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U.S. EPA METHODOLOGY FOR POWER SECTOR-SPECIFIC EMPLOYMENT ANALYSIS

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Contents

I. Overview

This document describes a methodology for estimating the impact on employment based on the differences in projections between any two modeling scenarios. Typically, these scenarios represent a business as usual (or base case) scenario, and a scenario that represents the effects of some change (e.g., an environmental policy); the difference between the scenarios can be interpreted as the incremental effect of that change (e.g., the impact of a policy).

The first section of this document describes two general approaches for estimating labor impacts: an approach relies on factors that can be developed using detail-rich employment data, and an approach that relies on Labor Intensity Ratios (LIR), which provide a relationship between employment and the value of output created by that labor at a sector level. These two general approaches are utilized throughout the document.

Sections IV – VIII of this document describe how these two generation approaches are utilized to estimate employment impacts in the U.S. electric power sector. Each of these sections is broken down into subsections that describe the methodology for a group of technologies. Section IV discusses how to estimate the employment impacts related to construction of new generation capacity and presents different methodologies based on the type of technology. Section V discusses how to estimate employment related to changes in operation of existing capacity, including the effects of projected plant closures. Sections VI and VII cover the methodology for estimating employment effects related to installation and operation of pollution controls, respectively. Section VIII discusses the methodology for estimating labor impacts related to changes in fuel production. Finally, Section IX discusses how the approaches discussed throughout this document are brought together to estimate an overall employment impact.

The appendices provide additional information on the assumptions used in this methodology. Appendix I documents resource price assumptions, and Appendix II provides additional information on nuclear power plant staffing assumptions.

II. Background

EPA has a long history of analyzing the potential impacts of air pollution regulations on changes in the amount of labor needed in the power generation sector and directly related sectors.[1] This document builds upon the approaches used in the past and takes advantage of newly available data to improve the assumptions and methodology. Additionally, this approach increases the precision of the modeling outputs that are used here as inputs.

This approach can still be characterized as an evaluation of "first-order employment impacts" using a partial equilibrium modeling approach. It does not include the potential ripple effects of these impacts on the broader economy. These ripple effects are generally classified as "multiplier" impacts and include the secondary job impacts in both upstream and downstream sectors. This approach also excludes the economy-wide effects of changes to energy markets (such as higher or lower forecasted electricity

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[1] EPA Methodology For Power Sector-Specific Employment Analysis (May, 2018), available at: https://www.epa.gov/airmarkets/power-sector-labor-analysis-methodology

prices) that would be included in a more general equilibrium modeling context. At the same time, this approach excludes labor impacts that are usually included in a benefits analysis for an environmental policy, such as increased productivity from a healthier workforce and reduced absenteeism due to fewer sick days of employees and dependent family members (e.g., children).

III. Two General Approaches

The methodology includes the following two general approaches, based on available data. The first approach utilizes the rich employment data that is available for several types of generation technologies. For employment related to other electric power sector generating and pollution control technologies, the second approach utilizes information available in the U.S. Economic Census. The following two sections describe the methodology for developing factors under each of these general approaches, which are referenced throughout the remainder of this document.

A. Generation- and Capacity-Based Employment Factors

Detailed employment inventory data is available regarding recent employment related to coal, hydro, natural gas, geothermal, wind, and solar generation technologies. The data enables the creation of technology-specific factors that can be applied to model projections of capacity (reported in megawatts, or MW) and generation (reported in megawatt-hours, or MWh) in order to estimate impacts on employment. Since employment data is only available in aggregate by fuel type, it is necessary to disaggregate by labor type in order to differentiate between types of jobs or tasks, for categories of workers. For example, some types of employment remain constant throughout the year and are largely a function of the size of a generator, e.g. fixed operation and maintenance activities, while others are variable and are related to the amount of electricity produced by the generator, e.g. variable operation and maintenance activities.

