Fossil Energy R&D . . .

Options to Secure America's Future

DOE/NETL-402/033106

2005 Analysis Highlights of
Prospective FE R&D Program Benefits

March 31, 2006

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FE’s R&D Portfolio

The US Department of Energy (DOE) Office of Fossil Energy (FE) performs energy and environmental research and development (R&D) that advance the efficiency, availability and affordability of coal-, natural gas- and oil-based technologies.[1] Through on-site laboratory work and partnerships with universities, the private sector and other government agencies, FE supports the development and demonstration of technologies and projects that provide both economic and environmental benefits to the US. These technologies and projects include, but are not limited to, advanced turbines, advanced fuel cells, advanced combined cycle systems, carbon sequestration, coal to liquids transformation and innovations for existing plants[2], the latter of which are technologies that allow existing plants to meet new emission regulations.

FE’s Role

FE is charged with engaging in R&D that introduces or accelerates the advent of technologies that provide measurable economic and environmental benefits to the nation. In addition to the economic and environmental benefits that FE’s work provides to the nation, FE’s role includes supporting the exploration, extraction and utilization of domestic energy resources and thus reducing the nation’s dependence on foreign energy sources. This R&D is federally funded for two principal reasons: 1) energy issues such as efficiency, security and environmental impacts are national concerns that can be collectively addressed by an agency that holds the nation’s interests at the core of its mission; 2) FE’s R&D is deemed to provide benefits that are significantly greater than the R&D costs.

Purpose of Multiple Scenarios

The goal of calculating and analyzing technology benefits is to gain insight into the potential impacts of FE R&D under defined economic and political parameters. To provide researchers, policy makers and industry with the most comprehensive knowledge possible, FE calculates and analyzes R&D impacts under numerous scenarios that depict various plausible future states of the economic and energy world. To cover the possible alternative futures, the benefits were calculated under six scenarios – Business-As-Usual (BAU), Clean Air Rules (CAR), Global Climate Change Initiative (GCCI), Severe Carbon Constraint (SCC), High Fuel Prices (HFP) and Very High Fuel Prices (VHFP).

Scope and Methodology

The scope of the 2005 benefit analysis is the entire FE portfolio. The analysis is based on scenarios in which all FE R&D technologies are deployed in the timeframe determined by the technology program areas. Because this analysis is based on scenarios in which all FE technologies are interacting, it is inappropriate to attempt to assign benefits to specific technology programs and assess the value of each technology program separately. This analysis presents an assessment of benefits provided to the nation when all FE R&D programs are successful and thus the results should be used to evaluate the benefits of the FE R&D portfolio on a whole.

The methodology employed in the 2005 benefit analysis of FE technologies assumes that policies existing under a given scenario do not change over the evaluated period (2004-2025). Therefore, if a policy exists in 2004, it will continue to exist through 2025; and if a policy is set to take effect in a given year, such as the environmental policies in the CAR scenario, then it will initiate in the preset year. Note that because the reference year for this 2005 analysis is 2004, the analysis does not include any impacts associated with the Energy Policy Act of 2005. It is also assumed that all technologies will reach their cost and efficiency goals on schedule.

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[1] The 2005 analysis only includes the impact of FE R&D in the coal and power program; this analysis did not attempt to calculate the benefits due to the FE oil and gas program.
[2] Innovations for existing plants are also referred to as “retrofits.”

The model used to evaluate the impacts of FE R&D is the US Energy Information Administration's (EIA) National Energy Modeling System (NEMS). EIA uses NEMS to calculate the forecasts represented in their Annual Energy Outlook (AEO). The *AEO2005* serves as the baseline for all alternative runs in NEMS. EIA modifies the baseline NEMS code to represent the economic and policy conditions that guide each scenario and provides these modified code sets to FE for analytical application. Each scenario was run both with and without all FE R&D impacts and the difference between the results are calculated as program benefits. Economic results are presented in 2003 constant dollars and all discounted values represent a 2005 present value.

Two benefit categories were estimated:

Economic Benefits

The primary benefits to US consumers derived from FE R&D in the 2005 analysis are economic benefits. Under this analysis, which is based on EIA's *AEO2005* reference case, focus is on the benefits associated with the generation of electricity from utilities. The most significant economic benefit is derived from reductions in the price of utility-generated electricity; this economic benefit will directly impact all US consumers. In all cases that include FE R&D,, the average price of electricity to consumers declines over the 22-year period. By 2025, the price difference between the case with no FE R&D and that with FE R&D is roughly 0.3 ¢/kWh in all scenarios except the Clean Air Rules (CAR) scenario where the price of electricity is 0.6 ¢/kWh cheaper in the case with FE R&D. See Graph 4 and Table 2. The trends of the average electricity price are similar in most of the scenarios; due to severe emissions constraints, the trend in the Severe Carbon Constraint (SCC) scenario is slightly different. Although the CAR scenario's price trend follows the trend seen in other scenarios, the price gap in 2025 is large because of trends in emission policy implementation and technology availability.

In 2009 the price levels jump up in the CAR scenario due to the implementation of CAMR and CAIR. When fuel cells come on-line in 2012 both the CAR and other scenarios, with the exception of the SCC scenario, begin to see a price reduction in the FE R&D case and the trends (but not the levels) fall back in line w/ each other (note the price trends in the No FE R&D cases are still in parallel). This price trend parallelism in the FE R&D cases remains until 2020. Starting in 2020 the price in CAR's FE R&D case levels off before beginning to decline due to capacity increases in fuel cells and IGCC w/o sequestration. The existence of a dual technology penetration, using technologies that are less expensive than those used in the No FE R&D case, allows the electricity price in the CAR scenario to fall faster and lower than that in the other scenarios. The BAU and GCCI FE R&D cases only experience a capacity increase in fuel cells. The HFP and VHFP scenarios show growth in multiple advanced, cleaner technologies, but these technologies are not significantly cheaper than the conventional pulverized coal technology that is used in the No FE R&D cases.

In the SCC scenario there is less of a gap in the electricity price because of the need to meet the emission standards which extend late into the analysis period. This scenario uses more expensive technologies (nuclear and renewable) until FE technologies come on-line. Although advanced FE technologies begin to penetrate the market, the carbon constraints are too severe to allow renewables to drop out of the picture, therefore the price of electricity in both the No FE R&D and the FE R&D cases remain high. In the GCCI case, the price of electricity rises as emission controls are implemented. Without FE R&D, emission standards are met using renewables and nuclear technology. Once FE fuel cells are available, nuclear and renewable capacity are significantly reduced allowing for a large price gap between the No FE R&D and the FE R&D cases. If it weren't for a last-year price spike in the FE R&D case, we would see an electricity price gap in the GCCI scenario of 0.7 ¢/kWh.

The average annual price decline from 2004 to 2025 across all six scenarios, in comparison to the case with no FE R&D, averages 1.5 percent. The largest average annual price difference exists in the GCCI scenario where the average is 2.7 percent. It is under this scenario that the largest benefit is forecasted – ($152 billion in electricity related savings in 2003 dollars, discounted to a 2005 present value). See Graph 2.

Environmental Benefits

Three of the six scenarios focus on the impact of environmental restrictions on the US energy situation. These three scenarios, CAR, GCCI and SCC, examine the impact on energy and fuel prices, the nation's capacity portfolio and emission levels under various types and levels of environmental restrictions. The primary benefit of these three scenarios, especially in the CAR and GCCI scenarios, is the reduction in the cost of electricity for US consumers. This economic benefit is not the only benefit provided by the existence and continuation of FE R&D. In all six scenarios, in the case with FE R&D applied, emissions of nitrous oxide (NO_x), sulfur oxides (SO_x) and carbon dioxide (CO_2) are either lower or equal to those emissions forecasted in the case with no FE R&D. See graphs under Emissions from the Electricity Generation Sector.

In the three scenarios with a focus on meeting emission standards, emission levels reach the policy-driven standards on schedule in both the FE R&D case and the case with no FE R&D. By only observing emission levels it seems as if the only benefit is the economic benefit of a price reduction in electricity; it appears as though there are no environmental benefits attributable to FE R&D. Moving the analysis beyond total emissions to emissions per GW of capacity reveals that when total emissions are constant over a period of time or are equal between the two cases, the emissions per GW are actually declining over time and are consistently lower in the case with FE R&D. This trend is shown in the "emissions per capacity GW" under Emissions from the Electricity Generation Sector.

Scenario Definitions

BAU – Business as Usual (BAU) scenario that assumes current regulatory structure as defined in EIA's *AEO2005*.

CAR – Clean Air Rule (CAR) scenario that includes the emission limitations set forth by the Environmental Protection Agency's (EPA) Clean Air Interstate Rule (CAIR) and Clean Air Mercury Rule (CAMR).

GCCI – Incorporates the White House's Global Climate Change Initiative (GCCI) that calls for an 18 percent reduction in greenhouse gas (GHG) intensity from 2002 to 2012. After that, emissions are assumed to remain at 2012 levels. This reduction is met through the use of a market-based cap-and-trade system aimed at reducing carbon emissions in the electricity sector.

SCC – Severe Carbon Constraint (SCC) scenario that employs the same market-based cap-and-trade system as used in the GCCI scenario, although the actual constraint is much more severe. Carbon emissions will be reduced gradually from 2010 to 2017 until emissions reach 5,793 MMT CO_2 across all sectors[3]. Reaching this level caps total CO_2 emissions to the emission level reached in 2001; emissions are stabilized at this level through 2050.

HFP – High Fuel Price (HFP) scenario that represents a world where, over the 25-year period, prices are, on average when compared to the BAU scenario, 28 percent higher for world oil and 26 percent higher for natural gas at the wellhead due to supply restrictions. This case is used in multiple offices within the Energy, Science and Environment (ESE) Program and thus must fall within mutually agreed upon parameters. Because of the inter-office collaboration, the resulting natural gas price in this case is higher than that set in FE's VHFP.

VHFP – Very High Fuel Price (VHFP) scenario that represents a world where, over the 25-year period, prices are, on average when compared to the BAU scenario, 50 percent higher for world oil and 22 percent higher for natural gas at the wellhead due to supply restrictions. The world oil price, which is exogenously set by EIA is highest in this scenario and thus provides the basis for the scenario's name.

[3] The Severe Carbon Constraint scenario is one in which the goals were set through a joint collaboration between Fossil Energy (FE) and Energy Efficiency (EE). The goal was to create a scenario with a plausible carbon constraint that was more severe than that in the GCCI scenario, crossed all sectors of the economy and was not tied to a regulatory proposal. The result of this collaboration was the setting of the goal constraint at 5,793 MMT CO_2, total CO_2 emissions from all sectors.

Key Benefits –

(See Graph 2 for a side-by-side comparison of discounted benefits across scenarios)

BAU – By continuing current environmental restrictions and using the baseline economic projections included in EIA's AEO 2005 reference case, the addition of FE R&D results in $71 billion (discounted[4]) in electricity related savings to the American consumer by 2025. A trend of moderate and steady price declines over a prolonged period, from 2008 through 2025, give rise to the savings forecasted for this scenario. Over the eighteen year period of price declines, the price difference between the case with FE R&D and that with no FE R&D begins at 0.1 percent and, by 2025 the electricity price in the FE R&D case is almost 5 percent lower than the forecasted price in the baseline case. See Graph 2 for discounted benefits.

CAR – In March 2005, the EPA issued two emissions-related rules, the Clean Air Interstate Rule (CAIR) and the Clean Air Mercury Rule (CAMR). CAIR implements caps on SO_2 and NO_x emissions. These caps aim to reduce emissions by 70 and 60 percent respectively over 2003 emission levels by 2015 in the eastern United States. CAMR introduces a cap on mercury emissions from coal-fired power plants across the United States. The goal of this rule is to cap mercury emissions at 15 tons per year by 2018 with an interim goal of capping emissions at 38 tons per year in 2010. Both the CAMR and CAIR caps are met in the No FE R&D and FE R&D cases. Both cases represent the scenario in which SO_2 and mercury emissions reach their lowest levels by 2025 as shown in Graph 32, and the lowest cumulative NO_x, SO_2 and mercury emissions. After the caps are met, the addition of FE R&D provides benefit to the American consumer via further reductions in emissions coupled with a reduction in the price of electricity. By using technologies supported by FE R&D, America's capacity suite shifts from one that is heavy in technologies such as conventional coal, advanced NGCC (without sequestration) and combustion turbines to a suite concentrated on fuel cell and advanced coal (without sequestration) technologies. For capacity shift trends over the 22-year period, see Graphs 20 and 21. For a snapshot of how the capacity diversity in 2025 differs between the case with No FE R&D and that with FE R&D, see Graphs 40 and 45. The cumulative discounted, electricity related benefit reaches $119 billion in 2025.

GCCI – American customers receive the largest electricity savings benefits, $152 billion (discounted), under the Administration's Global Climate Change Initiative plan. This plan calls for an 18 percent reduction in greenhouse gas (GHG) intensity from 2002 to 2012 with CO_2 emissions remaining at 2012 levels throughout the analysis period. In both the baseline and the FE R&D case under this scenario, the GHG intensity goal is met. One year after the goal is met the utility sector begins to rapidly increase power generation capacity via FE fuel cells, see Graph 11. The introduction of these advanced fuel cells, which are a competitive, viable power generation option because of FE R&D, allows the energy sector to reach emission standards while reducing the price of electricity. Without the FE R&D that brings the fuel cells to market, emission standards are met largely by switching to renewable energy that causes the price of electricity to rise. In the latter years of the "with" FE R&D case, the amount of renewable capacity added to the nation's energy portfolio begins to plateau and electricity prices begin to fall again as advanced IGCC with sequestration technology comes on-line allowing coal to be used in power generation that meets the desired emission standards.

SCC – When severe constraints are placed on total CO_2 emissions, electricity prices are significantly impacted. In the early and mid years of the analysis, prior to 2021, electricity prices rise sharply, with prices jumping 15.7 percent in just the two year period from 2007 to 2009. The price increase continues through 2021, with the result that over the longer period from 2007 to 2020 the price of electricity rises by more than 50 percent. This rise in price results from the need to constrain carbon emissions, and thus move away from conventional coal-based generation which previously resulted in low electricity prices. In the short- and medium-term, this shift causes a move away from pulverized coal plants, with coal plant capacity being replaced by renewable energy capacity. See Graph 12 and Graph 24. Because electricity generated from renewable energy sources is typically more expensive than coal generated electricity, the price of electricity rises considerably. In 2021, two changes due to FE R&D occur that allow the price of electricity to begin to fall. First, fuel cell capacity, which has been steadily growing since 2014, surpasses, and begins to replace, renewable energy capacity in new builds. Second, advanced coal technology, (IGCC with sequestration) begins to come on-line, allowing the inexpensive, abundant resource of coal to replace more expensive electricity generation feedstocks while still meeting carbon constraint requirements. The additions

[4] All discounted values are in 2003 dollars with a present value of 2005 dollars.

of fuel cells and IGCC can be seen in Graph 13 and Graph 25. In an effort to meet the carbon emission requirements, which are the most stringent in this scenario, this scenario's case with FE R&D has the largest share (nine percent), as shown in Graph 49, of advanced coal with sequestration in its technology suite. Meaningful electricity price deviations between the "FE R&D" and "no FE R&D" cases do not emerge until 2021; by 2025 the price of electricity in the FE R&D case is already five percent lower than the baseline price in 2020. Although the switch to two less-expensive FE technologies allows economic benefits to begin to accrue, because these new technologies come on-line late in the analysis period there is not sufficient time for larger benefits to be measured, therefore cumulative electricity price savings only reach $25 billion (discounted) by 2025, resulting in the observation that economic benefits over the time period to 2025 are lowest in this scenario. This scenario does, however, provide environmental benefits – CO_2 and NO_x emissions reach their lowest levels and SO_x and mercury emissions are second lowest in this scenario. To view emission trends, see graphs under Emissions from the Electricity Generation Sector.

HFP – Only moderate benefits are generated when high fuel prices are imposed upon the economy. In this scenario, the world oil price increases 12 percent from 2004 to 2025 while other scenarios, excluding the VHFP scenario, see the world oil price decline 13 percent over the same period. Like FE R&D cases in other scenarios, fuel cells become a key component of America's technology suite as does advanced coal technology, namely IGCC without sequestration, which becomes the predominant technology by 2025. Graphs 50 and 51 show how the capacity suite changes once FE R&D is added. It is only after FE fuel cell technology comes to market that electricity prices begin to decline. They decline further after IGCC technology comes on-line, and bring an electricity related economic benefit of $57 billion (discounted) to consumers. This scenario focuses on meeting capacity requirements while facing increased world oil and natural gas prices, and thus generation technologies are brought on-line based on availability and cost effectiveness, rather than based on the technologies ability to meet an emissions goal. Because of this scenario's focus, conventional technologies that do not reduce emissions and are less expensive than FE R&D technologies retain large shares of electricity generation capacity until the latter years of the analysis when FE technologies become economically viable options. This delay in the introduction of FE R&D technologies is what restrains the benefits realized by the American consumer. In this scenario, emissions of NO_x, SO_x, mercury and CO_2 are nearly identical to those forecasted in the BAU scenario.

VHFP – In this scenario, the 2004 world oil price is six percent higher than in other scenarios and increases 30 percent by 2025. It should be noted that in the construction of this scenario, the restrictions imposed by EIA to meet the desired oil prices actually resulted in a lower natural gas price as compared to that found in the HFP scenario. Both the baseline and the FE R&D cases present a technology suite that is similar to the HFP scenario in total capacity and its composition. The benefits provided by FE R&D, therefore, are low in comparison to other scenarios at $41 billion (discounted). As in the HFP scenario, the focus of the VHFP scenario is not to reduce emissions. The focus of the VHFP scenario is to meet capacity demands when world oil prices are at their highest levels. Thus, as was found in the HFP scenario, generation technologies are brought on-line based on availability and cost effectiveness and this trend results in high emissions levels for all tracked emissions. The average annual price decline in the case with FE R&D is 0.9 percent and price savings do not begin to occur until 2015. This savings onset is later than that in the HFP scenario and the average annual price difference is lower as well. These two factors are why the cumulative savings are lower in this scenario than the savings in the HFP scenario.

FE R&D Program

The guiding principles of FE's coal program are to develop technologies that foster clean power generation that meet climate change standards while relying on America's most secure, reliable energy resource. FE's coal program is focused on both short- and long-term achievements that support these principles and allow coal to be a mainstay in the nation's power generation portfolio while bringing cost savings to American consumers.

In the short-term, FE's coal-focused R&D is centered on technologies for retrofitting existing plants to meet emission control restrictions. Even before advanced clean-coal technologies come on-line, coal remains a predominant generation fuel when environmental restrictions exist because of the retrofit technologies developed by FE's coal program. As evidenced in all six scenarios, the inclusion of FE short-term technologies, many of which are commercially available today, permits emission standards to be met in the early years of the analysis period even as traditional coal technologies, such as pulverized coal, maintain their share of the capacity portfolio.

The goal, and hence the purpose, of FE's long-term R&D is to develop advanced technologies that are more efficient and emit less pollution than present-day technologies. These technologies, such as coal gasification, advanced turbines, advanced combustion units, distributed generation and fuel cells, extend coal's importance by answering the future's concerns about emission levels and increasing electricity prices with the nation's most abundant energy resource. The addition of advanced coal technologies results in a coal-focused, yet technologically diverse generation portfolio that couples continued, and often increased, emission reductions with reduced electricity prices. The impact of FE's advanced technologies is substantiated by the capacity and electricity price trends in the with FE R&D cases in all six scenarios. The cases demonstrate that coal technologies and fuel cells can replace more expensive non-fossil technologies, meet emission standards and provide significant savings to consumers. The cumulative electricity related savings range from $25 to $152 billion (discounted) over the 22-year analysis period.

Environmental Challenges Met Using FE R&D Technologies

Conventional power generation without the impact of FE R&D results in high emission levels of NO_x, SO_x and CO_2. Given the abundant domestic availability coal as a resource, it is essential to keep coal a predominant player in power generation. Maintaining and improving the role of coal in power generation while supporting relatively low electricity prices is the primary goal of FE's coal program. To meet this goal and meet increasingly stricter emission standards, FE's R&D must develop technologies that allow the coal generation of tomorrow to be a cleaner, more efficient process than what exists today. In addition to the development of technologies that support continued and increased coal usage, FE R&D focuses on fuel cell development to assist in meeting emission and price goals. Together, the coal and fuel cell programs underway at DOE are on track to meet the nation's needs and expectations.

