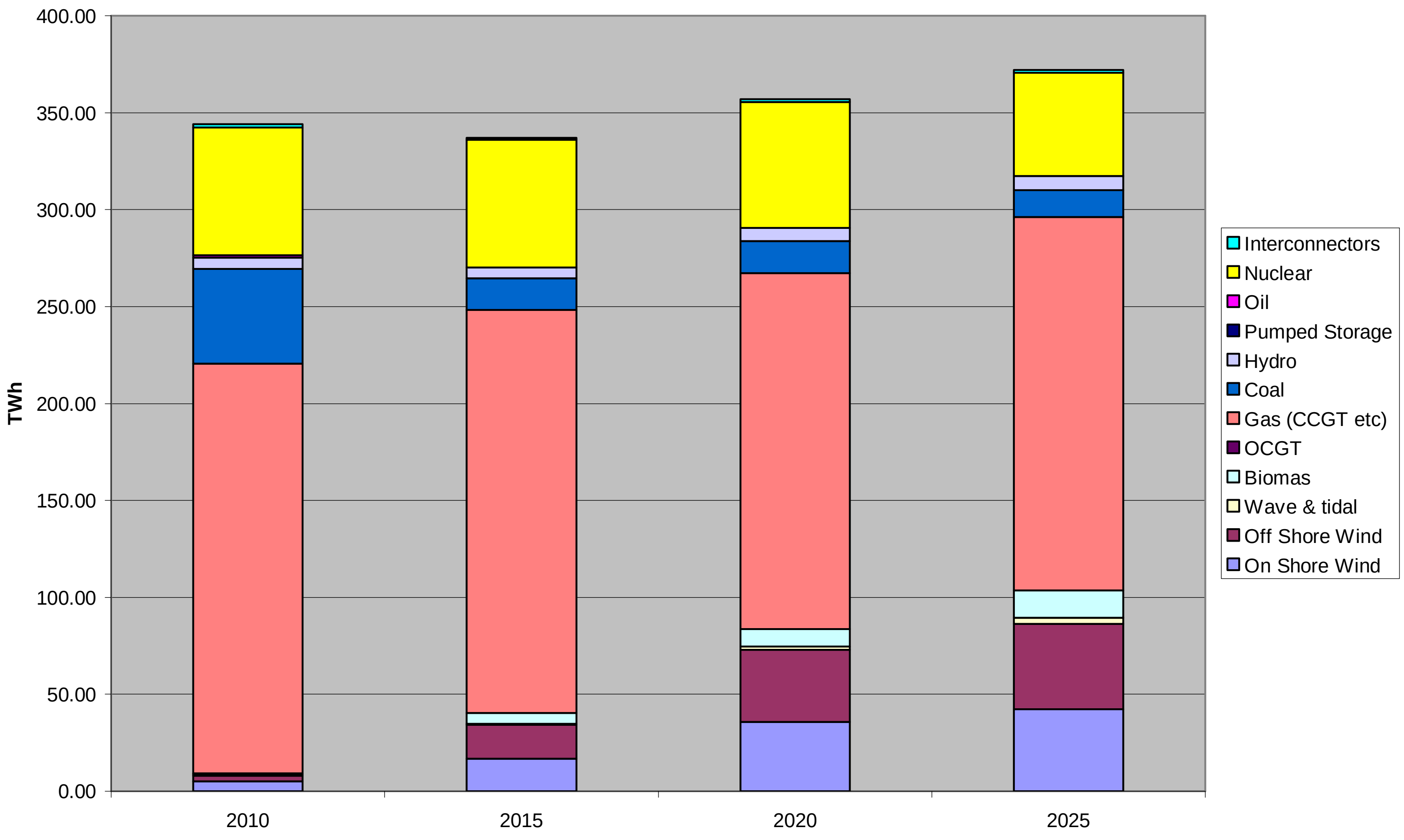

Figure 4D: Generation by Generator Type for the Ofgem "Dash for Energy" Scenario