The approach can be summarized in three basic steps:

1) Quantify the total number of employees by fuel type in a given year
2) Estimate total fixed operating & maintenance (FOM), variable operating & maintenance (VOM), and capital expenditures by fuel type in that year
3) Disaggregate total FTE[2] employees into three expenditure-based groups and develop factors for each group (FTE/MWh, FTE/MW-year, FTE/MW new capacity)

Step 1:

The total number of employees by electric power generation type in 2019 was obtained from the 2020 U.S. Energy and Employment Report (2020 USEER)[3] for battery storage, coal, geothermal, hydro, natural gas, and wind. The natural gas total was broken down into combined cycle (NGCC), combustion turbine (NGCT), and steam based on the pro rata share of total estimated FOM in 2019.[4]

[2] Full-Time Equivalent
[3] https://www.usenergyjobs.org/
[4] Total Natural Gas employees reported in Table 1 are split into NGCC, NGCT, and steam proportionally based on an estimate of total FOM expenditures in 2019. The total FOM estimate is the product of the capacity values reported in in Table 3 for each technology and the FOM cost assumptions summarized in Table 4.

Table 1. Total Number of FTE by Electric Power Generation Type (2019)

Technology	Total
Battery Storage	65,904
Coal	79,711
Geothermal	8,794
Hydro	67,772
NGCC	79,250
NGCT	22,631
NG Steam	19,931
Utility-Scale Solar	See below
Wind	114,774

Source: 2020 USEER; EIA Form 860

Note: Total natural gas employment apportioned to NGCC, NGCT, and NG Steam based on share of total estimated FOM costs in 2019, calculated using capacity from EIA Form 860 and average FOM costs from EPA modeling projections (footnoted above).

Solar is treated uniquely in this methodology due to prevalence of employees who spend less than half of their time on solar-related work. The total number of employees related to solar in 2019 was obtained from the National Solar Jobs Census (The Solar Foundation), which presents total employment of "Americans who spent 50 percent or more of their time working to manufacture, install, distribute, or provide professional services to solar technologies across the nation"[5] and excludes "94,549 employees spent less than half their time on solar work."[6] Since this report includes both utility and distributed solar generation, it is necessary to estimate the number of jobs related to utility generation for consistency with EPA's current power sector modeling.[7] The total number of Installation and Project Development jobs related to utility-scale solar is reported in the National Solar Jobs Census.[8] For the remaining sectors, the number of employees associated with utility-scale solar power is estimated using the ratio of utility-scale solar expenditures in 2019 to the total expenditures related to solar power development and operation in 2019, based on information obtained from the US Solar Market Insight Executive Summary 2019 year in review.[9]

[5] "The National Solar Jobs Census applies a rigorous test in counting solar jobs across the United States. Since 2010, The Solar Foundation has defined a solar job as one held by a worker spending at least 50% of his or her time on solar-related work. Census findings have consistently shown that roughly 90% of these workers (91.4% in 2019) spend 100% of their time on solar-related work."

[6] A copy of the report was available at https://www.thesolarfoundation.org/national/, accessed on 8/5/2020.

[7] While EPA's current power sector modeling projects impacts on utility-scale solar only, future modeling might consider potential changes in distributed generation, in which case factors could be developed which incorporate the "total solar" values in Table 2.

[8] See Table 2 of the 2020 National Solar Jobs Census

[9] https://www.seia.org/research-resources/solar-market-insight-report-2018-year-review, accessed on 8/5/2020

Table 2. Total Number of Employees, Solar (2019)

Sector	Total Solar	Estimated Utility-Scale Solar
Installation and Project Development	162,126	31,452
Wholesale Trade and Distribution	29,798	12,277
Operations and Maintenance	11,583	4,772
Manufacturing	34,423	14,182
All Others	12,053	4,966
Total	249,983	67,650

Source: Total Solar: National Solar Jobs Census (The Solar Foundation)
Note: For sectors other than installation and project development, estimated utility-scale is about 41 percent, and is calculated using capacity and $/W information reported in Sections 2.1 and 2.2 of the US Solar Market Insight Executive Summary 2019 year in review