In the two scenarios that limit carbon emissions, GCCI and SCC, the net change in pulverized coal (PC) plant capacity shows large volumes of retirements. By 2025, the case with no FE R&D show net retirements of PC plants at 25 GW in the GCCI scenario and 99 GW in the SCC scenario; see Graph 10 and Graph 12. Additionally, 0 GW of advanced coal capacity are added in the GCCI scenario and only 7 GW are added in the SCC scenario. Without clean coal technology provided by FE R&D, coal is simply not competitive in a world that faces stringent emission caps, with one major result being that electricity prices are significantly higher absent FE R&D. To ensure sufficient capacity is available to American consumers, and to meet CO_2 emission standards, coal generating capacity is replaced largely with renewables, which reach 120 GW of capacity by 2025 in the GCCI scenario and 175 GW in the SCC scenario. Other technologies that make up for the reduction in coal-based capacity in the GCCI and SCC scenarios are nuclear at 21 and 79 GW respectively, and Natural Gas Combined Cycle (NGCC) without sequestration at 40 and 36 GW respectively. The result of the required carbon caps and large volumes of replacement capacity borne by renewables and nuclear energy is, in both scenarios, severe price spikes in the cost of electricity after 2009 (the year in which efforts to meet the carbon constraints begin). See Graphs 38-41 under Capacity Suite Diversity under Carbon Cap Cases to view how the net capacity changes in 2025 vary between the case with no FE &D case and the FE R&D case. As shown in Table 2, these two scenarios are forecasted to have the highest costs of electricity. In the GCCI scenario, the price of electricity when FE R&D is not applied rises 23 percent from 2004 to 2025. This price increase reaches 35 percent in the SCC scenario.

With FE R&D in the picture, FE fuel cells offset and/or replace renewables, nuclear and NGCC without sequestration technologies as the primary generation technology used to meet carbon constraints; see Graph 11 and Graph 13. The result of using FE fuel cells as the primary electricity generation technology is a reduction in prices. FE fuel cells begin to come on-line in 2012 and this low-emission technology will allow the nation's reliance on more expensive, non-fossil energy resources to decline, thus decreasing the price of electricity. In the GCCI scenario, FE fuel cell capacity additions reach 211 GW by 2025. These additions, in comparison to the case with no FE R&D, significantly reduce the need for conventional nuclear technology and renewables, the latter of which is reduced from 120 to 30 GW. Capacity held by NGCC without sequestration also declines, moving from 40 to 6 GW. In the SCC scenario, FE fuel cell additions reach 180 GW. Because the carbon constraints are more severe in the SCC case, renewable technology is still important in meeting the emission standard. Therefore, the capacity suite under SCC with FE R&D is still comprised of 110 GW of renewables. Nuclear capacity additions are restrained to 5 GW and NGCC without sequestration capacity is held to 3 GW.

In the latter years of the analysis period, a second FE technology comes on-line and enhances coal's importance in the quest to meet emission standards while providing less expensive electricity to consumers. In 2021 the capacity additions of Integrated Coal Gasification Combined Cycle (IGCC) with sequestration surpass 9 GW in both the GCCI and SCC scenarios. By 2025, capacity additions of this technology reach 29 GW in the GCCI scenario, replacing combustion turbine capacity, and 108 GW in the SCC scenario, leveling the growth of renewables. Because more expensive technologies, such as renewables and nuclear, are replaced early in the time period under the GCCI scenario, benefits begin to accrue earlier (than in the SCC scenario). From 2013[5] to 2025, the cost of electricity is, on average, 4.6 percent lower in the case with FE R&D than the case without. This sustained, measurable difference allows the cumulative benefits forecasted to reach an impressive level by 2025 -- $152 billion (discounted). In addition to cost savings provided by fuel cells and coal-based technologies, emission standards are still met. Under the GCCI scenario, the goal to reduce GHG intensity by 18 percent by 2012 and maintain this level throughout the analysis period is met and, when emissions of NO_x, SO_x and CO_2 are measured on a per GW basis, emissions are lower in the FE R&D case than those cases with no FE R&D.

In the SCC scenario, carbon emission standards are stringent enough to require the continued addition of renewable capacity even after FE R&D technologies come on-line. As in the GCCI scenario, FE technologies such as fuel cells and IGCC with sequestration, the latter of which allows coal to maintain an important role in meeting the country's energy needs, result in a lowered price of electricity to consumers while supporting America's goal of lowering NO_x, SO_x, mercury and CO_2 emissions. Because the role of renewables is so prevalent, however, the higher cost of electricity generated through that technology overshadow the cost benefits provided by fuel cells. Cost savings provided by FE R&D only become measurable once FE fuel cells and IGCC with sequestration come on-line. In 2021, the benefits from both FE technologies being on-line begin to outweigh the cost increase caused by significant renewable capacity. From 2021 to 2025 the forecasted price difference between the case with FE R&D and that without averages 1.9 percent. This relatively small average price difference, coupled with the late timeframe in which it occurs, results in the smallest forecasted economic benefit, $25 billion (discounted). Despite the relatively low forecasted economic benefits, environmental benefits in the scenario are significant. NO_x and CO_2 emissions are the most significantly reduced in this scenario. In the case with no FE R&D, NO_x emissions drop 52 percent from 2007 to 2025 and CO_2 emissions drop 44 percent. In the case with FE R&D, and thus with advanced fuel cells and coal-based technologies, the decline in emissions increases to 58 percent for NO_x and 51 percent for CO_2. Mercury and SO_x emissions reach the second lowest levels in this scenario. In the case with no FE R&D these emissions decline by 56 percent and 43 percent respectively. Again, in the case with coal-based technologies, these emission declines increase to 61 and 58 percent respectively.

As noted, NO_x and SO_x emissions are also traditional negative externalities of using coal in traditional power generation. Analysis of the emissions graphs shown under Emissions from the Electricity Generation Sector reveals that emissions of NO_x and SO_x are either held constant or reduced in all scenarios once FE R&D technologies are injected into America's electricity generation capacity suite. Shown in the table below are the differences between the NO_x, SO_x and CO_2 emissions in 2025 for the case with FE R&D case and the case with no FE R&D. The table also shows the difference in the price of electricity between the two cases in 2025. While this table does not reveal year-by-year trends of these factors, it does provide evidence that FE technology allows emission reductions to stabilize or improve while the price of electricity is reduced.[6]

Table 1. Emission Differences in 2025, Levels and Percent Change

Scenario	NO_x		SO_x		CO_2		Electricity Price	
	Mil. Tons	Percent	Mil. Tons	Percent	MMetT CO_2	Percent	¢/kWh	Percent
BAU	0.27	6.2	0.00	0.0	296.14	8.8	0.35	4.6
CAR	0.17	7.2	0.11	2.6	225.26	6.8	0.65	8.5
GCCI	0.03	0.9	0.00	0.0	3.54	0.2	0.28	3.1
SCC	0.25	13.6	1.66	26.9	184.71	13.3	0.26	2.6
HFP	0.28	6.6	0.00	0.0	266.64	7.8	0.34	4.3
VHFP	0.30	7.1	-0.01	-0.1	269.82	7.8	0.30	3.9

[5] Year the price difference between the case without and with FE R&D exceeds 1 percent.
[6] To view year-by-year emission trends, see the graphs under "Emissions from the Electricity Generation Sector".

Diversity of Power Generation Suite

It is often thought that diversity lends itself to survival. In terms of an energy portfolio, diversity in capacity can lend to stability because no one technology breakdown can cripple the energy sector. In the scenarios with no FE R&D, power generation is concentrated in single-fuel, conventional technologies. The addition of FE technologies allows the power generation sector to invest in alternative technologies that, in some instances, are multi-fuel technologies. By 2025, the addition of FE technologies as viable generation options allows the generation sector to diversify the nation's capacity suite while allowing a more balanced mix of fuels to be used in the effort to meet emission standards and provide economic savings to consumers. FE technologies such as fuel cells and IGCC without sequestration are particularly important in increasing the diversity of the power generating capacity; see graphs under Total Capacity Diversity.

Summary

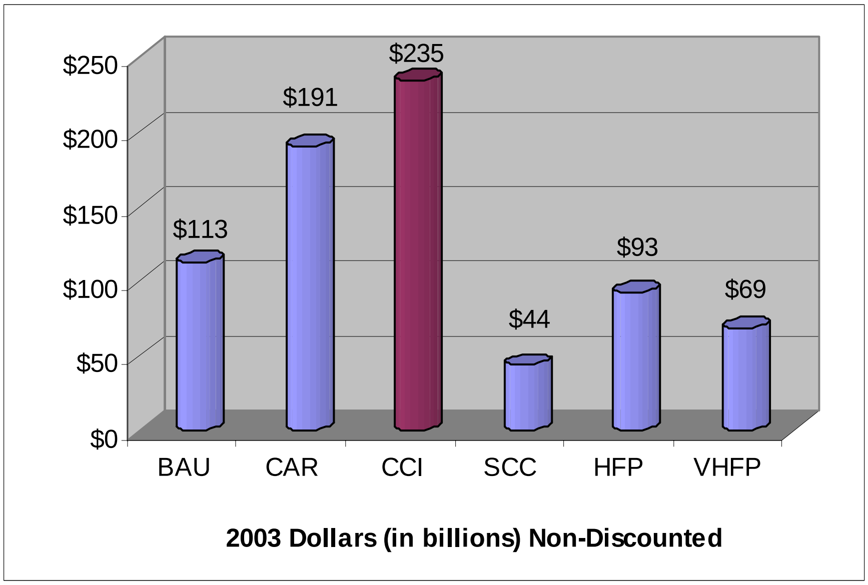
FE is charged with engaging in R&D that introduces or accelerates the advent of technologies that provide measurable economic and environmental benefits to the nation. Under the six scenarios analyzed, scenarios that represent plausible futures comprised of various levels of emission constraints and fuel policies, quantifiable benefits are incurred by society as a result of FE R&D. Cumulative economic benefits resulting from declines in the price of utility-generated electricity range from $25 to $152 billion (discounted); environmental benefits include NO_x reductions of more than 50 percent, SO_x reductions exceeding 60 percent, mercury reductions surpassing 70 percent and CO_2 emissions falling by more than 45 percent. In addition to these key benefits, the advent of FE R&D lends to a more stable and diverse power generation portfolio that supports the role of America's more secure and abundant fuel resource – coal.

Abbreviations Legend

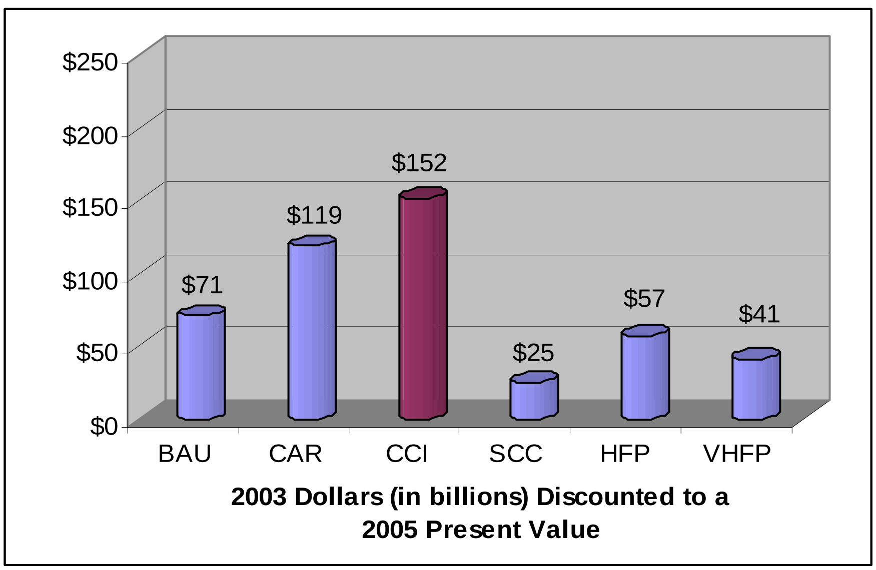
AEO	Annual Energy Outlook
Btu	British Thermal Unit
CAIR	Clean Air Interstate Rule
CAMR	Clean Air Mercury Rule
GCCI	Global Climate Change Initiative
CO_2	Carbon Dioxide
DG	Distributed Generation
DOE	US Department of Energy
EIA	US Energy Information Administration
EPA	US Environmental Protection Agency
ESE	Energy, Science and Environment
FE	Office of Fossil Energy
FY	Fiscal Year
GHG	Greenhouse Gas
GW	Gigawatt
H_2	Hydrogen
Hg	Mercury
IGCC	Integrated Gasification Combined-Cycle
kWh	Kilowatt Hour
LNG	Liquefied Natural Gas
MMBtu	Million Btu
NEMS	National Energy Modeling System
NGCC	Natural Gas Combined-Cycle
NOx	Nitrogen Oxides
PC	Pulverized Coal
R&D	Research & Development
Seq.	Sequestration
SO_2	Sulfur Dioxide
SOx	Sulfur Oxides
Tcf	Trillion Cubic Feet

FE R&D Economic Benefits
Cumulative Electricity Savings from 2004 to 2025

Graph 1.

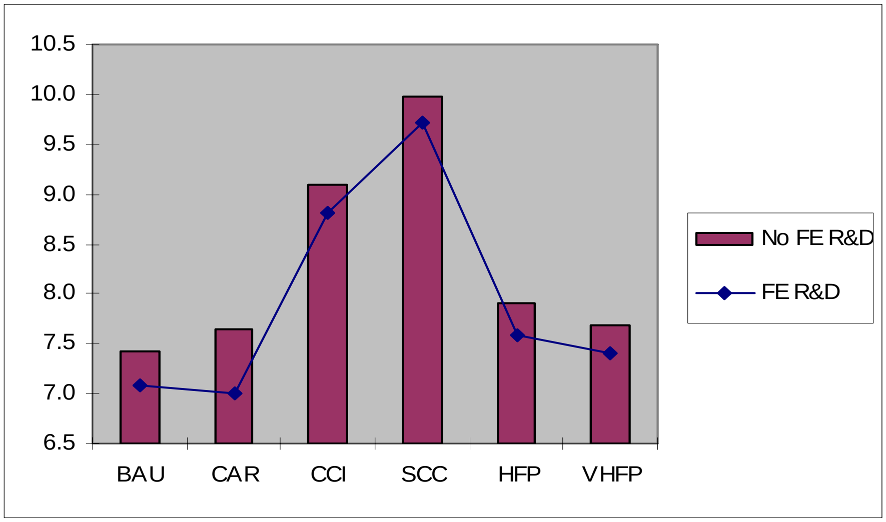


Graph 2.



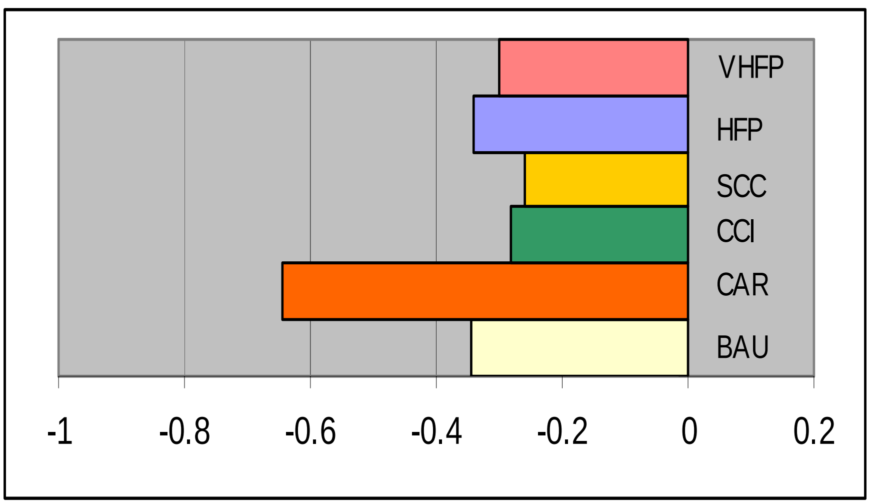
Average Price of Electricity
¢/kWh, 2025

Graph 3.



Electricity Price Difference in 2025
"FE R&D" less "No FE R&D" Prices

Graph 4.



¢/kWh

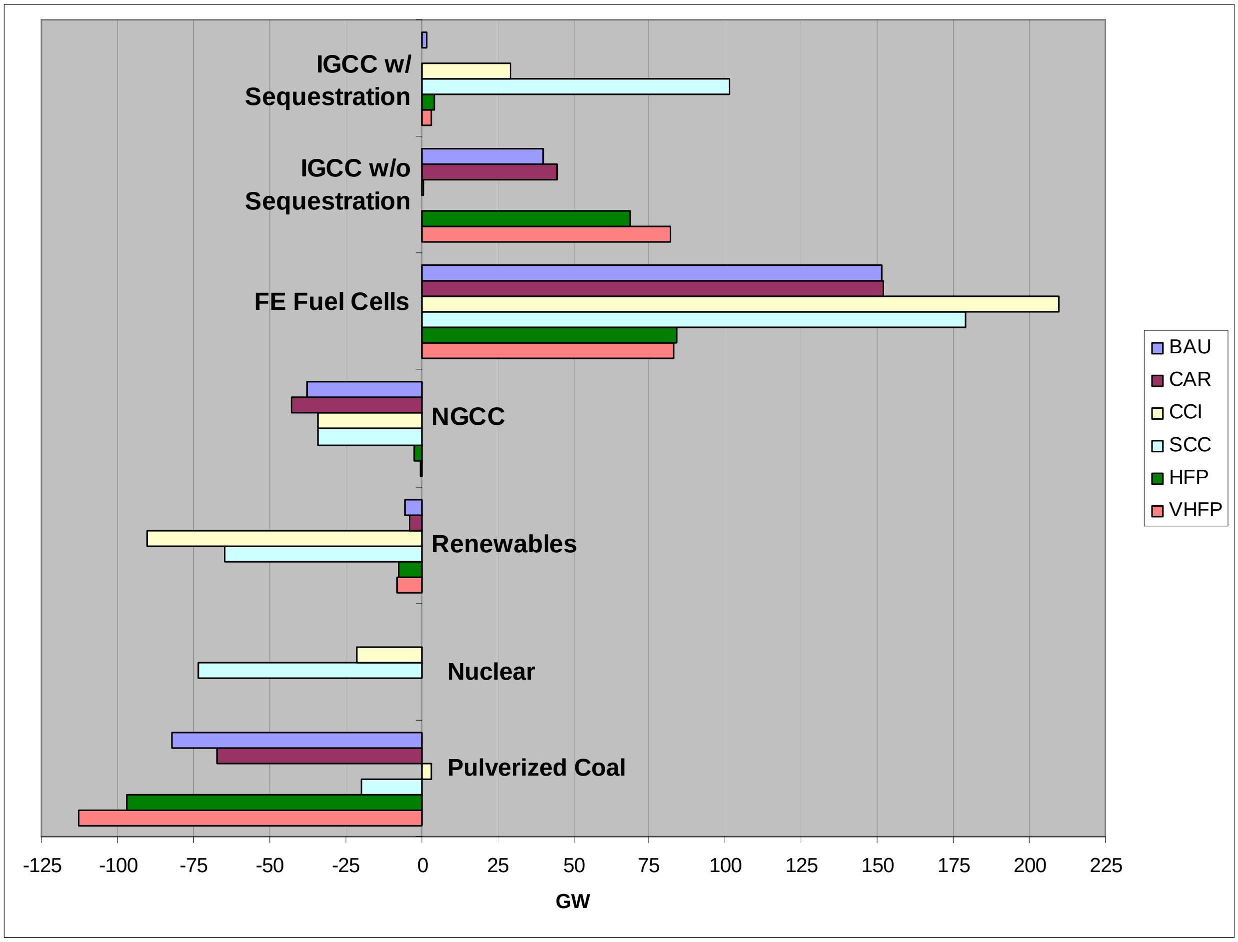
Table 2. Average Price of Electricity (¢/kWh), 2005 and 2025

	Average Price of Electricity (¢/kWh)	
	2005	2025
Business-As-Usual		
No FE R&D	7.4	7.4
FE R&D	7.4	7.1
Clean Air Rules		
No FE R&D	7.4	7.6
FE R&D	7.4	7.0
Global Climate Change Initiative		
No FE R&D	7.4	9.1
FE R&D	7.4	8.8
Severe Carbon Constraint		
No FE R&D	7.4	10.0
FE R&D	7.4	9.7
High Fuel Prices		
No FE R&D	7.4	7.9
FE R&D	7.4	7.6
Very High Fuel Prices		
No FE R&D	7.4	7.7
FE R&D	7.4	7.4

Note: Recall that the High Fuel Price (HFP) and Very High Fuel Price (VHFP) cases are defined as having higher world oil prices than other cases, with the world oil price in the VHFP being the highest.