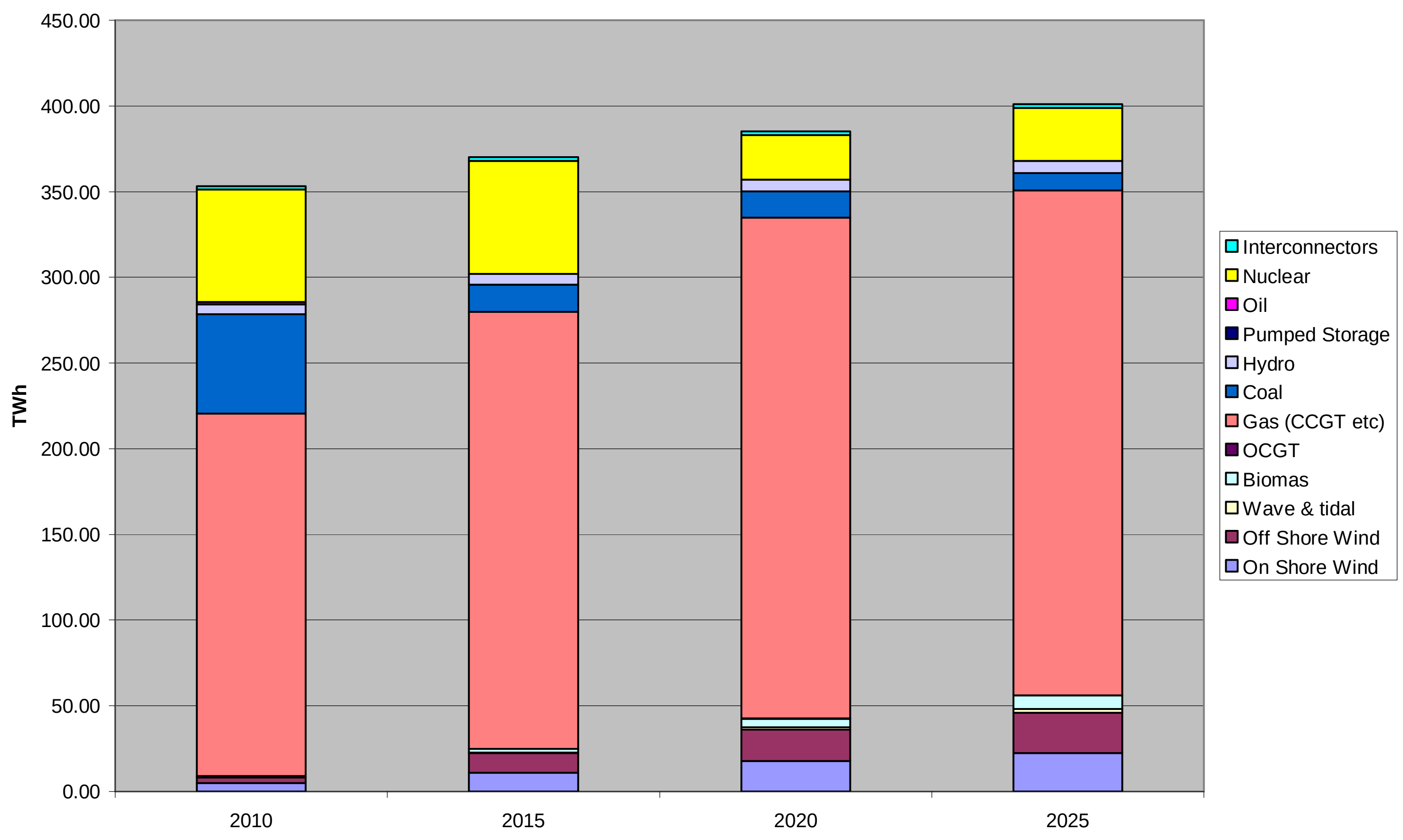

Figure 4E: Generation by Generator Type for the Ofgem "Slow