Similarly, for battery storage, since the total number of jobs reflects employment related to both behind-the-meter (BTM) and front-of-the-meter (FTM) capacity, it is necessary to estimate FTM jobs in isolation for consistency with EPA's modeling projections. The number of employees associated with battery storage related to electric utilities only (FTM) is estimated using the ratio of FTM market size to the total market size in 2019, based on information obtained from the US Energy Storage Monitor Q2 2020 Executive Summary (June 2020).[10]

Table 3. Battery Storage: Total Number of Employees, Market Size, and Estimated FTM Employment, 2016-2019

	2016	2017	2018	2019
Total Battery Storage Jobs	47,634	53,369	62,910	65,904
Market size ($MM)	316	316	489	712
FTM market share	81.3%	56.3%	37.1%	33.3%
FTM Market Size ($MM)	257	178	182	237
Estimated FTM Jobs	38,703	30,020	23,367	21,968

Source: 2020 National Solar Jobs Census (total jobs); US Energy Storage Monitor Q2 2020 Executive Summary (June 2020)

Step 2:

The total amount of FOM, VOM, and capital expenditures for 2019 is estimated for each generation type by combining information from the Energy Information Administration (EIA) with EPA modeling assumptions. Total FOM is estimated as the product of the 2018 total operating capacity and average

[10] "Market Size" is reported as the "product of deployments and installed system prices." This report presents total market size graphical format for residential, non-residential, and FTM storage. FTM is estimated by measuring the height of the relevant portion of the bar and comparing to the total height of the bar in the graph.

FOM cost assumptions based on EPA's power sector modeling.[11] Total VOM is the product of 2019 total generation by fuel type and average VOM cost assumptions based on EPA's power sector modeling. Total capital costs for new capacity is the product of total new capacity online in 2019 and capital costs for new capacity based on EPA's power sector modeling.

Table 4. 2019 Capacity and Generation

	Coal	Geothermal	Hydro	NGCC	NGCT	NG Steam	Solar	Wind
Total Generation (GWh)	965,831	15,569	272,377	1,289,792	92,841	91,783	71,547	299,785
Total Capacity (MW)	227,211	2,506	79,430	267,553	122,647	68,412	36,968	103,437
New Capacity (MW)	0	20	5	6,614	1,178	17	5,406	9,313

Source: Generation: EIA Data Browser, Net Generation for Electric Power, 2019; NG Generation: EIA Form 923; Total Capacity and New Capacity: EIA Form 860 2019 Early Release for generators in Electric Utility, IPP CHP, and IPP Non-CHP sectors

Table 5. Average VOM, FOM, and Capital Cost Assumptions by Generation Type

	Coal	Geothermal	Hydro	NGCC	NGCT	O/G Steam	Solar	Wind
VOM ($/MWh)	5.37	5.49	2.66	2.19	8.88	1.08	0.00	0.00
FOM ($/kW-yr)	46.4	93.5	14.9	30.5	19.0	30.0	28.0	30.0
Capital Cost for New Capacity ($/kW-yr)	N/A	3,253	1,558	1,081	662	N/A	1,034	1,404

Source: Average Costs based on EPA's Power Sector Modeling Platform v6 using IPM May 2019 Reference Case

Table 6. Total Estimated Costs, 2019 (millions of 2016$ and percent of total)

	Coal	Geothermal	Hydro	NGCC	NGCT	NG Steam	Solar	Wind
VOM	5,187	0	725	2,825	824	99	0	0
(%)	*33%*	*0%*	*38%*	*16%*	*21%*	*5%*	*0%*	*0%*
FOM	10,543	234	1,184	8,160	2,330	2,052	1,035	3,103
(%)	*67%*	*78%*	*62%*	*45%*	*59%*	*95%*	*16%*	*19%*
Capital (New Capacity)	0	65	7	7,150	780	0	5,590	13,076
(%)	*0%*	*22%*	*0%*	*39%*	*20%*	*0%*	*84%*	*81%*

Note: Product of Table 4 and Table 5

For battery storage, the FOM costs are very low (approximately 2%) relative to capital costs. We therefore make a simplifying assumption that all labor associated with battery storage is related to