Additional Net Capacity[7]
(cumulative, 2004-2025)
"FE R&D" less "No FE R&D" Net Capacity Change[8]

Graph 5.

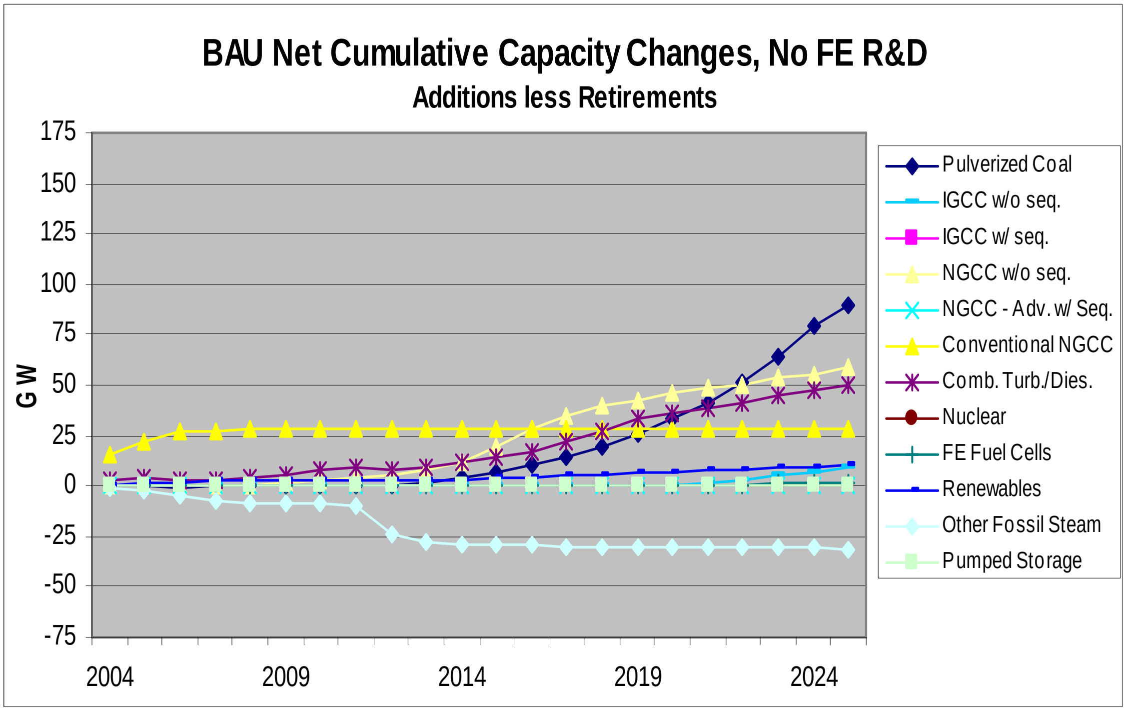


[7] Net Capacity Change is calculated as Capacity Additions less Capacity Retirements

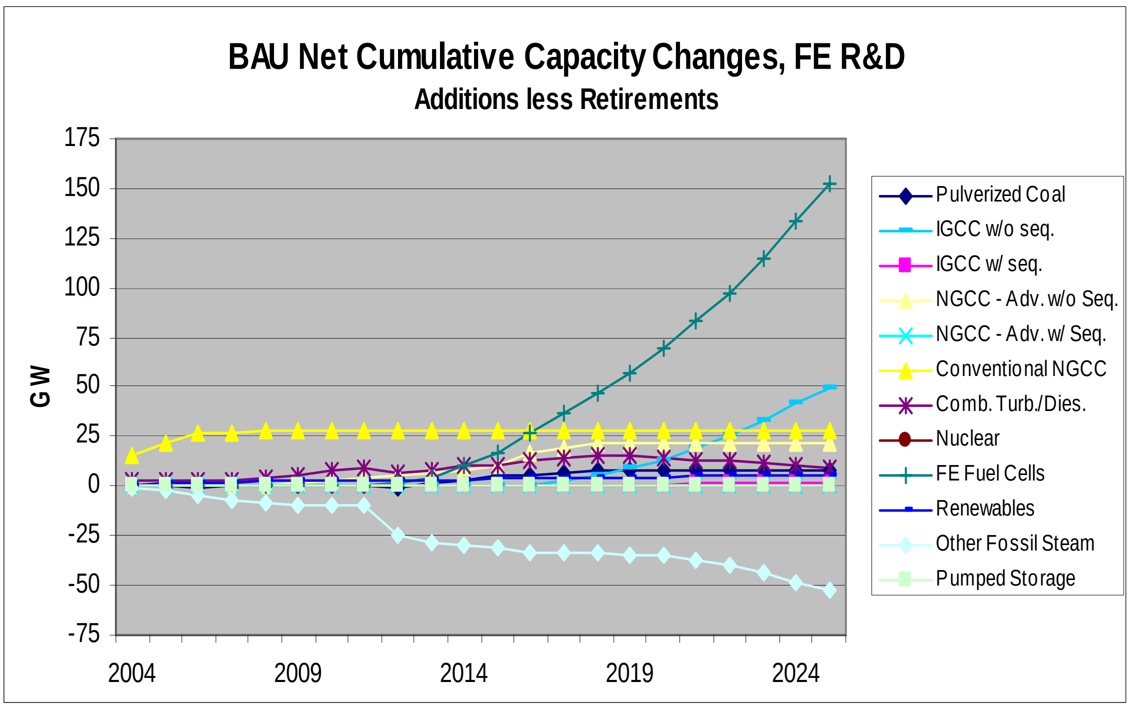
[8] Note that this graph represents the difference between two cases. A positive difference only indicates that the case with No FE R&D had fewer additions or more retirements and does not indicate that additions were greater than retirements. For example, the net capacity change of PC plants under the GCCI scenario fell (retirements > additions) in both the FE R&D case and the No FE R&D case. The positive result in this graph represents that there were fewer net retirements in the FE R&D case.

Power Generation Net Capacity Change

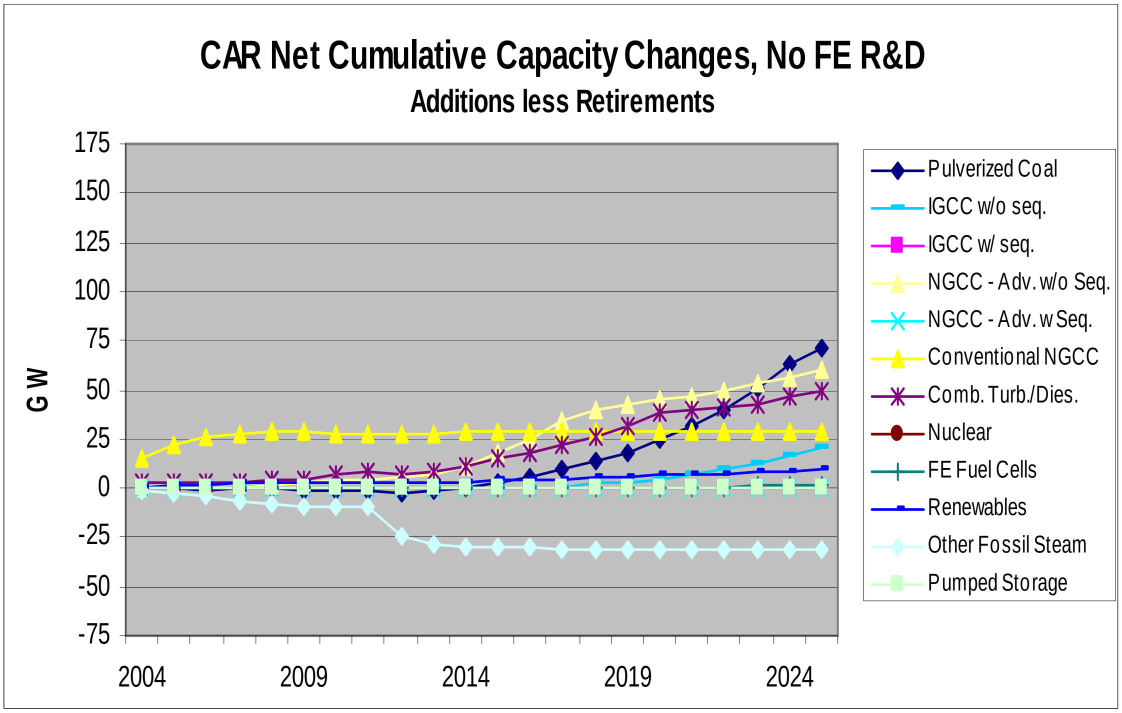
Graph 6.



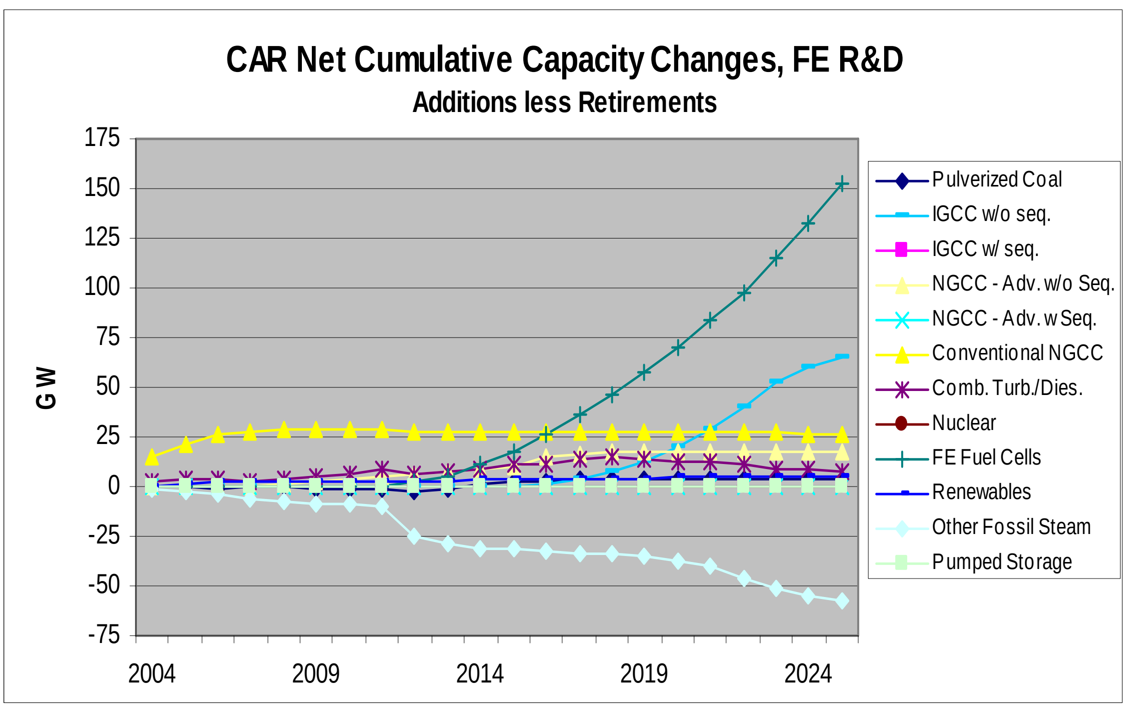
Graph 7.



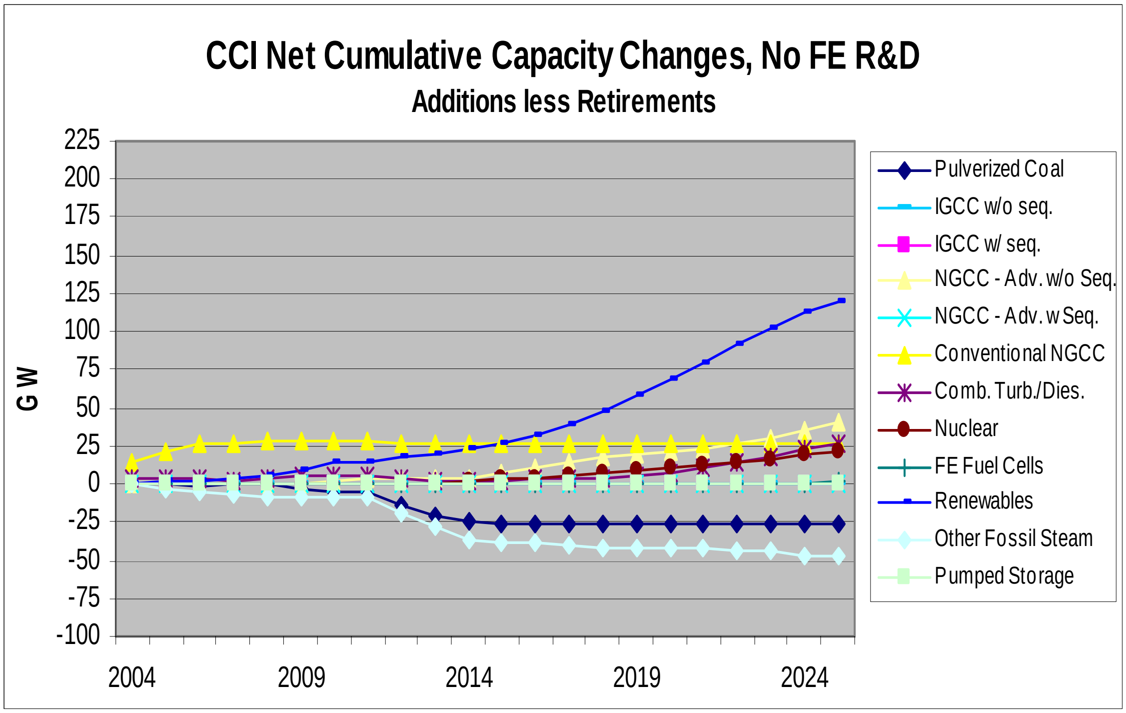
Graph 8.



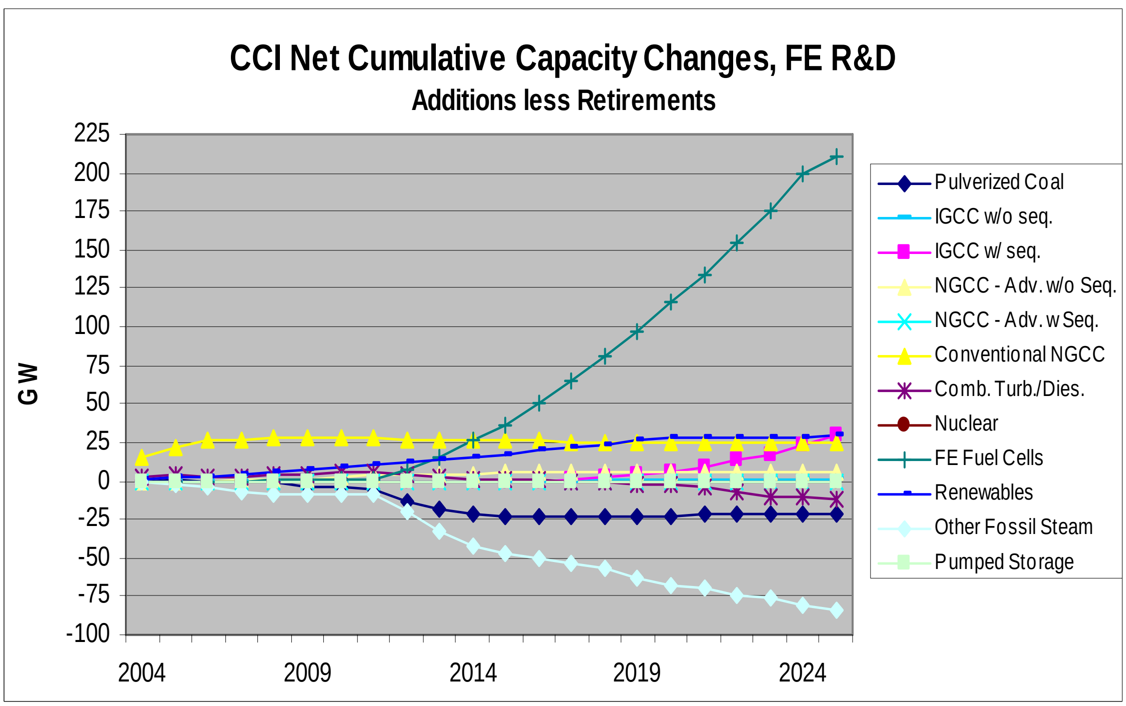
Graph 9.



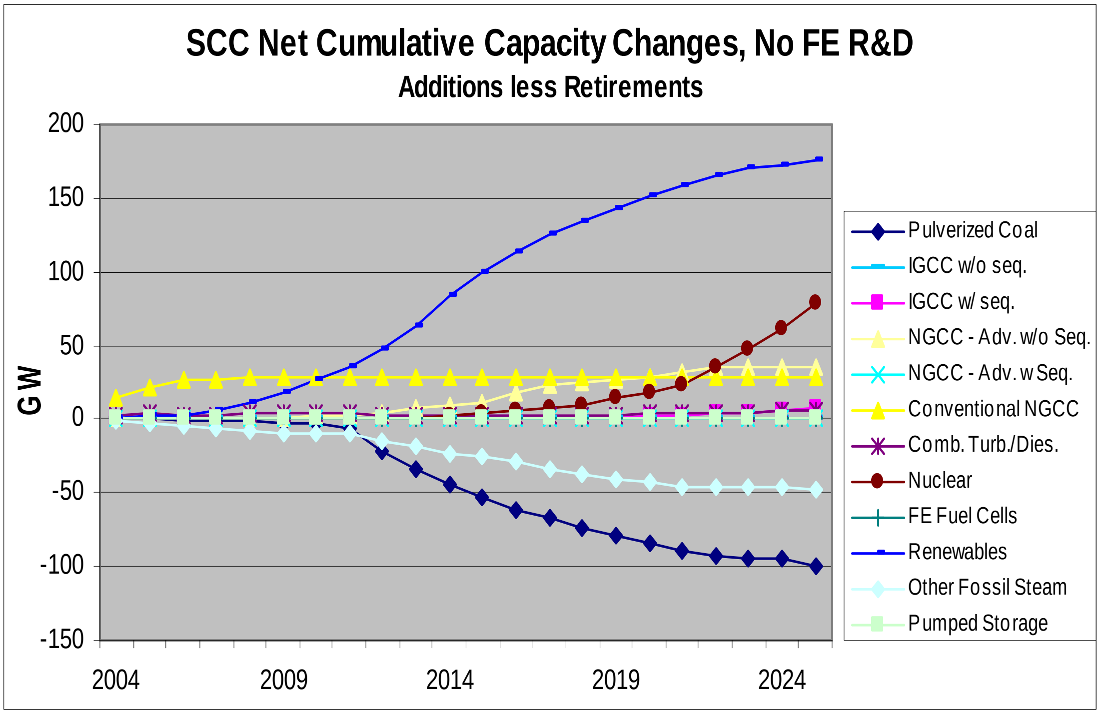
Graph 10.



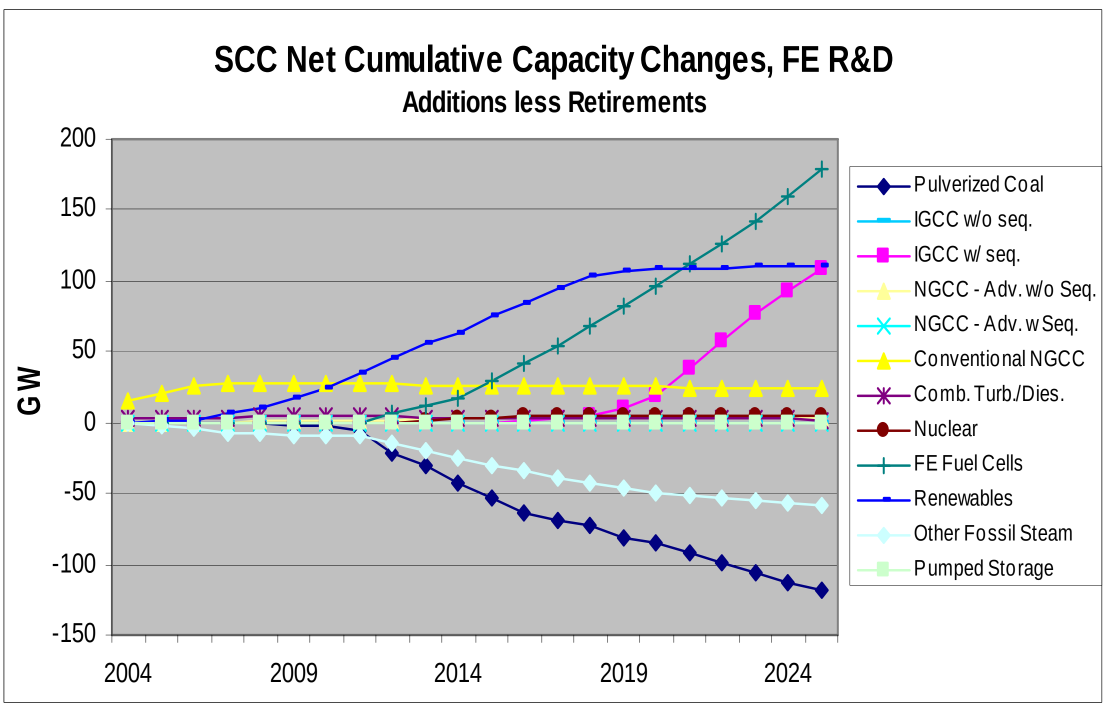
Graph 11.