Growth" Scenario

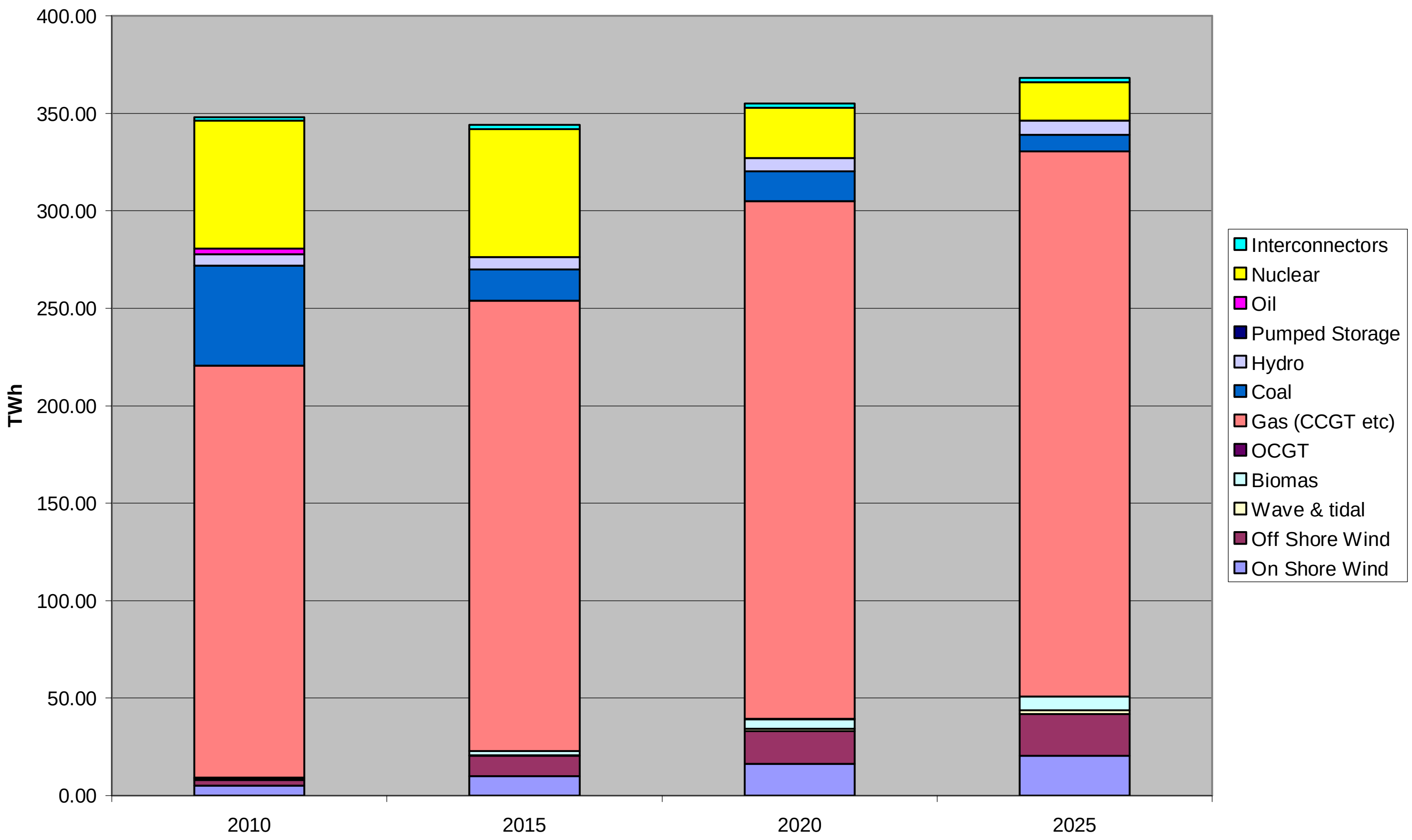

Figure 4F: Generation by Generator Type for the "Slow Nuclear" Scenario

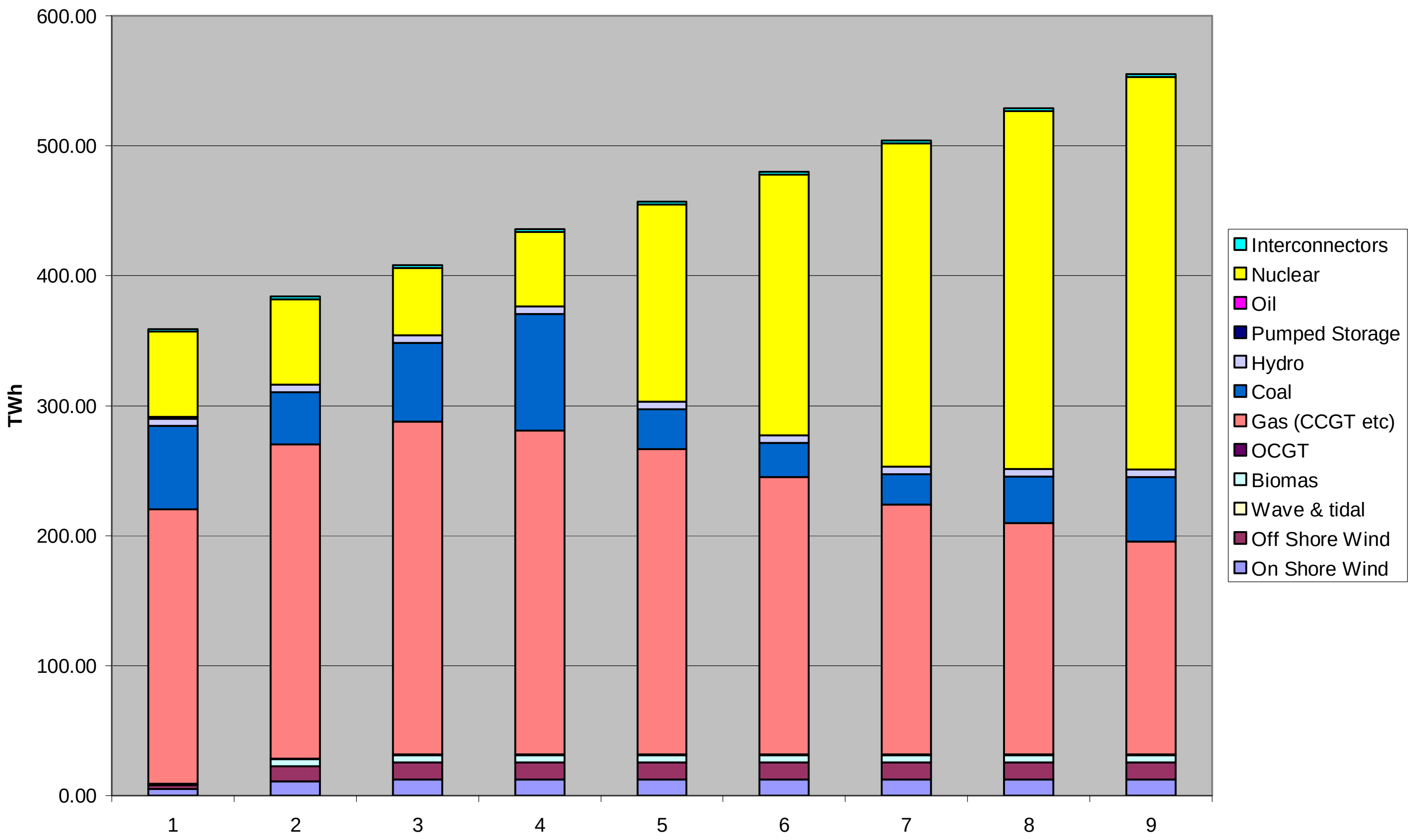

Figure 4G: Generation by Generator Type for the "Fast Nuclear" Scenario

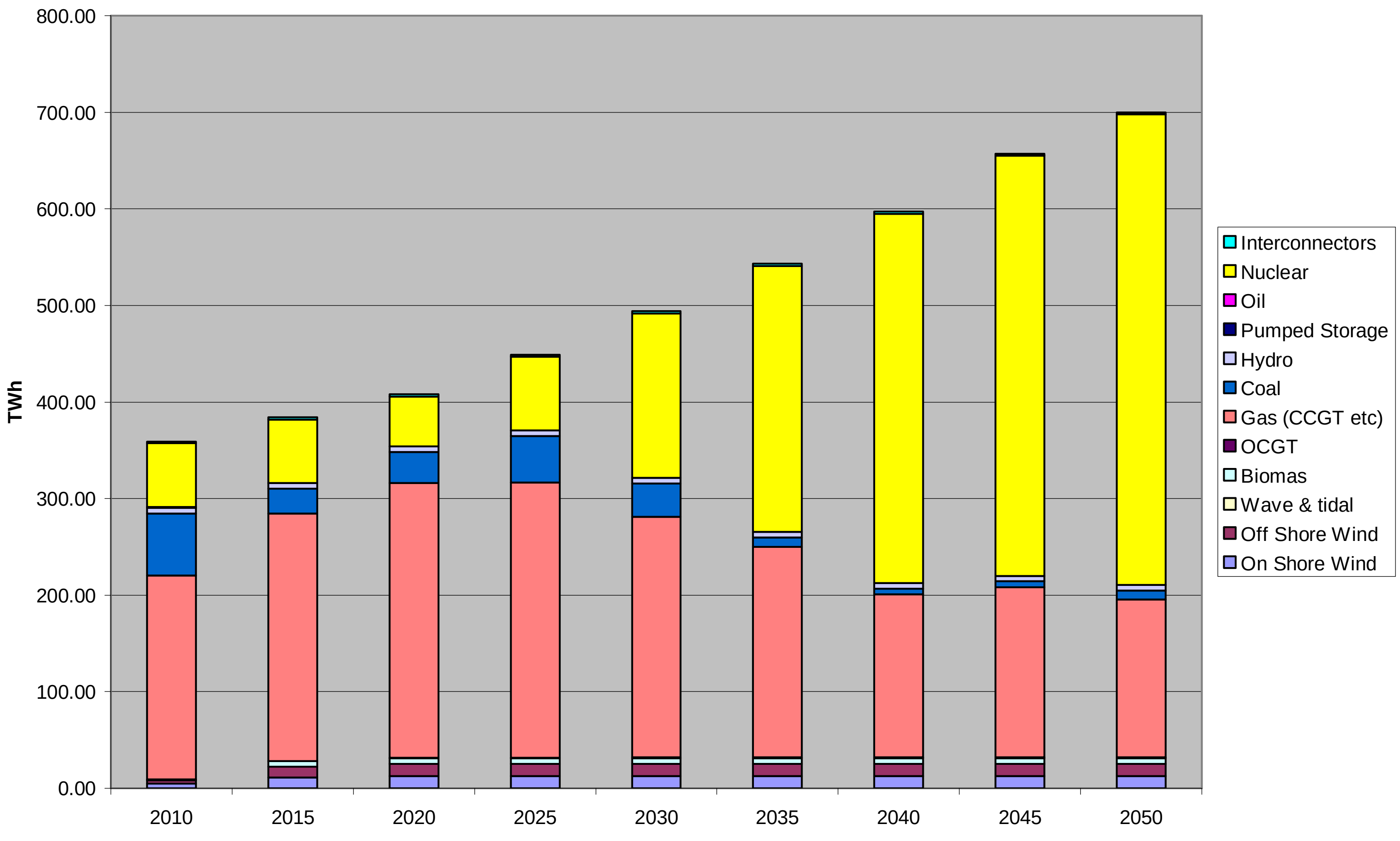

Figure 5A: Total CO2 Emissions for Each Scenario