[11] Average FOM, VOM, and capital costs for new capacity based on reference case projections in Power Sector Modeling Platform v6 November 2018, available at: https://www.epa.gov/airmarkets/power-sector-modeling-platform-v6-november-2018

capital (new development). Total new FTM deployments are estimated based on information obtained from the US Energy Storage Monitor Q2 2020 Executive Summary (June 2020).[12]

Table 7. Energy Storage Deployments, 2016-2019 (MW)

	2016	2017	2018	2019
Front-of-the-Meter Deployments	155	174	149	252
Total Energy Storage Deployments	213	213	311	523

Source: US Energy Storage Monitor Q2 2020 Executive Summary (June 2020)

Step 3:

In order to create factors that can be applied to projected changes in electric power sector capacity and generation, the final step of this methodology combines Table 1, Table 2, and Table 3 with Table 6 and Table 7.

Generally, for each fuel type, the total number of FTEs in a given year is divided into one of three labor categories (variable O&M, fixed O&M, and capital costs for new units) based on the relative share of costs, and then a factor is created by dividing by the relevant metric. To estimate the number of FTEs per unit of generation for each fuel type, the share of variable O&M costs is multiplied by the total number of employees for each fuel type, and then divided by the total generation for that fuel type. To estimate the number of FTEs per unit of existing capacity, the share of fixed O&M costs is multiplied by the total number of employees for each fuel type, and then divided by the total amount of capacity for that fuel type. Finally, to estimate the number of FTEs for each MW of capacity constructed in that year, the share of capital costs is multiplied by the total number of employees for each fuel type, and then divided by the total amount of new capacity constructed in that year for each fuel type.

Table 8. FTE Factors for Battery Storage, Coal, Geothermal, Hydro, Natural Gas, Solar, and Wind (2019)

	Total FTEs per GWh	Total FTEs per GW-yr	Total FTEs per GW New Capacity
Battery Storage	--	--	87,239
Coal	0.027	235.1	N/A
Geothermal	0.094	527.3	55,132
Hydro	0.161	2745.8	95,529
NG Combined Cycle	0.010	133.3	4,724
NG Combustion Turbine	0.051	109.3	3,808
Solar	0	285.9	10,559
Wind	0	212.8	9,960

Source: Table 1, Table 2, Table 3, Table 6, and Table 7

[12] FTM deployments are estimated by measuring the height of the relevant portion of the bar and comparing to the total height of the bar in the graph.

Solar, wind, and in particular battery storage, are all relatively young industries, and we expect to continue observing a decrease in costs as well as a decrease in the number of jobs per unit capacity. This decrease in incorporated into the analysis using the National Renewable Energy Lab's (NREL) 2019 Annual Technology Baseline (ATB)[13] estimates for capital cost for each of these technologies. This methodology assumes that the number of jobs required to construct one GW of capacity follows the same trajectory as the projected capital expenditures (on a $/kW basis) starting in 2019 through 2050.[14] The capital trajectory for each technology is replicated for the respective jobs/GW factor by applying the percent change of the estimated capital costs in each year relative to 2019. In order to estimate values that integrate into EPA's current power sector modeling, an average factor is calculated for 2021, 2023, 2025, 2030, 2035, 2040, 2045, and 2050, which is equal to a simple average of the job factors associated with each calendar year mapped to that run year.[15] Unlike the other factors presented in Table 11, which we assume remain constant over time, we assume that the labor factors for new battery storage, solar, and wind decline throughout the model horizon as presented in Table 9.

Table 9. Battery Storage, Solar, and Wind: Total FTEs per GW New Capacity, 2019-2050

	2019	2021	2023	2025	2030	2035	2040	2045	2050
Battery Storage	87,239	76,937	70,953	60,490	51,877	47,879	44,687	41,495	38,577
Solar	10,559	10,165	9,855	9,236	8,376	7,847	7,394	6,987	6,622
Wind	9,960	9,608	9,343	8,814	8,083	7,657	7,282	6,897	6,535

Source: Table 8 and 2019 NREL Annual Technology Baseline

B. Output Value-Based Labor Intensity Ratios

Where detailed employment data is unavailable, it is possible to estimate labor impacts using labor intensity ratios (LIR). These factors provide a relationship between employment and economic output. These factors are used to estimate employment impacts related to construction and operation of pollution control retrofits well as some types of electric generation technologies. More detail on the application of these factors is provided in sections IV through VIII.