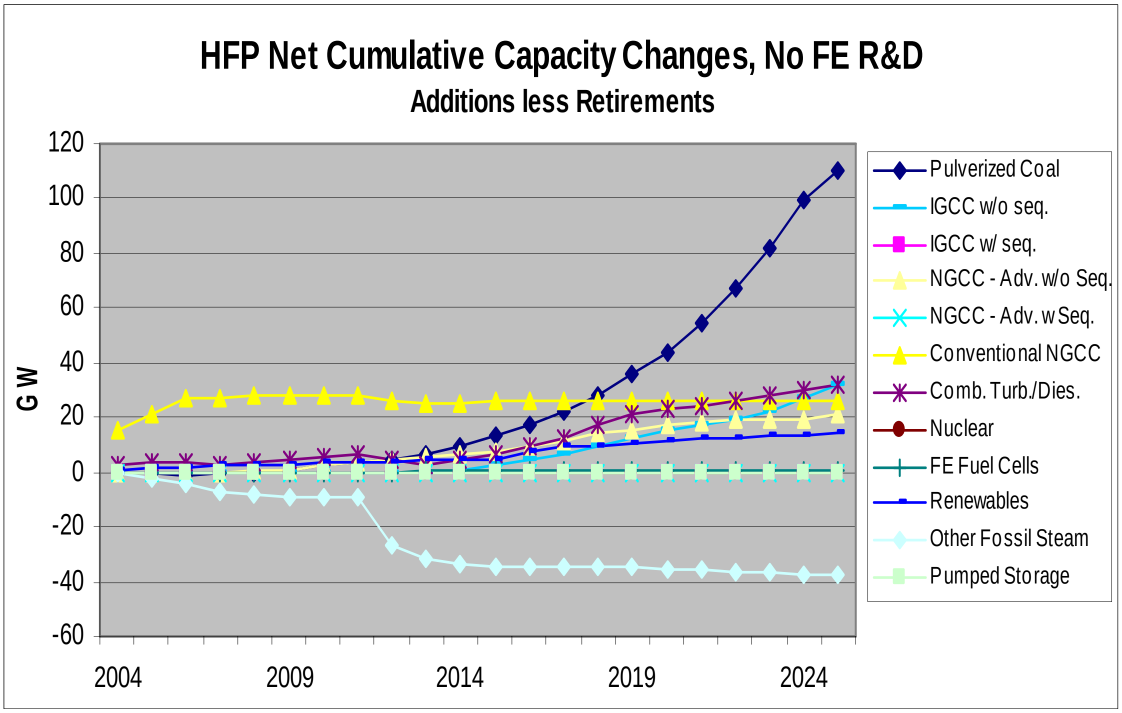
Graph 12.



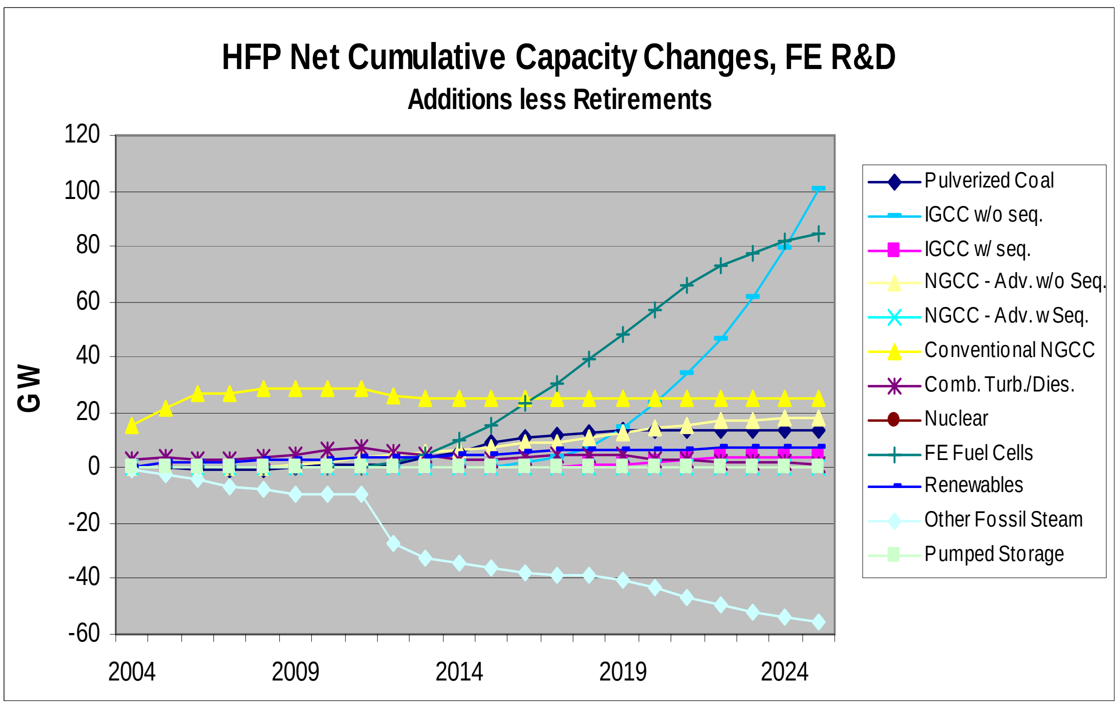
Graph 13.



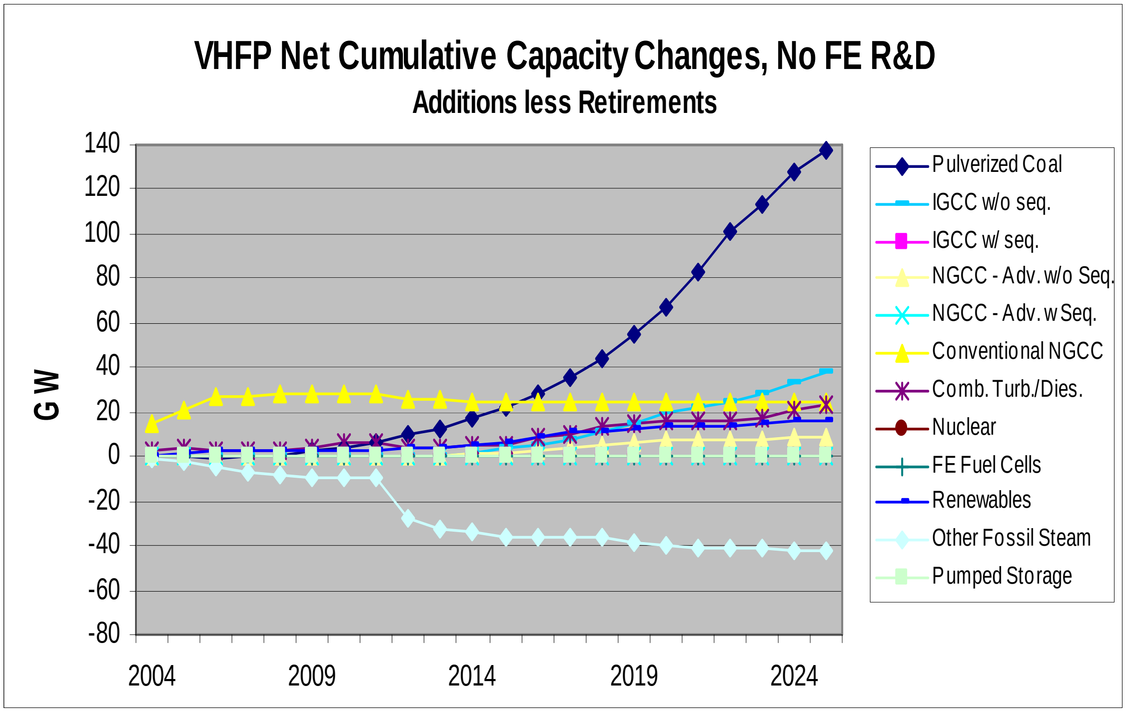
Graph 14.



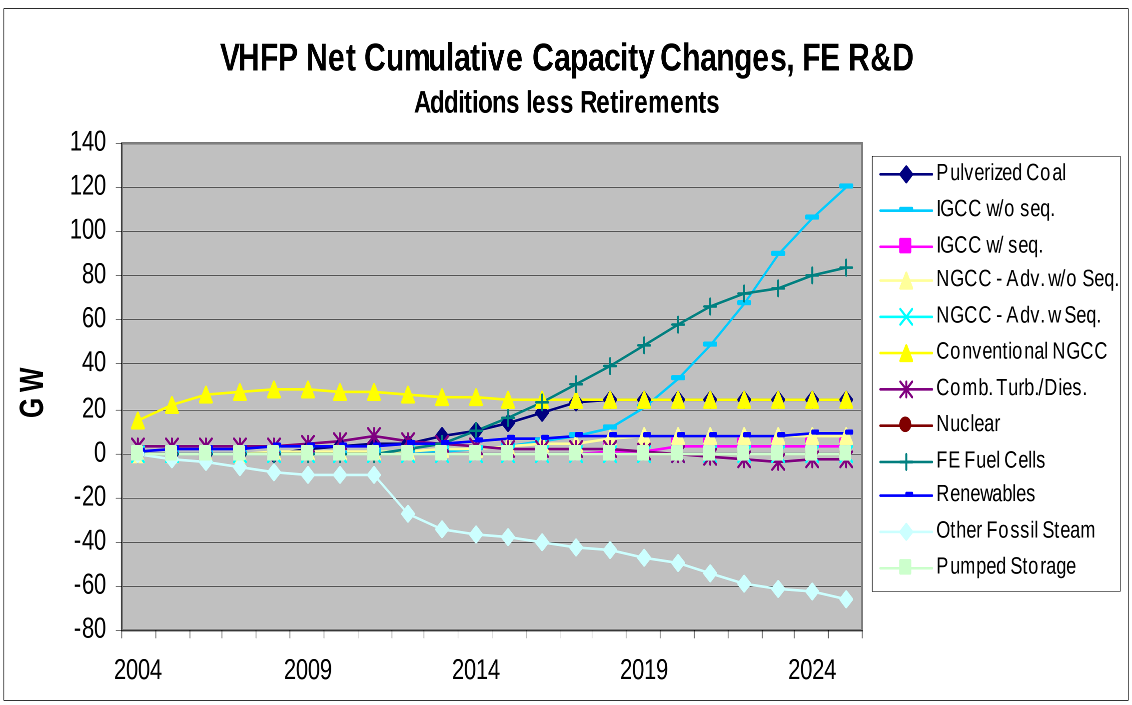
Graph 15.



Graph 16.

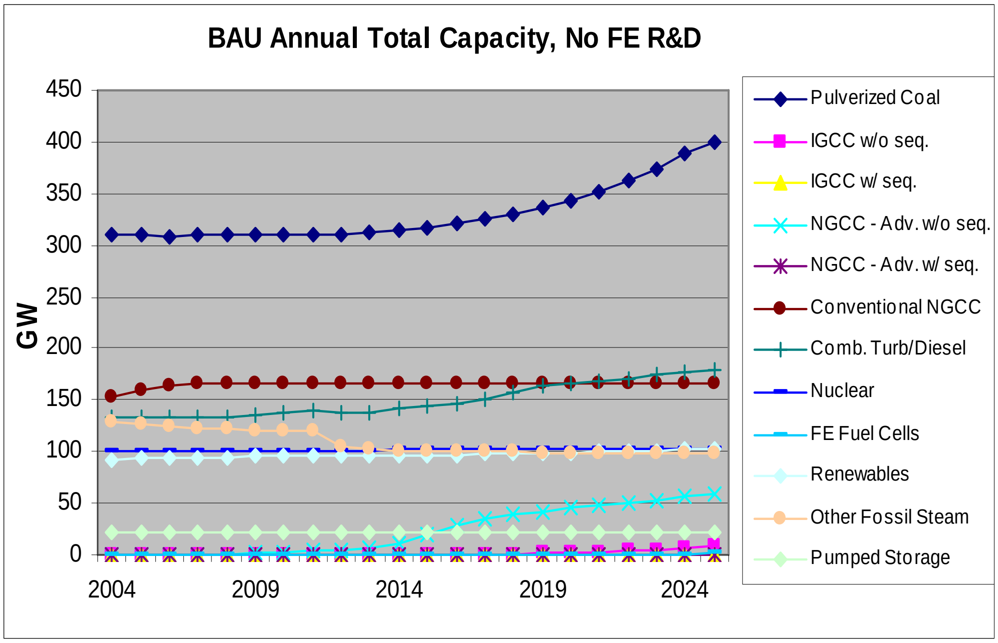


Graph 17.

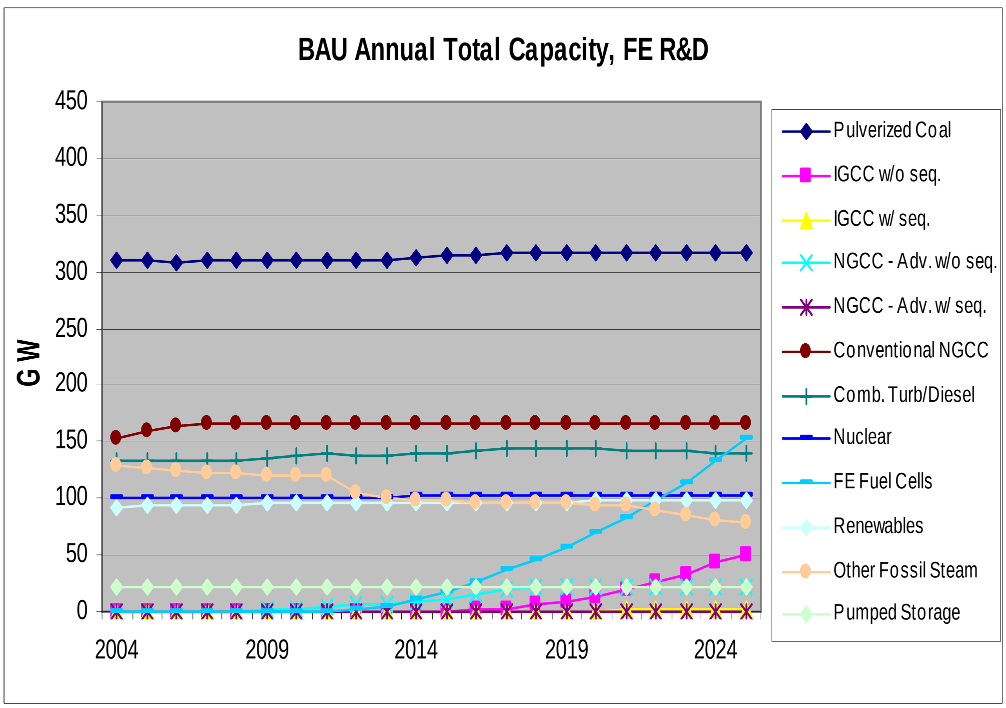


Power Generation Total Capacity

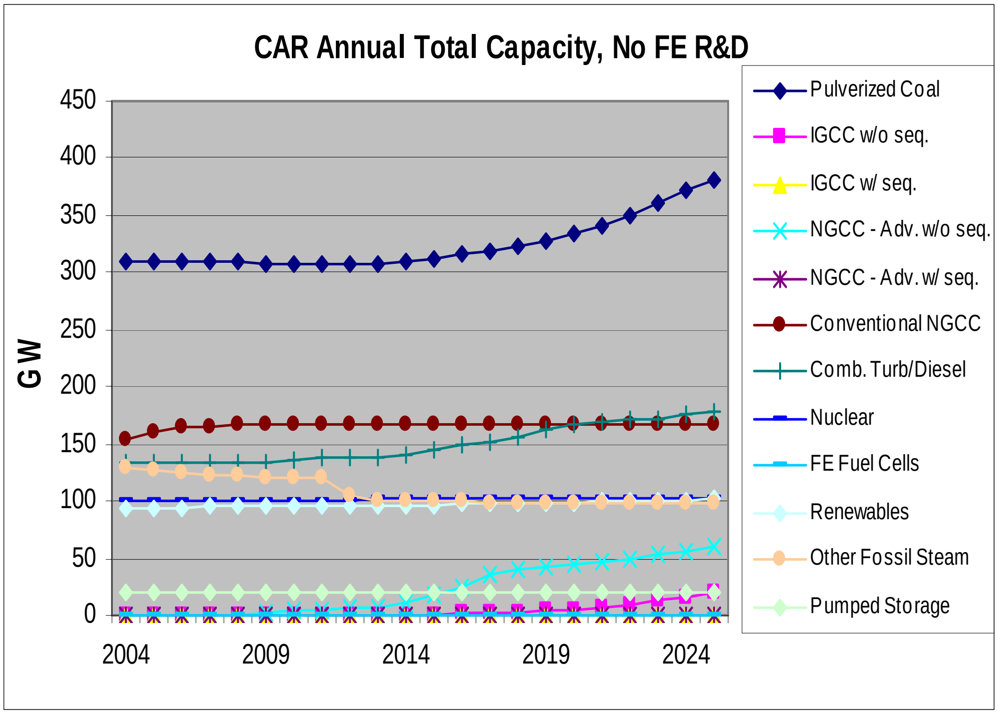
Graph 18.



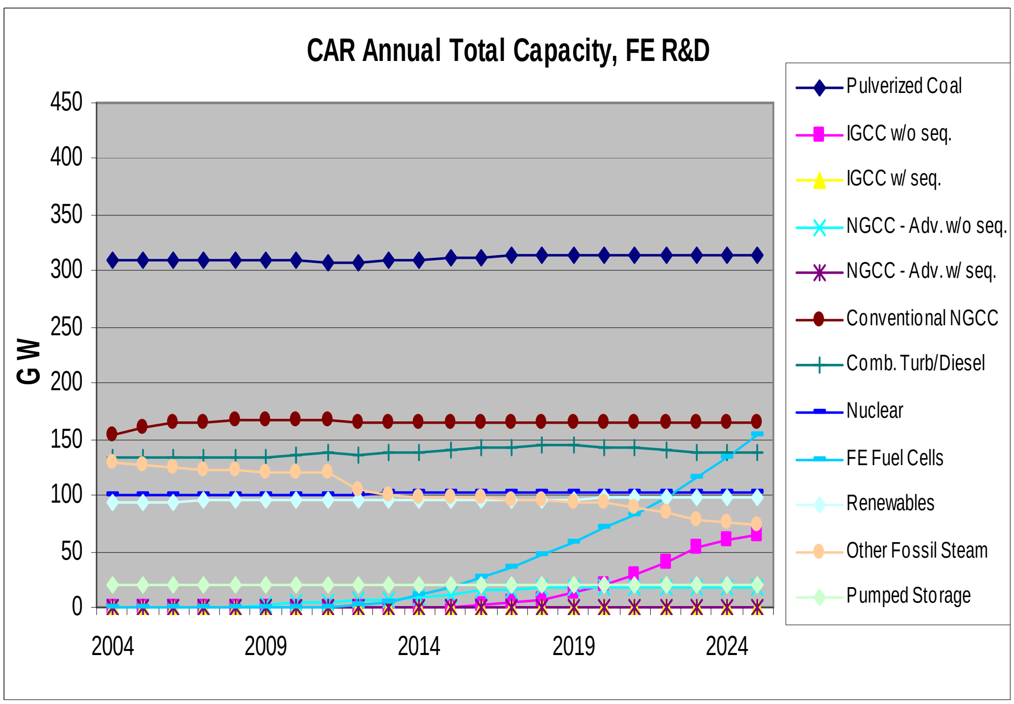
Graph 19.