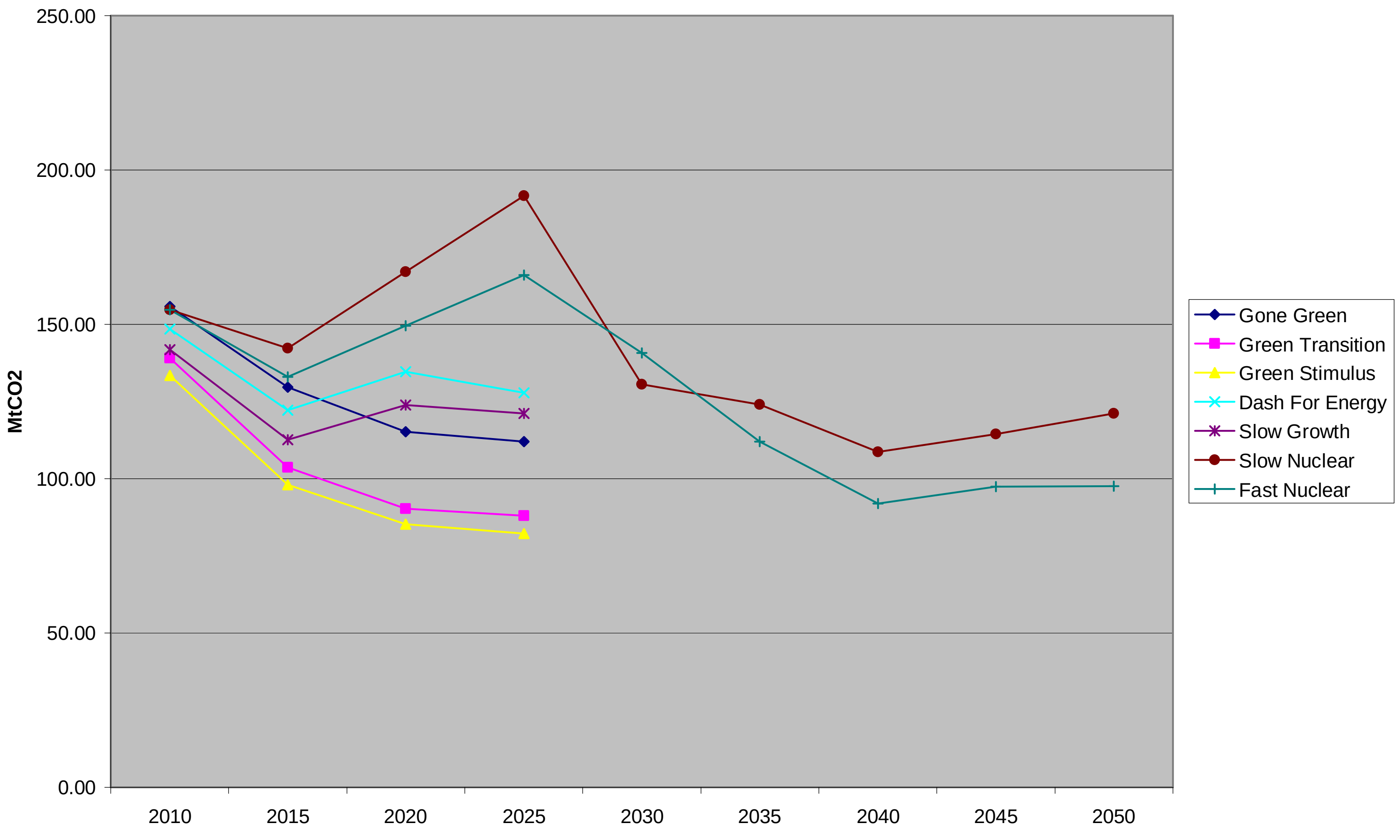

Figure 5B: CO_2 Emissions per TWh (electrical) for Each Scenario