[13] Available at: https://atb.nrel.gov/

[14] This methodology uses capital expenditures (CAEPX) for the "scenario" estimated for utility-scale PV, land-based wind, and storage. We calculate a simple average of the capex values for TRG 1-10 (wind) and across all five localities for solar.

[15] Note that for application to other modeling platforms, these averages could also be calculated over different time periods using the same methodology. For further information on calendar years and run years as currently used in EPA's power sector modeling, see section 2.3.2 of the Documentation for EPA Platform v6 November 2018 Reference Case, available at: https://www.epa.gov/airmarkets/documentation-epas-power-sector-modeling-platform-v6-november-2018-reference-case.

Table 10. Labor Intensity Ratios (2017)

Resource	NAICS Sector(s)	Total Value of Shipments ($ Million)	Total Employees	Labor Ratio (Employees per $ Millions of Shipments)
Steel	33121	11,162	24,747	2.2
Limestone	32741	2,249	3,976	1.8
Ammonia (NH3)	32518	31,434	38,605	1.2
Catalyst	331410, 331492	17,040	16,641	1.0
Activated Carbon	325998	22,774	36,210	1.6
Trona	212391	2,303	3,560	1.5
Fabric Filter (FF) Resource	325211	90,209	73,979	0.8
Power Plant Construction	237130	61,815	223,786	3.6
Equipment Manufacturing	333	356,613	1,024,849	2.9
Engineering	54133	237,304	1,081,471	4.6
Power Plant Operators	22111	119,266	138,647	1.2
Pipeline Construction	237120	48,940	200,209	4.1
Boilermakers	332410	6,894	23,313	3.4

Source: U.S. Census Bureau, 2017 Economic Census.[16] Table Name: All sectors: Core Business Statistics Series: Comparative Statistics for the U.S. and the States (2007 NAICS Basis): 2012 and 2007

In order to apply these labor intensities to projections of expenditures related to construction and operation of generation and control technologies, it is necessary to disaggregate total expenditures into expenditure categories that are consistent with the labor productivity factors. These disaggregations are discussed in more detail in sections IV through VIII.

IV. Construction of New Generators

A. Coal, Hydroelectric, Natural Gas Combined Cycle (NGCC), Natural Gas Combustion Turbine (NGCT), Solar, and Wind

The labor associated with projected construction of new coal, hydro, NGCC, NGCT, solar, and wind generation is estimated by using the factors developed in section III.A. Projected changes in capacity (MW) are multiplied by factors for total FTEs per MW-yr and total FTEs per MW of new capacity. Projected changes in generation (MWh) are multiplied by the factor for total FTEs per MWh.

[16] https://www.census.gov/data/tables/2017/econ/economic-census/naics-sector-00.html

Table 11. Summary of Methodological Approach for Estimating Employment Impacts Related to Construction of New Generation Technology by Technology: Coal, Geothermal, Hydro, NGCC, NGCT, Solar, and Wind

<table>
<tr><th>Plant Type</th><th>Projection</th><th>Factor</th></tr>
<tr><td rowspan="3">New Battery Storage*
New Coal,
New Geothermal,
New Hydro,
New NGCC,
New NGCT,
New Solar,
New Wind**</td><td rowspan="2">Capacity (MW)</td><td>Total FTEs per MW-yr</td></tr>
<tr><td>Total FTEs per MW New Capacity</td></tr>
<tr><td>Generation (MWh)</td><td>Total FTEs per MWh</td></tr>
</table>

*Note that for new battery storage, total FTEs per MW of new capacity is the only applicable factor.
**The factors for new wind are applied to both land-based wind and off-shore wind projections.