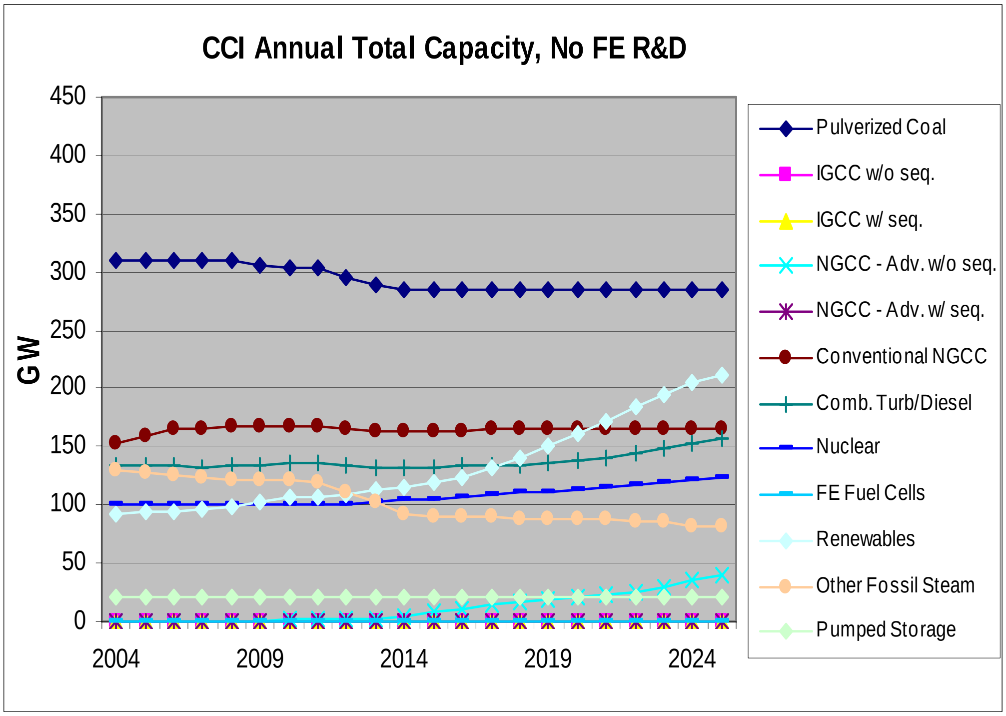
Graph 20.



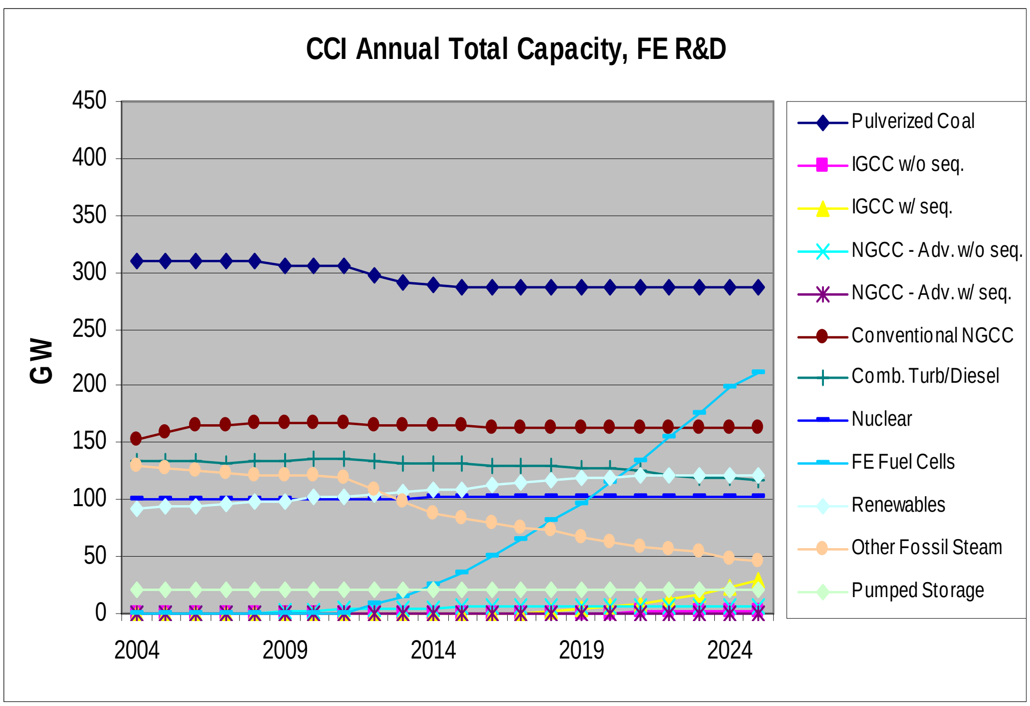
Graph 21.



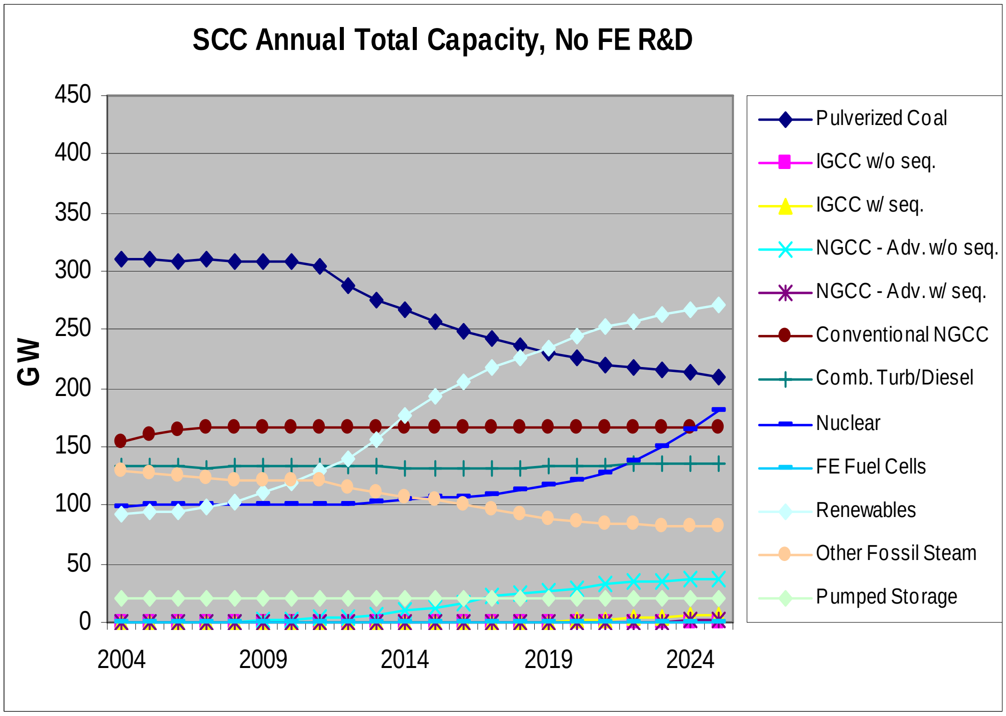
Graph 22.



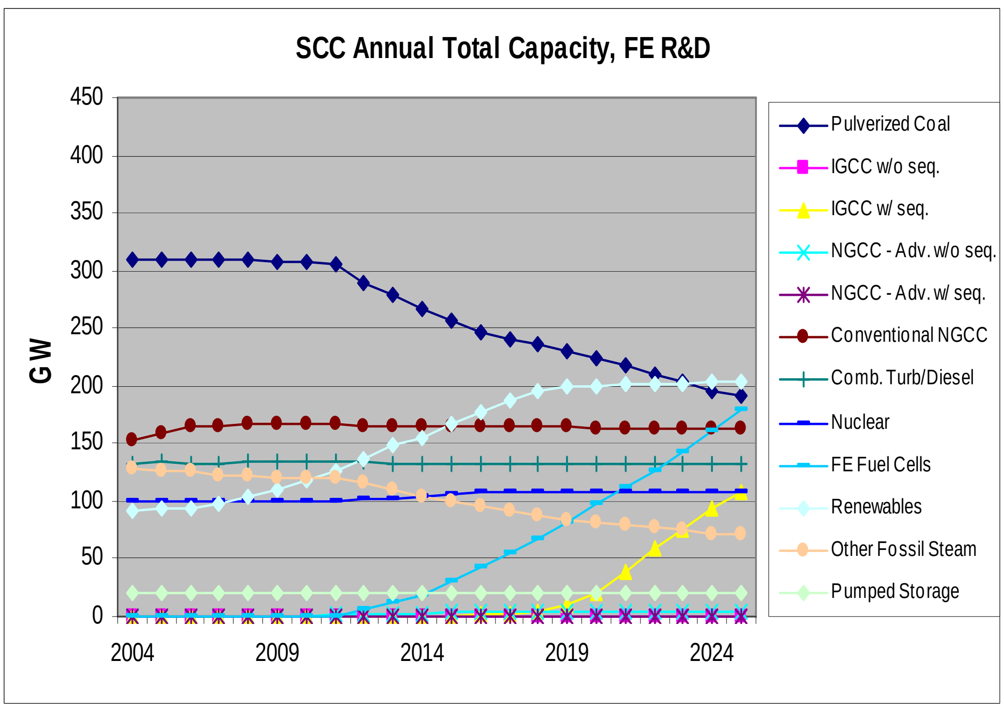
Graph 23.



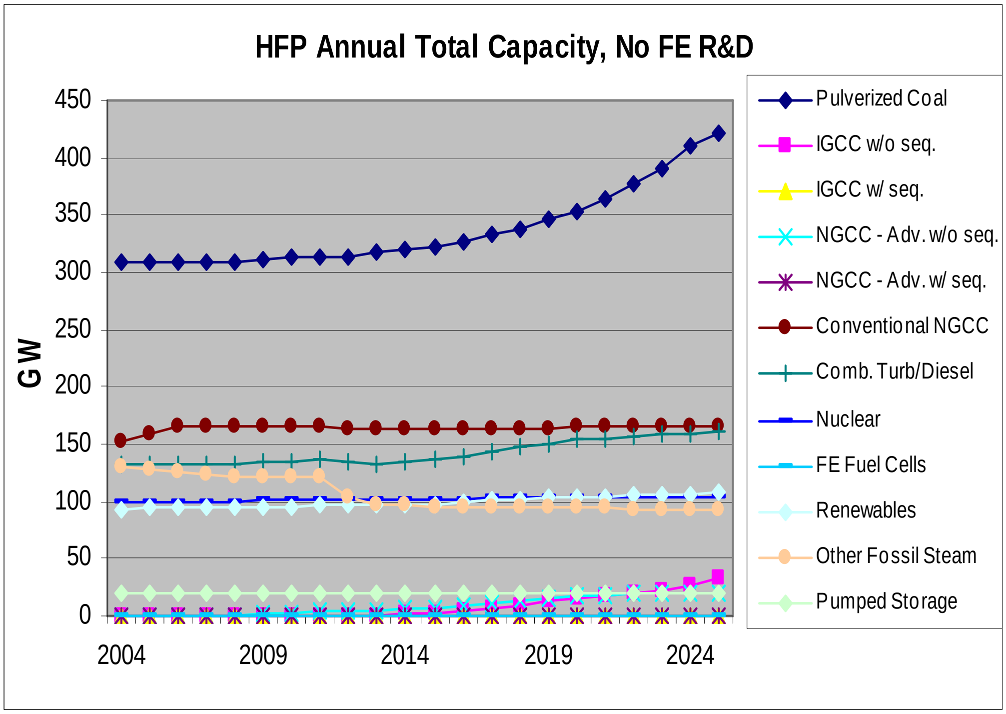
Graph 24.



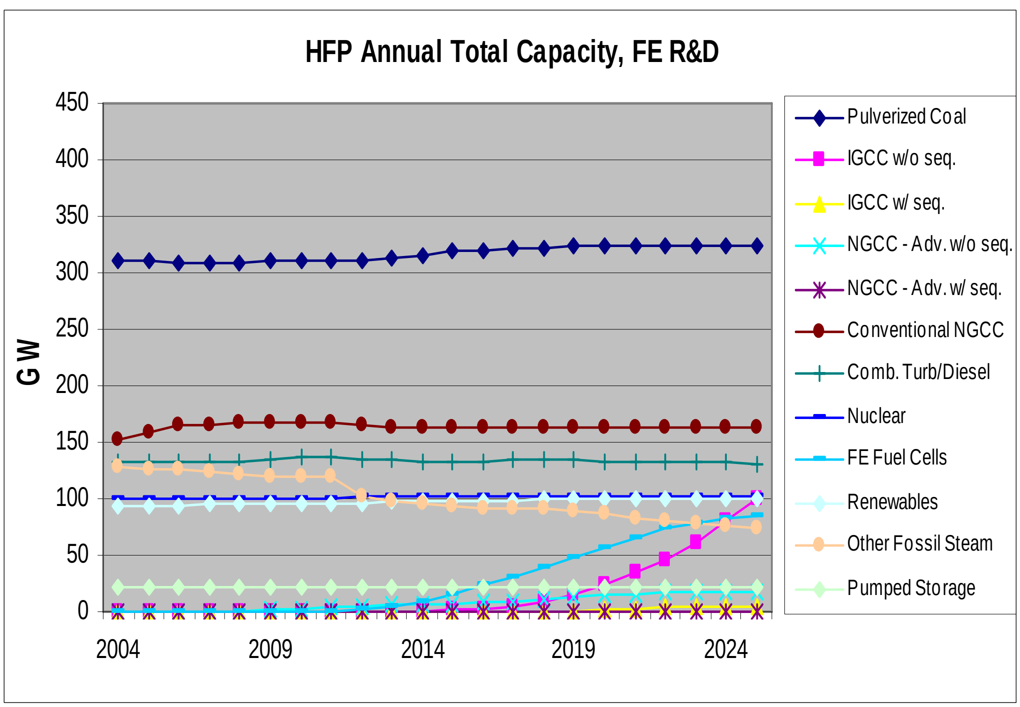
Graph 25.



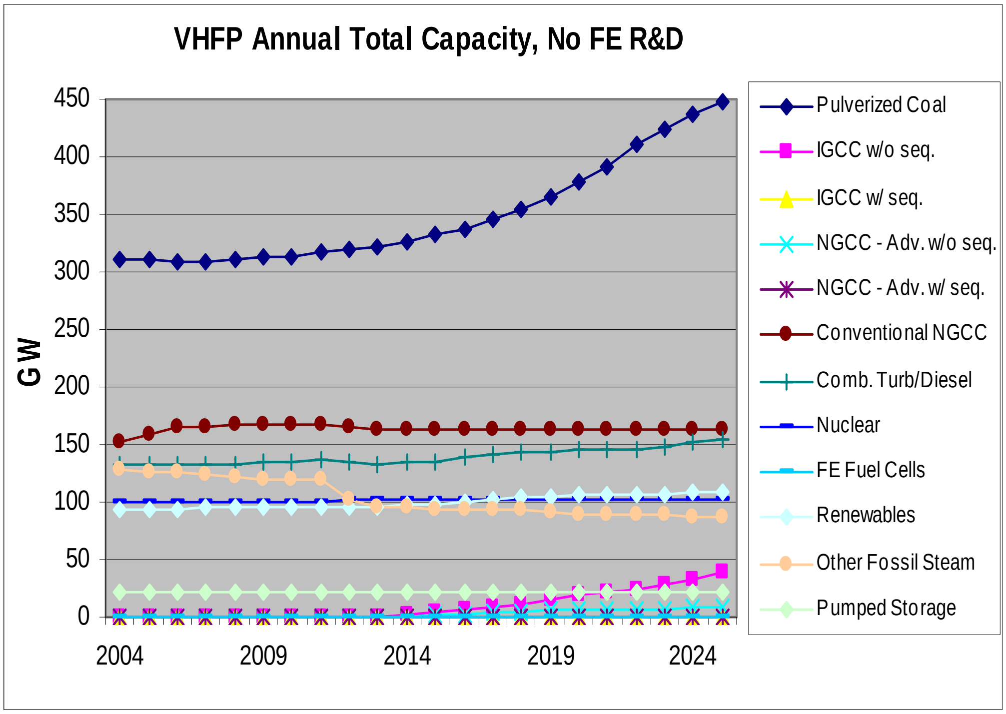
Graph 26.



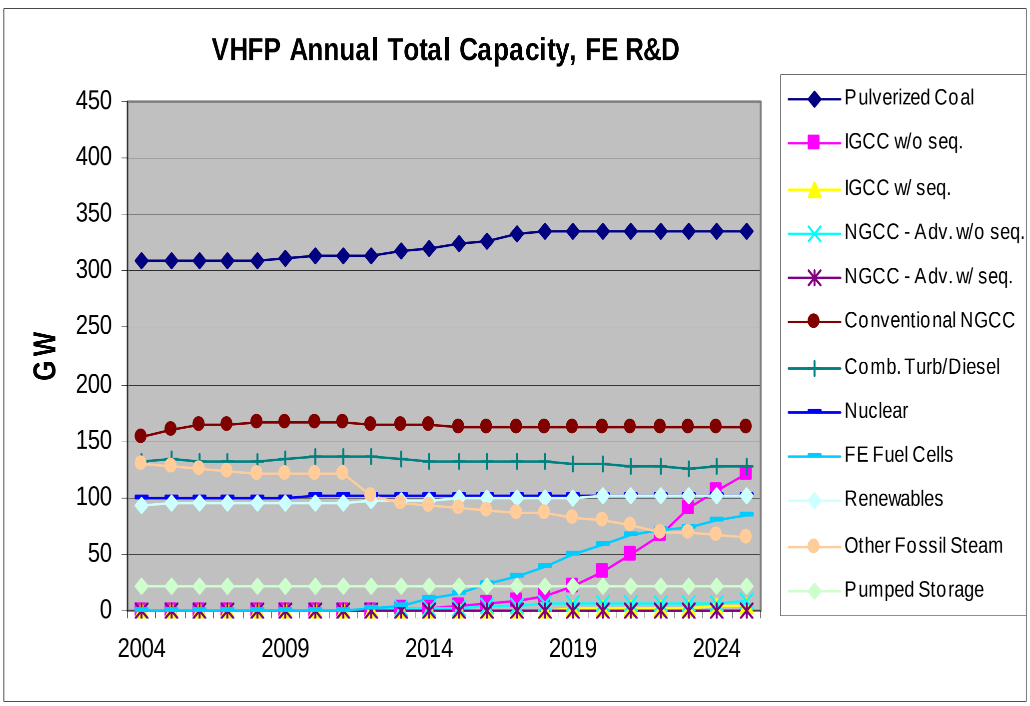
Graph 27.



Graph 28.

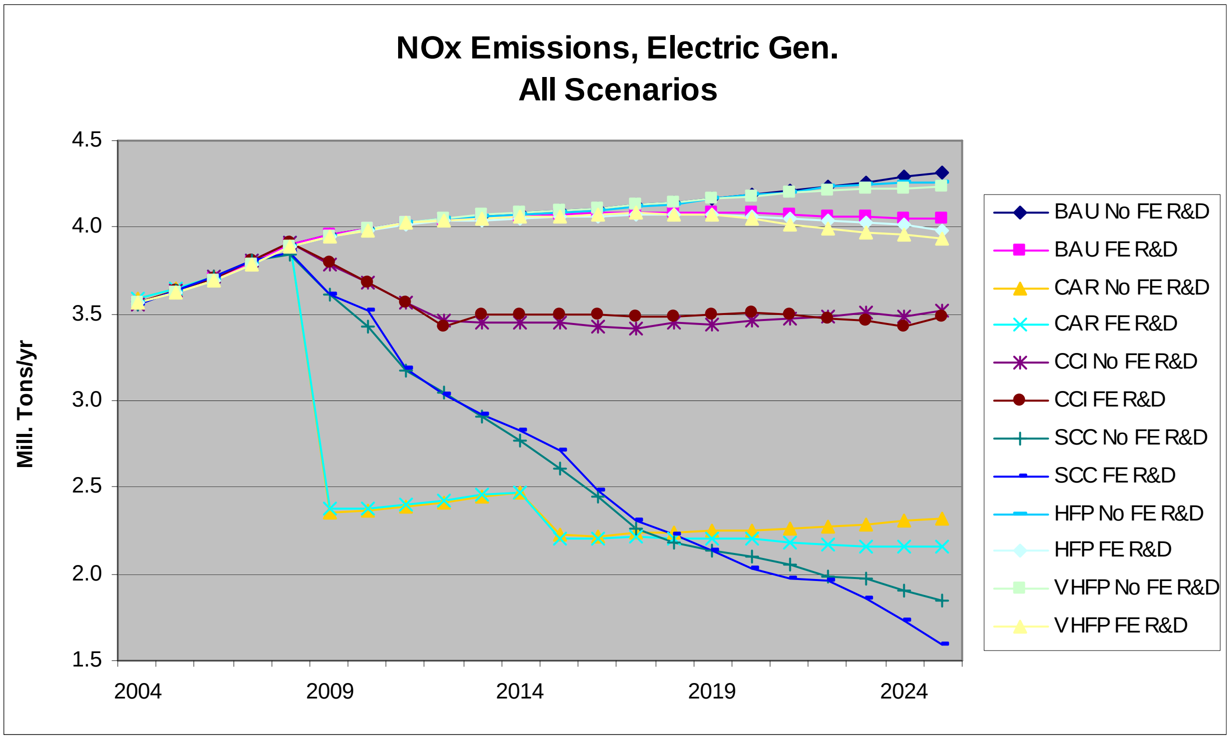


Graph 29.