Additionally, note that construction of many of these technologies requires more than single year of work, and often impacts employments over several years. In order to estimate the annual change in employment (the change in associated with any given year), it is also necessary to incorporate the average construction time of each technology by dividing the total in the projection years by the average construction time for that technology. See Table 12

Table 12. Assumed Construction Times for New Capacity (years)

New Plant Type	Construction Time (years)
Battery Storage	1
Combined Cycle	3
Combustion Turbine	2
Hydro	3
Solar	2
Wind	3

B. Landfill Gas and Oil/Gas Steam

The labor associated with projected changes in construction of landfill gas capacity is estimated by using labor intensity ratios. Changes in the projected FOM costs associated with these plants are multiplied by the LIR for power plant operators. Changes in the total capital construction costs associated with these plants are broken down into four specific components: equipment (54%), material (6%), labor (31%), and engineering and construction management (9%).[17] These costs are then subsequently

[17] Source: EPA (2002) and Staudt (2011a)

multiplied by the applicable LIR factors: equipment manufacturing, steel, power plant construction, and engineering. This methodology can also be used for other generation technologies.

Table 13. Summary of Methodological Approach for Estimating Employment Impacts Related to Construction of New Landfill Gas and Oil/Gas Steam Capacity

Plant Type	Projection	Capital Cost Category	Labor Ratio (employees per $ of output)
Landfill Gas, O/G Steam	Capital Costs ($)	Equipment Share (54%)	Equipment Manufacturing
		Material Share (6%)	Steel
		Labor Share (31%)	Power Plant Construction
		Engineering and Construction Management Share (9%)	Engineering
	FOM Costs ($)	N/A	Power Plant Operators

Source: see footnote 17

V. Change in Operation of Generators (Retirements)

A. Coal, Hydro, Natural Gas CC, Natural Gas CT, Solar, and Wind

The labor associated with a change in operation levels of existing coal, hydro, NGCC, NGCT, solar and wind generators is estimated using the factors developed in section III.A. The projected change in capacity (MW) is multiplied by factors for total FTEs per MW-yr, and the projected change in generation (MWh) is multiplied by the factor for total FTEs per MWh. This captures effects associated with retirements, as well as any projected increase or decrease in dispatch.

Table 14. Summary of Methodological Approach for Estimating Employment Impacts Related to Changes in Plant Operation, by Technology: Coal, Geothermal, Hydro, NGCC, NGCT, Solar, and Wind

Plant Type	Projection	Technology-Specific Factor
Coal, Geothermal, Hydro, NGCC, NGCT, Solar, Wind	Capacity (MW)	Total FTEs per MW-yr
	Generation (MWh)	Total FTEs per MWh

Note: See technology-specific factors summarized in Table 8.

B. Biomass, Oil/Gas Steam

The labor associated with projected changes in retirements of biomass, and oil/gas steam generators is estimated using labor productivity factors. The projected change in FOM costs associated with these units is multiplied by the LP factor for power plant operators.

Table 15. Summary of Methodological Approach for Estimating Employment Impacts Related to Changes in Plant Operation: Biomass, Oil/Gas Steam

Plant Type	Projection	LP Factor (employees per $ of output)
Biomass, Oil/Gas Steam	FOM Costs ($)	Power Plant Operators

C. Nuclear

Similar to the technologies in Section V.A., estimates of employment associated with changes in projected retirements of nuclear generating capacity are based on detailed survey data. However, in addition to the 2020 USEER, the factors developed for this technology are also based on information available in an Electric Utility Cost Group (EUCG) benchmarking study,[18] as well as information available in an International Atomic Energy Agency (IAEA) report.[19] For more detail, see Appendix II.

This information was combined to develop equations that describe three types of employment at the plant level: onsite employees, offsite employees, and contractors. Each of these equations is a function of capacity at each plant. In order to estimate the change in employment related to projected plant closures, these equations are applied to the average projected plant-level capacity and projected capacity of plant retirements. See Table 16.