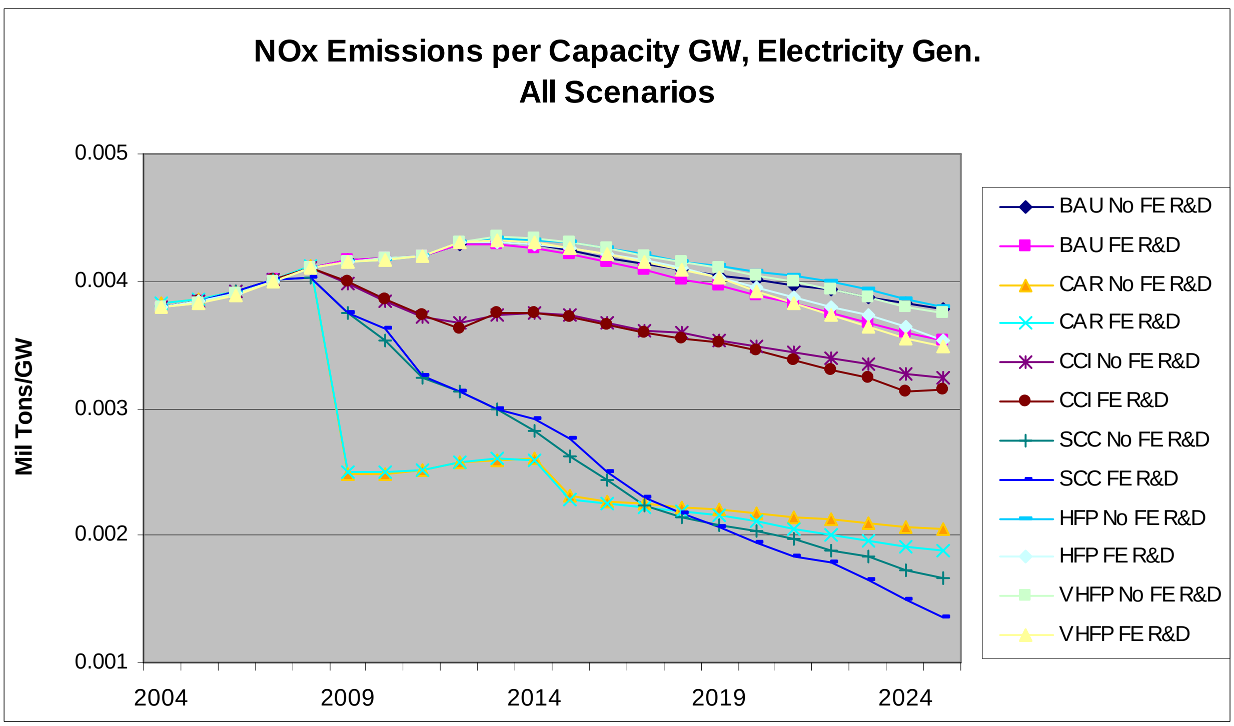


Emissions from the Electricity Generation Sector

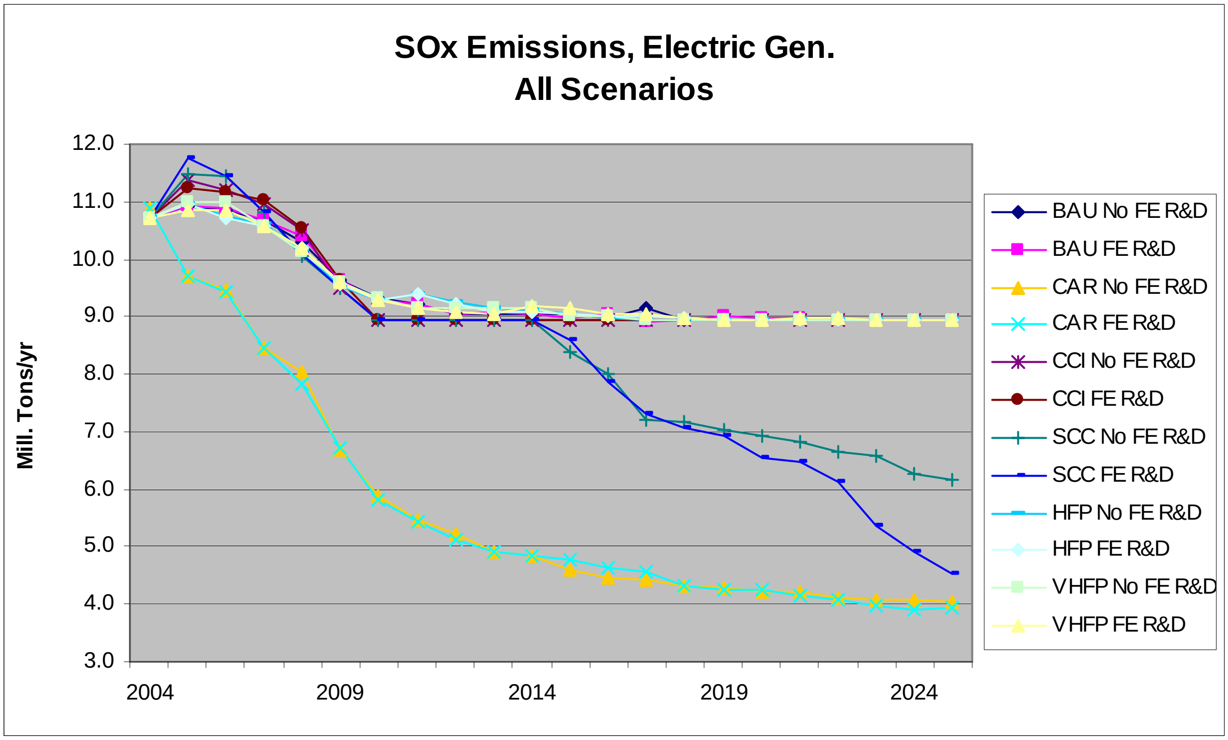
Graph 30.



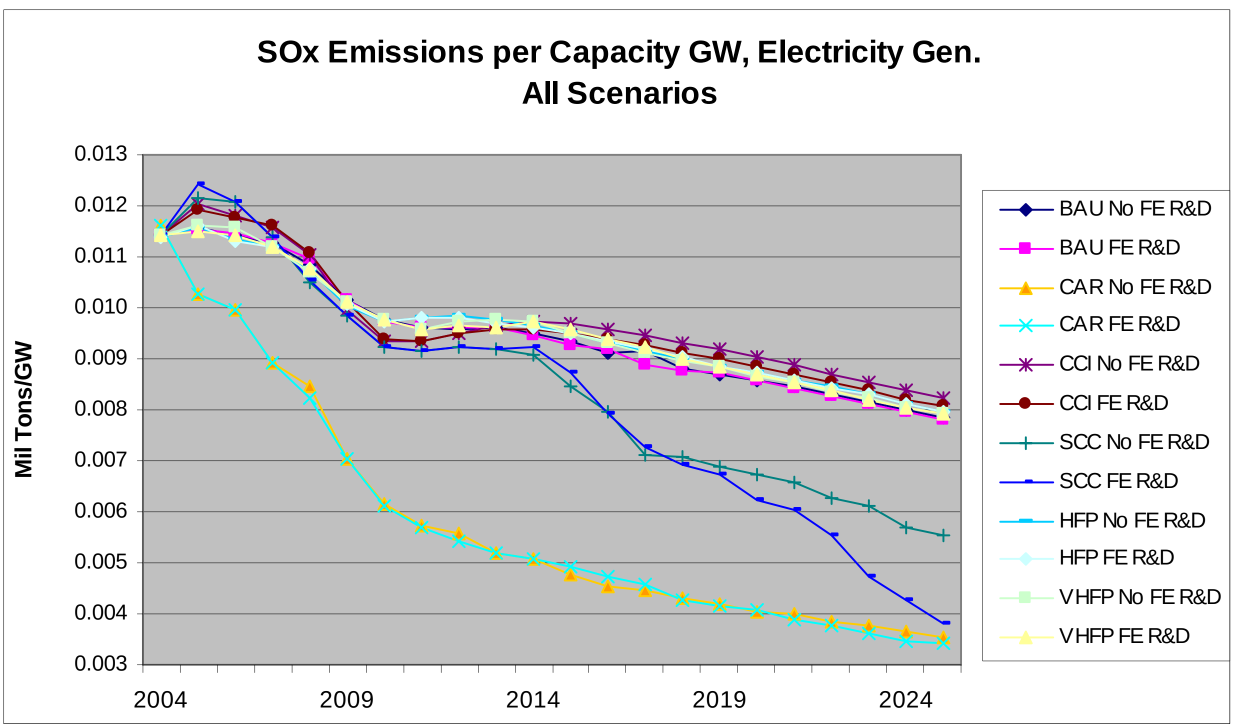
Graph 31.



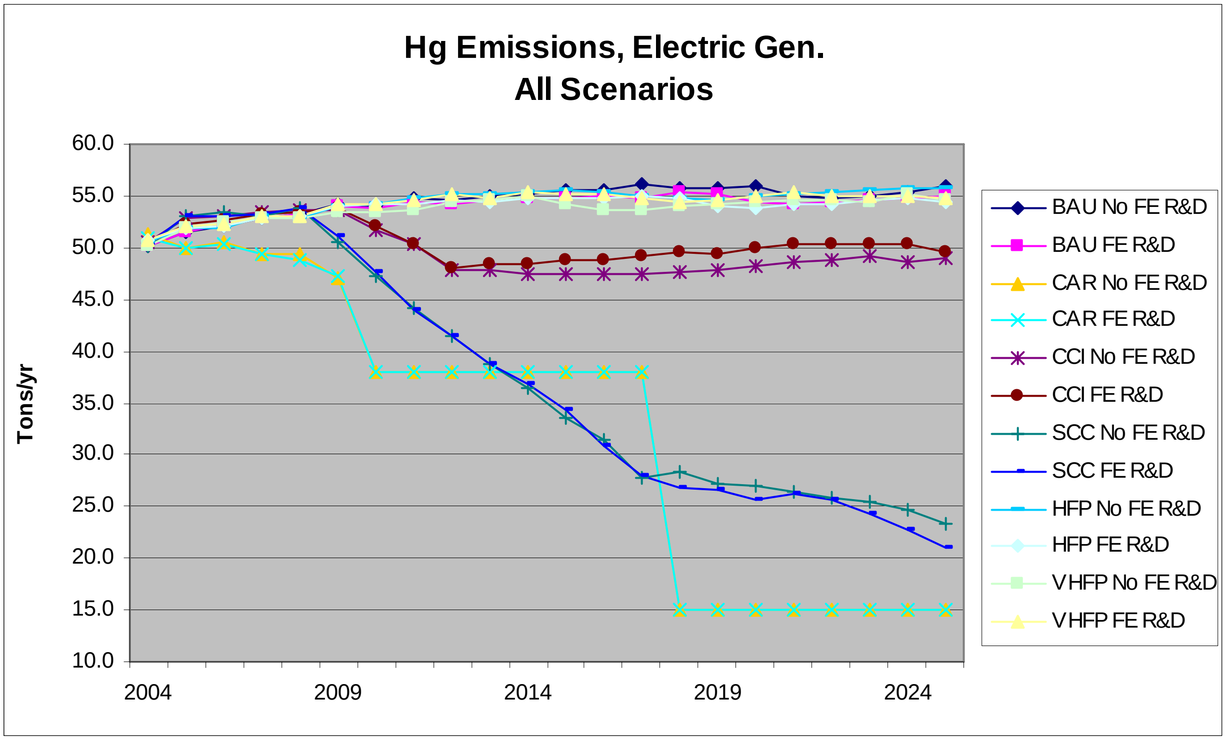
Graph 32.



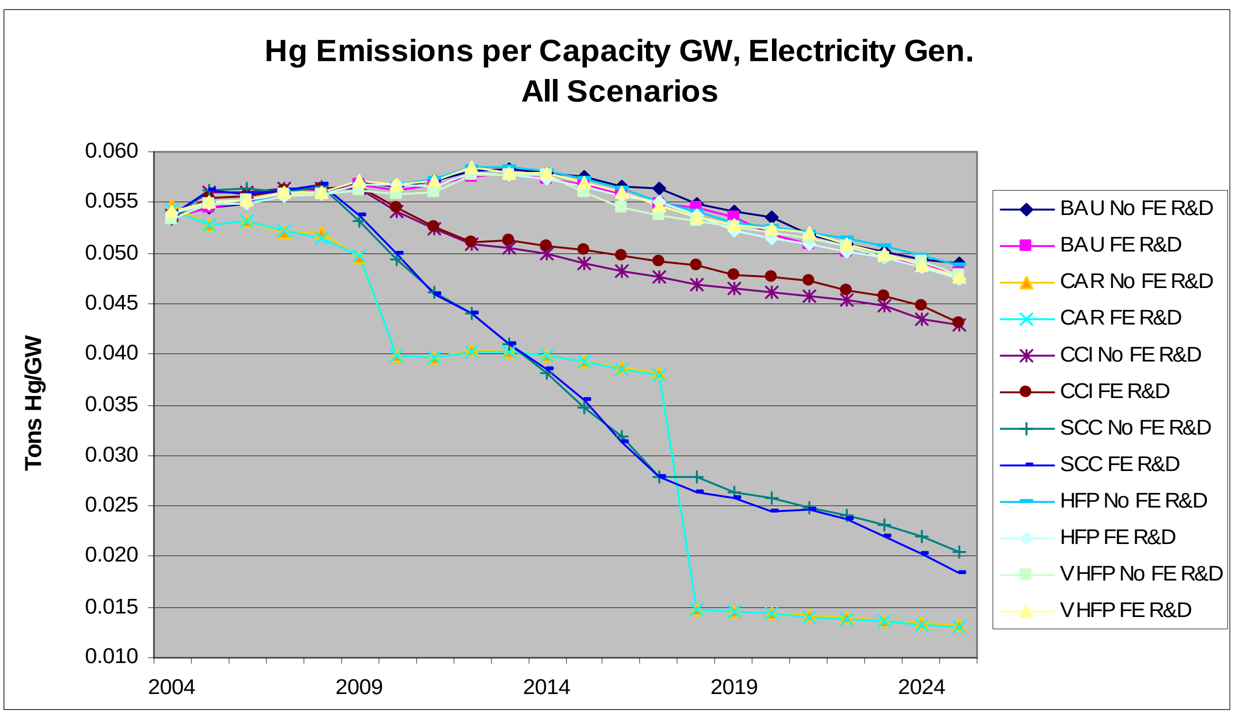
Graph 33.



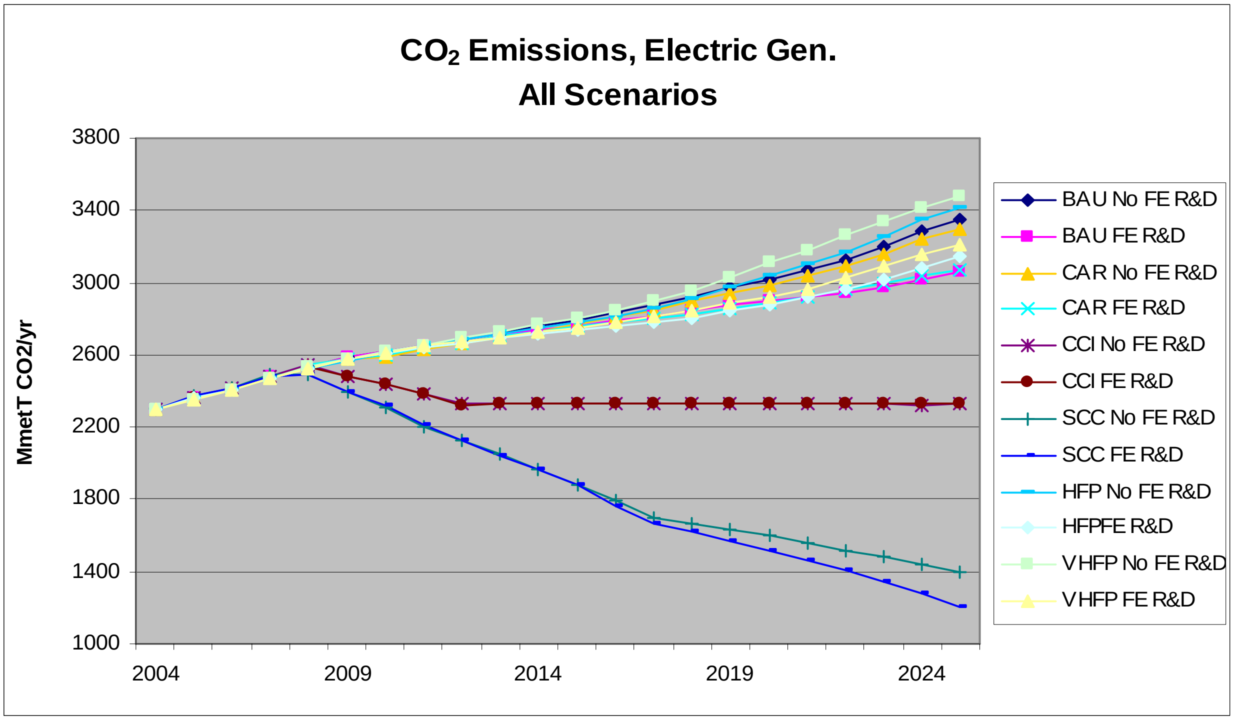
Graph 34.



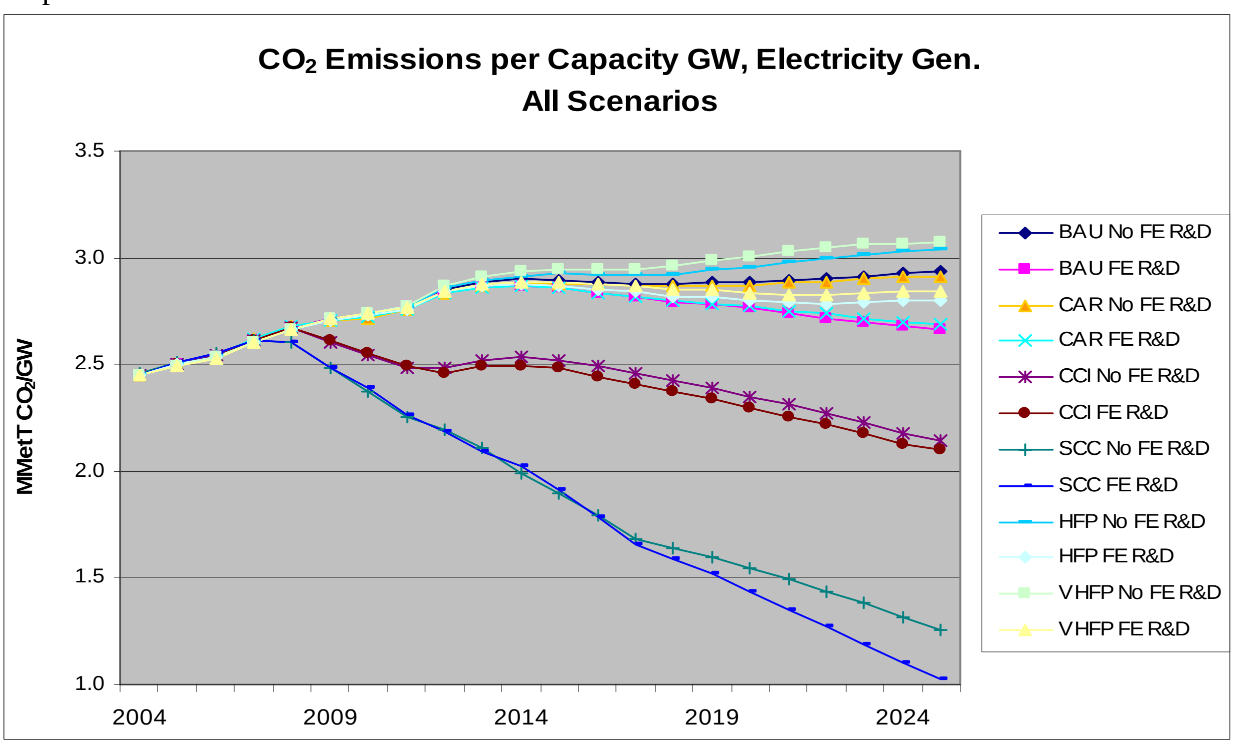
Graph 35.



Graph 36.

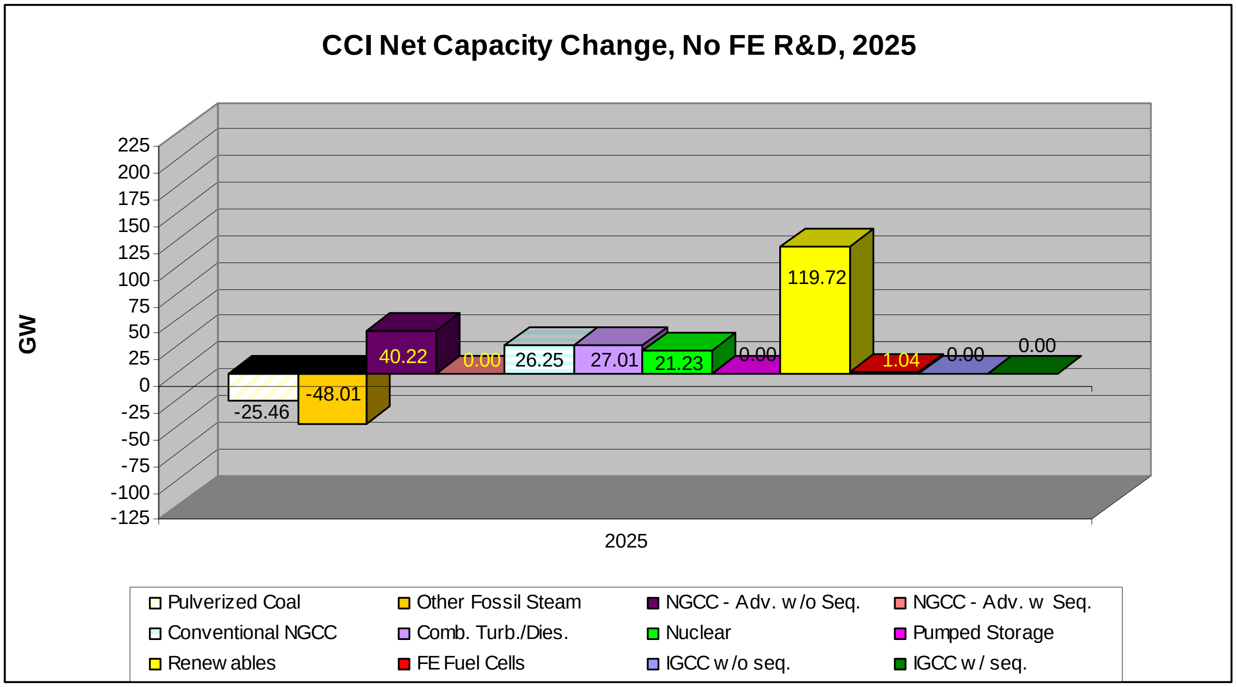


Graph 37.

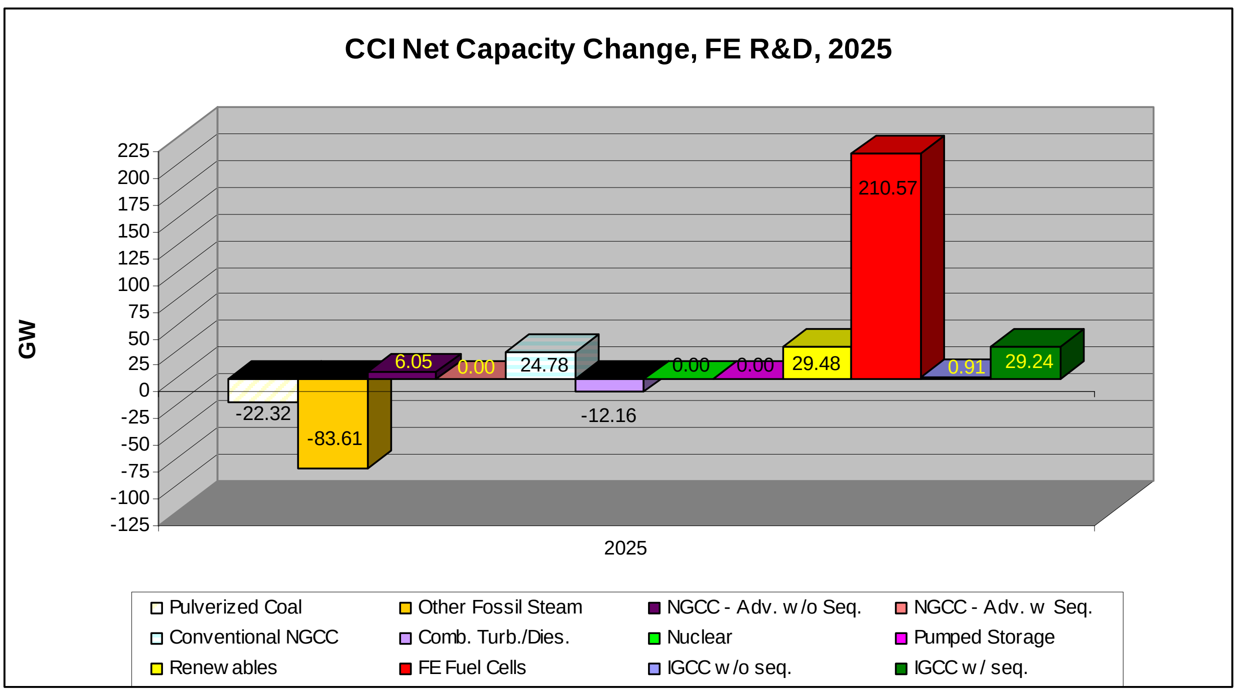


Capacity Suite Diversity under Carbon Cap Cases

Graph 38.

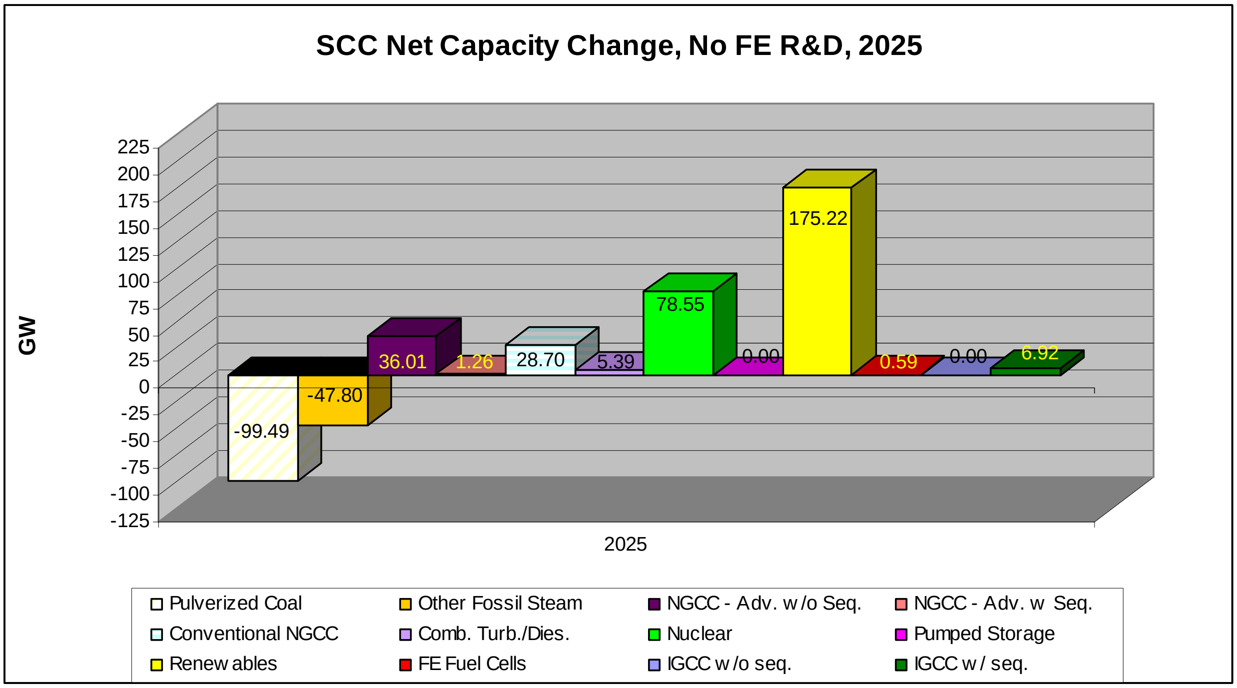


Graph 39.

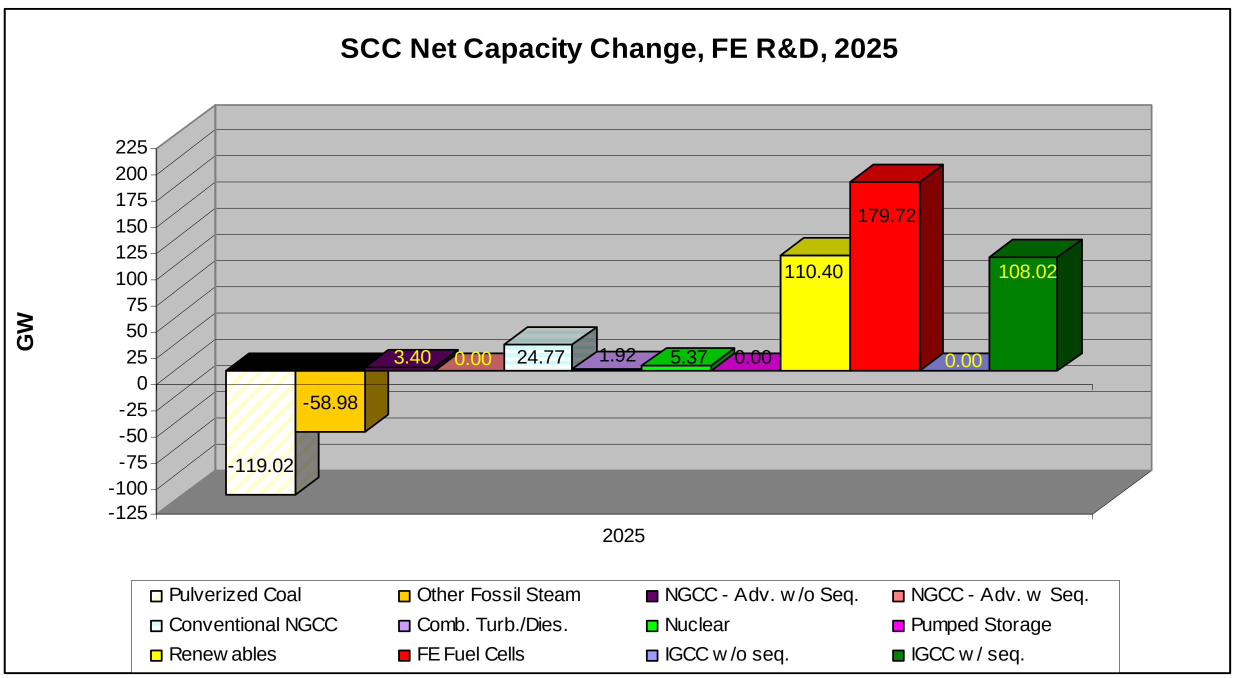


Cost of electricity reduced from 9.1 ¢/kWh in the No FE R&D case to 8.8¢/kWh in the FE R&D case, (2025).

Graph 40.



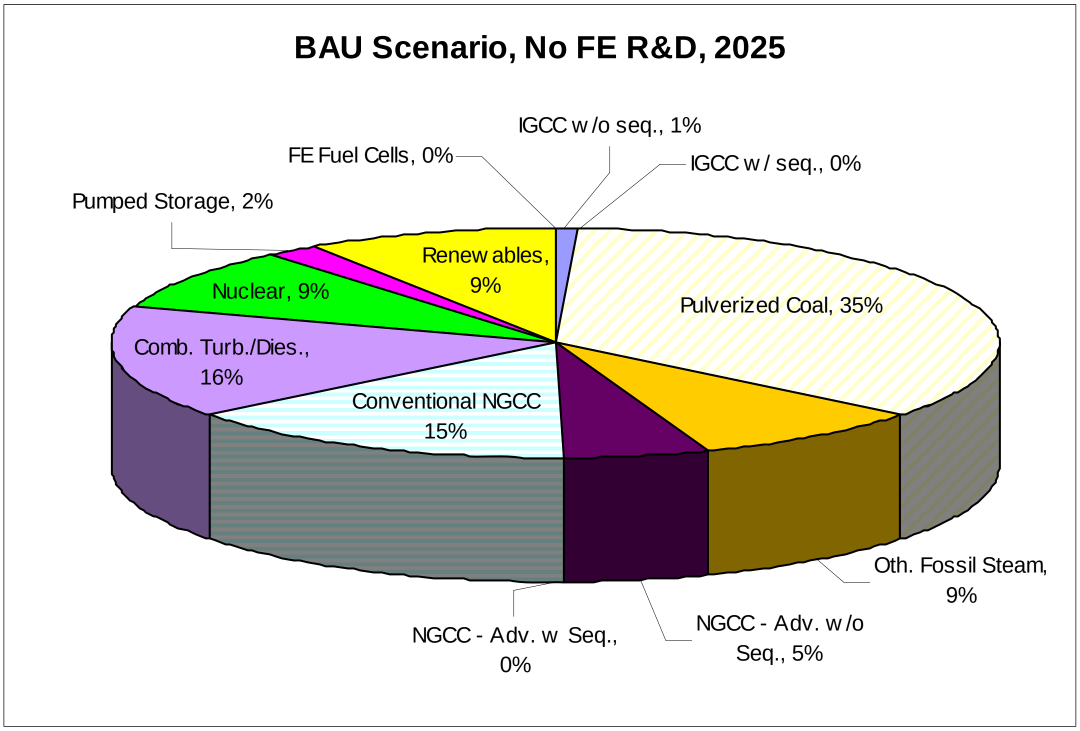
Graph 41.



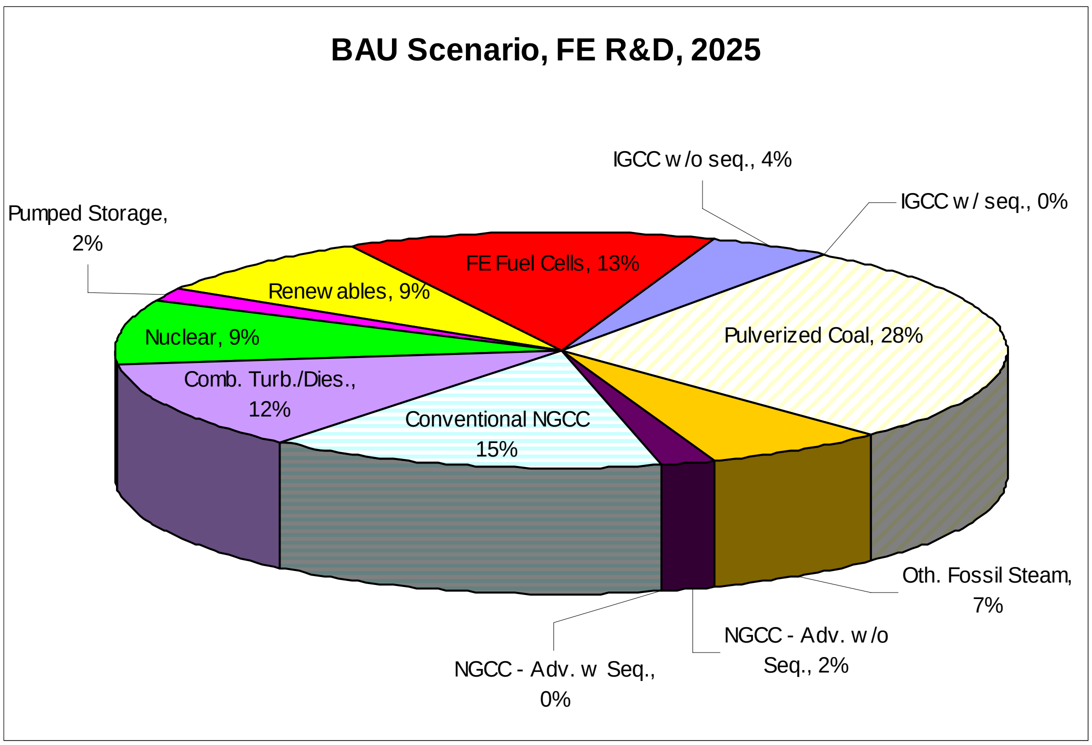
Cost of electricity reduced from 10.0 ¢/kWh in the No FE R&D case to 9.7¢/kWh in the FE R&D case, (2025).

Total Capacity Diversity

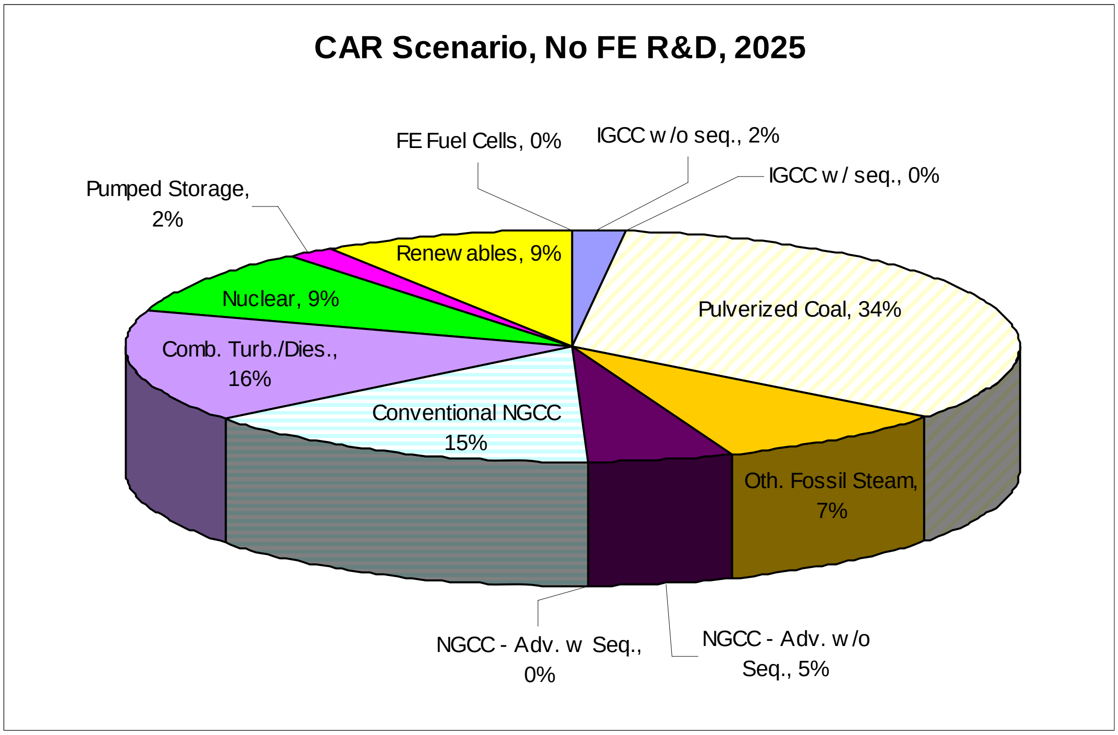
Graph 42.



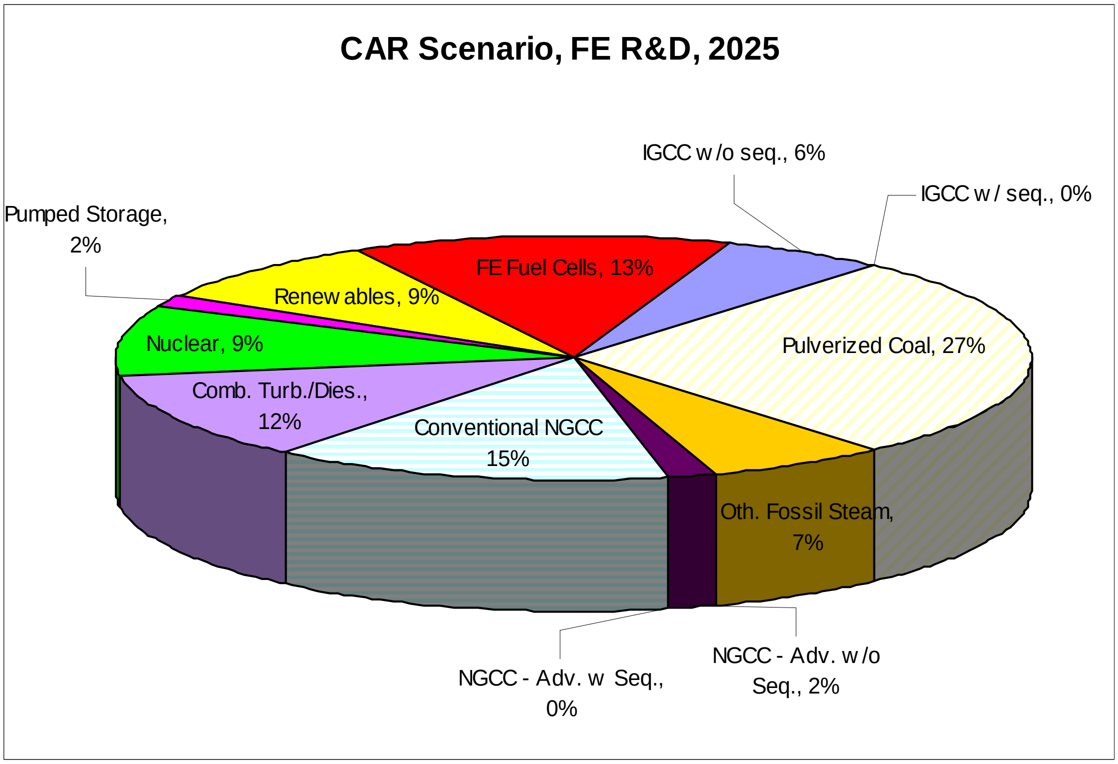
Graph 43.



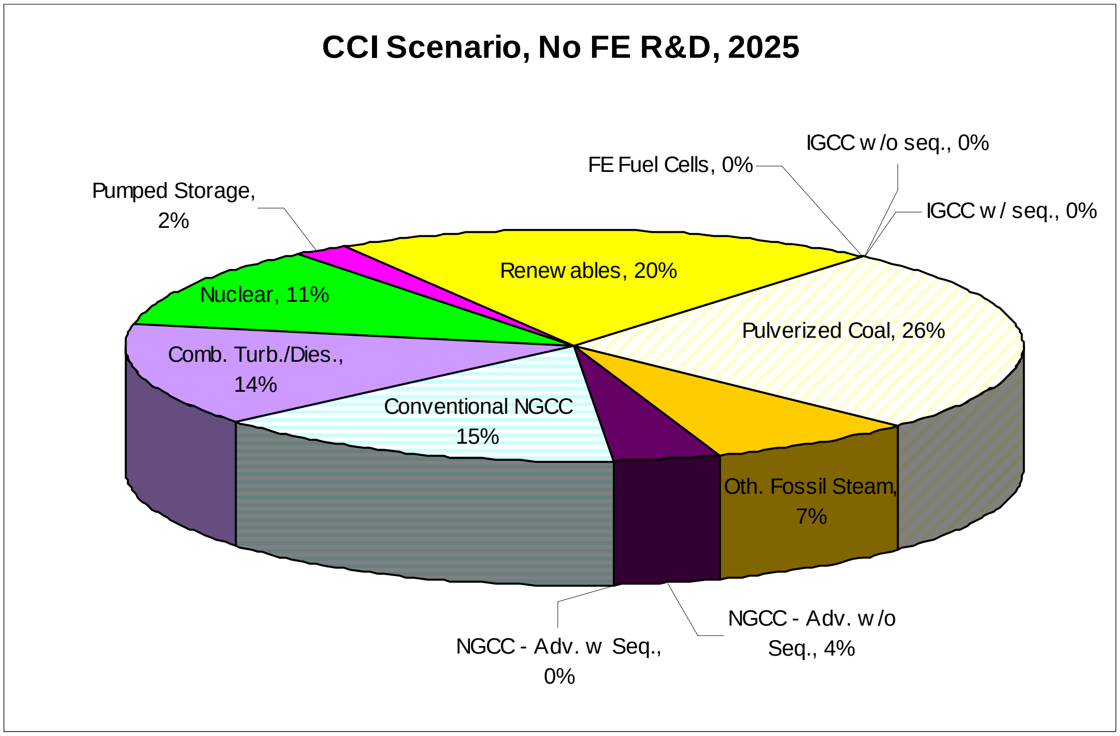
Graph 44.



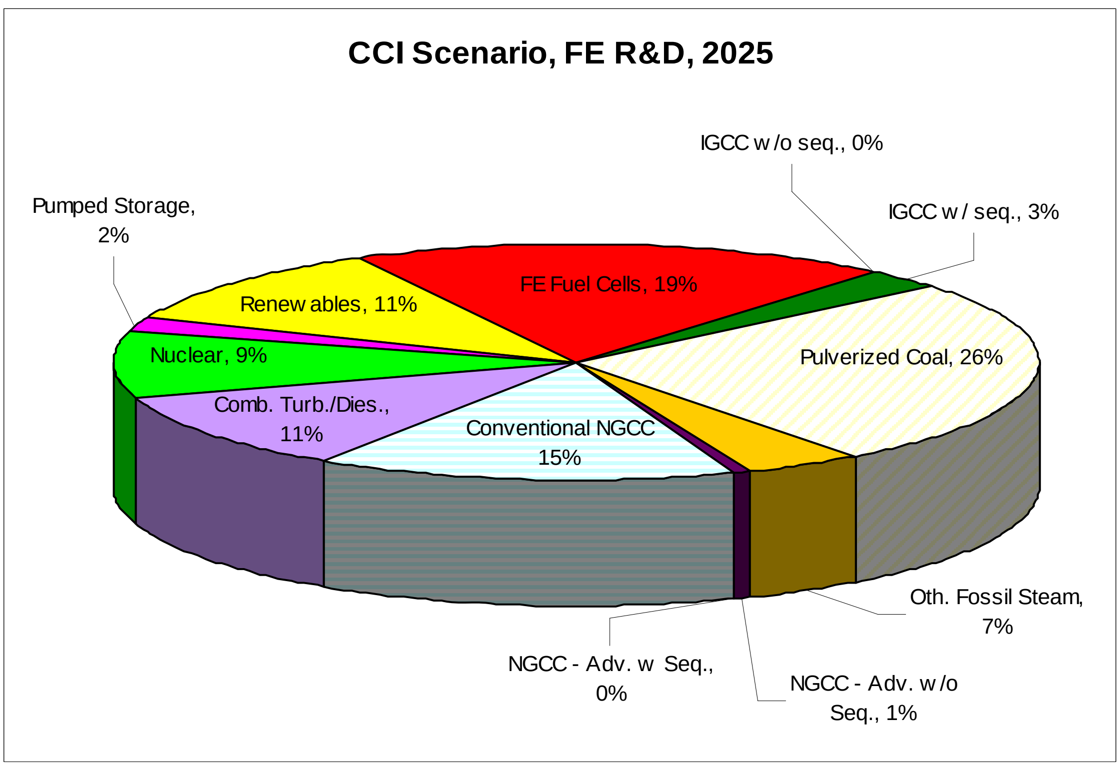
Graph 45.



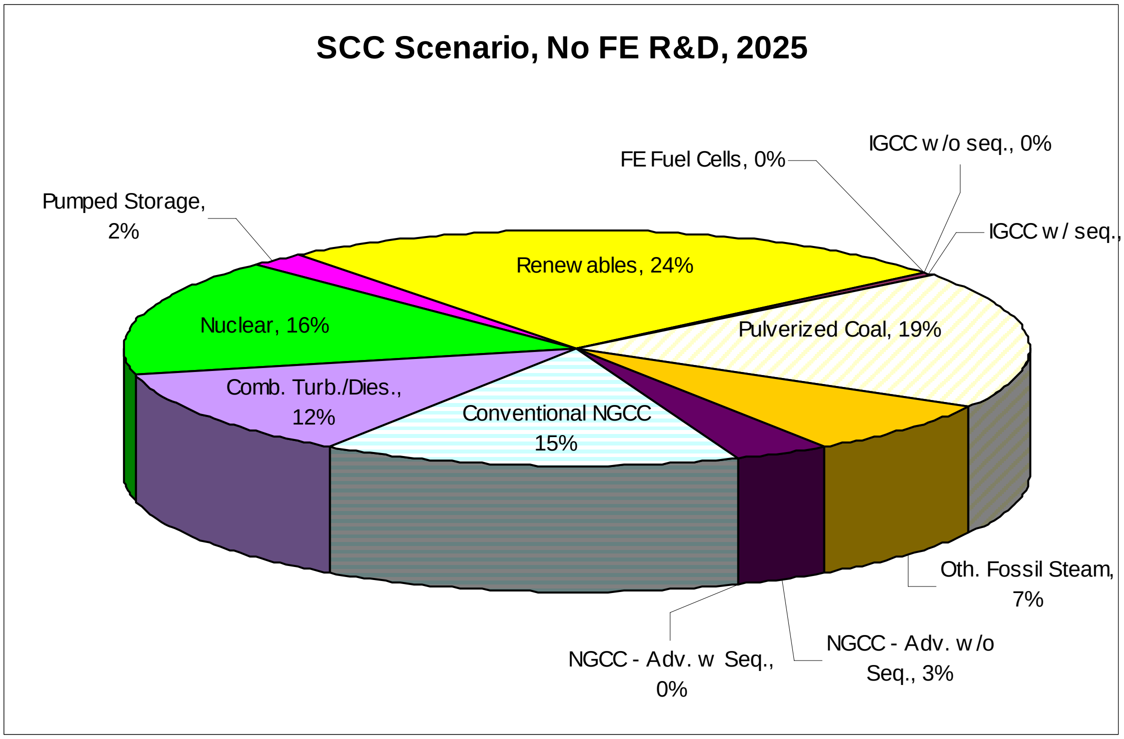
Graph 46.



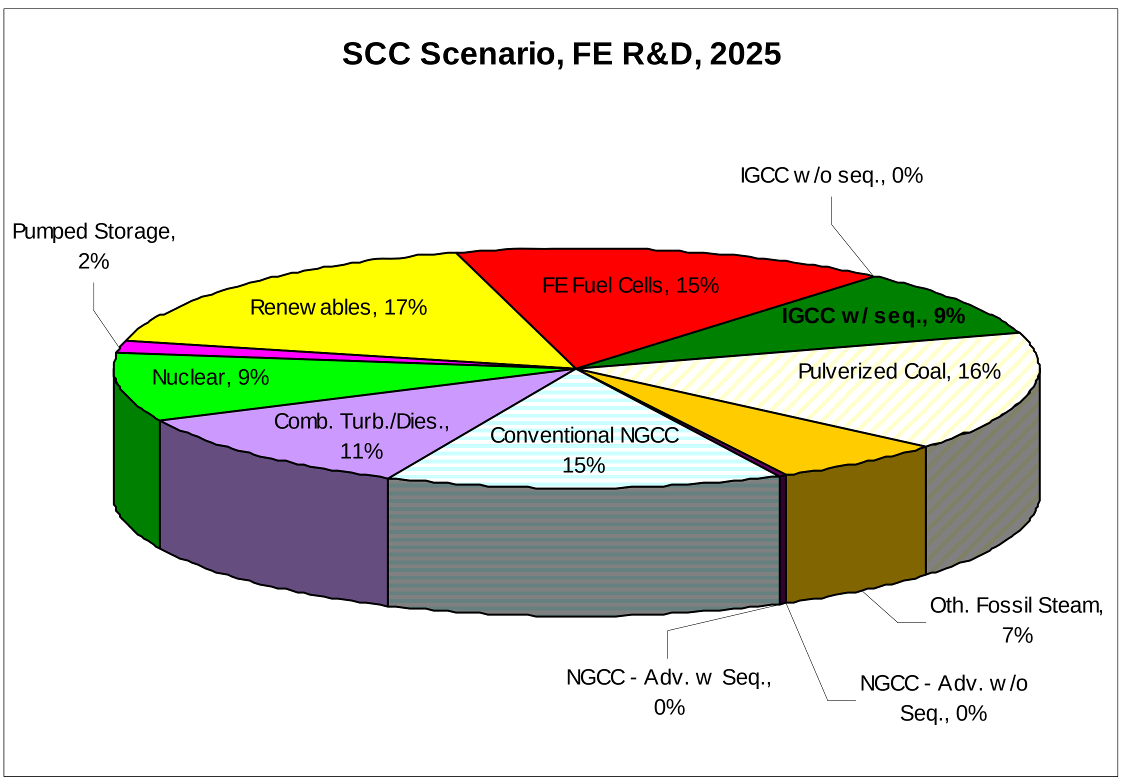
Graph 47.



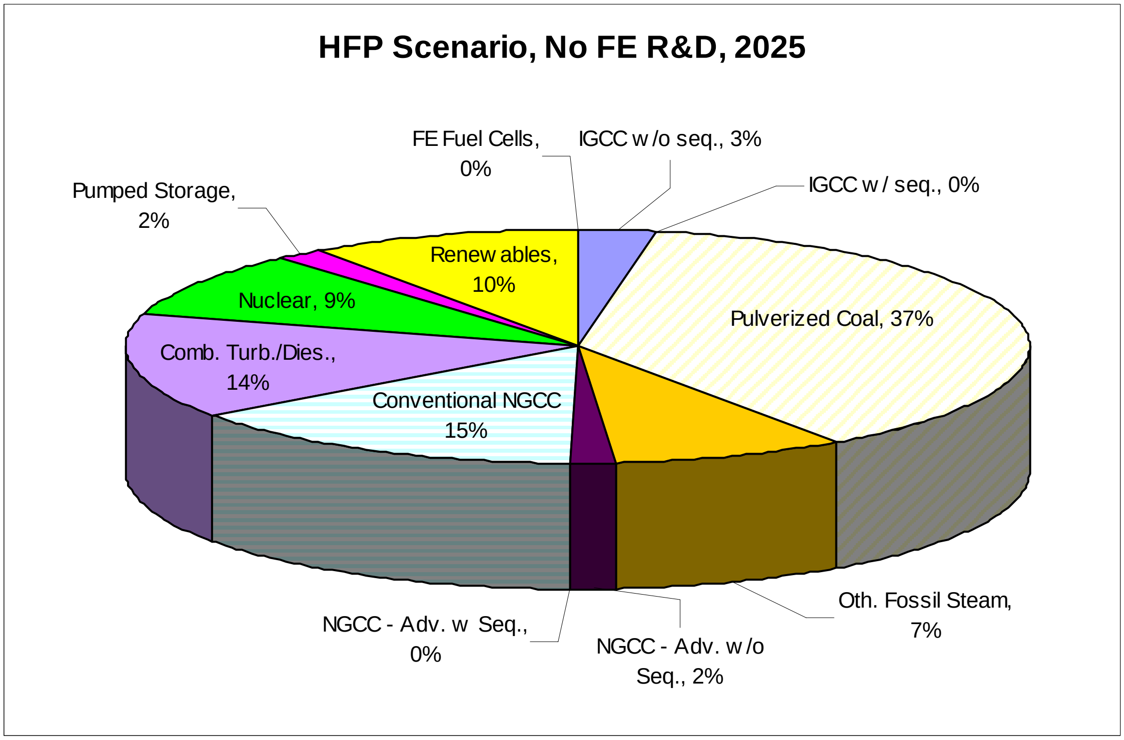
Graph 48.



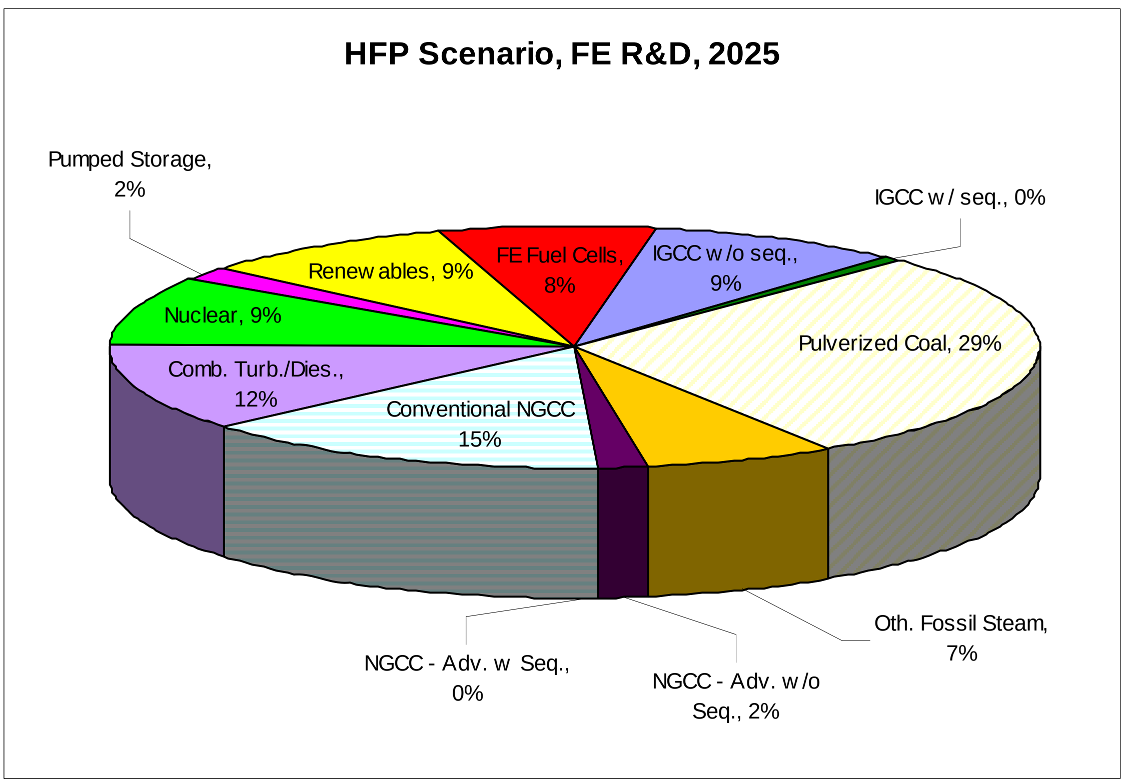
Graph 49.



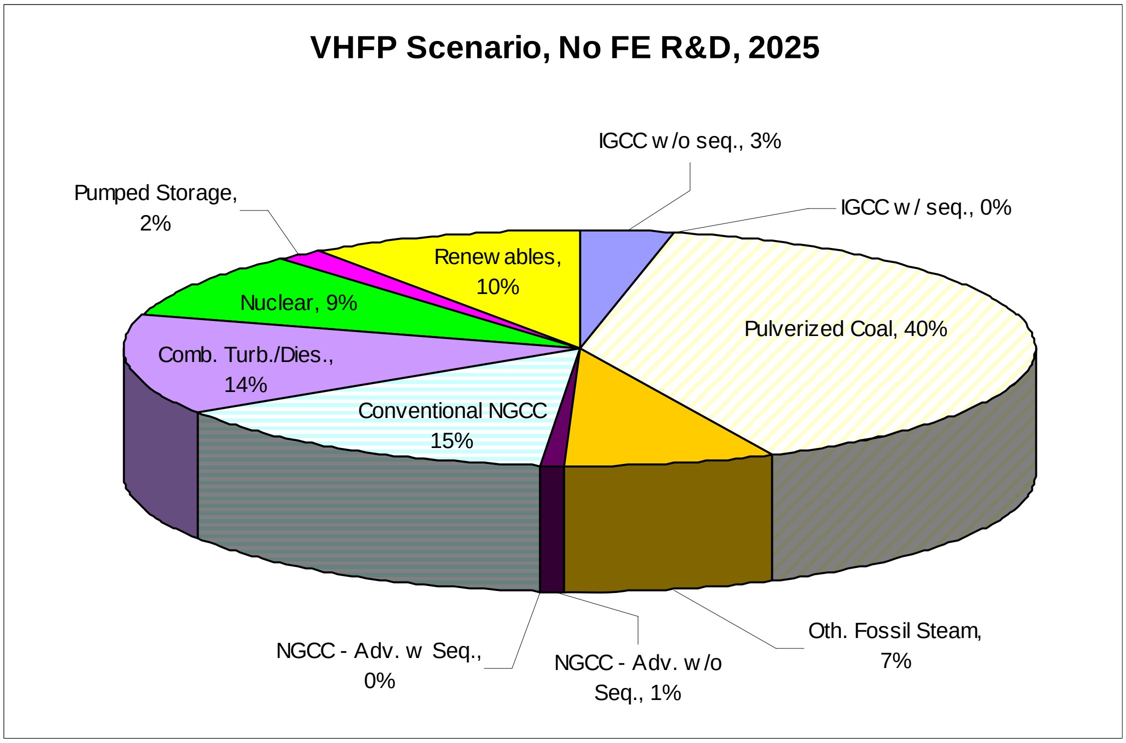
Graph 50.



Graph 51.



Graph 52.



Graph 53.