Table 16. Equations for FTE Employment Related to Nuclear Energy Generation

FTE Type	Equation
Utility onsite FTE workers, per plant	328 + 0.3235 x plant capacity (MW)
Utility offsite FTE workers, per plant	17 + 0.0363 x plant capacity (MW)
Contractor FTE workers, per plant	85 + 0.0263 x plant capacity (MW)

Source: See Appendix II

[18] Peltier, R., "Benchmarking Nuclear Plant Staffing", Power Magazine, April 1, 2010 (available at: https://www.powermag.com/benchmarking-nuclear-plant-staffing/). Contractors would include contractors that regularly work at the utility premises. It is not unusual for utilities to utilize contractors for some engineering or service functions. Data from the Nuclear Committee of the EUCG

[19] International Atomic Energy Agency, "Nuclear power plant organization and staffing for improved performance: lessons learned", IAEA-TECDOC-1052, 1998, especially see Annex E, pp. 41-57. Available at: https://www-pub.iaea.org/MTCD/Publications/PDF/te_1052_prn.pdf

VI. Construction of New Pollution Controls

Employment changes related to projected changes in the construction of new retrofit pollution controls is estimated using required labor hours per unit capacity where available, and labor intensity ratios where direct labor hour estimates are unavailable.

For wet scrubbers, SCR, DSI, ACI, CCS, ESP upgrades, FF, and FF bag upgrades, employment changes are estimated using direct labor factors that are related to the capacity of the control. See Table 17.

Table 17. Labor Hours per MW Factors for New Pollution Controls

Technology	Projection	Labor Hours per MW[20]
Wet FGD	Capacity (MW)	760
SCR	Capacity (MW)	730
DSI	Capacity (MW)	43.5
ACI	Capacity (MW)	9.6
CCS	Capacity (MW)	5,782
Minor ESP Upgrades	Capacity (MW)	208
Typical ESP Upgrades	Capacity (MW)	420
ESP Rebuild	Capacity (MW)	520
Fabric Filter	Capacity (MW)	780
Fabric Filter Bag Upgrades	Capacity (MW)	12

Source: EPA 2002 for FGD/SCR, Staudt 2011a for DSI/ACI/CCS, Staudt 2023 for ESP/FF

[20] In order to convert to jobs, EPA assumes 2,080 hours is the equivalent of one job

For dry scrubbers and SNCR (where direct hour-per-MW factors are unavailable) the projected capital cost of the new controls is broken down into three specific labor components (boilermakers, engineering, and other installation labor) based on the control type.[21] See Table 18.

Table 18. Summary of Methodological Approach for Estimating Employment Impacts Related to Labor Necessary for Construction of New Pollution Controls

Technology	Projection	Capital Cost Categories	LIR Factors
Dry FGD	Capital ($)	boilermaker (40%)	Boilermakers
		engineering (20%)	Engineering
		other installation labor (40%)	Power Plant Construction
SNCR	Capital ($)	boilermaker (45%)	Boilermakers
		engineering (7%)	Engineering
		other installation labor (48%)	Power Plant Construction

Source: See Footnote 21

Additionally, the labor associated with the steel necessary to build all of the controls listed in Table 17 and Table 14 is estimated using projected changes in capacity for each control type and a factor for the amount of required steel per capacity being retrofitted (tons/MW). For SCR, the labor associated with producing the necessary catalyst is also taken into consideration. The total amount of steel and catalyst is converted to a total expenditure using prices of each resource, and then multiplied by an appropriate LIR. See Table 19.

[21] Source: EPA (2002) and Staudt (2011a)

Table 19. Summary of Methodological Approach for Estimating Employment Impacts Related to Materials Necessary for Construction of New Pollution Controls

Technology	Projection	Resource Requirement	Resource Price	LIR Factor
Wet and Dry FGD	Capacity (MW)	Steel (2.25 tons/MW)	$827/ton	Steel
DSI	Capacity (MW)	Steel (2.2 tons/MW)	$827/ton	Steel
SCR	Capacity (MW)	Steel (2.5 tons/MW)	$827/ton	Steel
		Catalyst (1.2 m3/MW)	$3,676/m3	Catalyst
SNCR	Capacity (MW)	Steel (2.5 tons/MW)	$827/ton	Steel
ACI	Capacity (MW)	Steel (0.35 tons/MW)	$827/ton	Steel
Minor ESP Upgrades	Capacity (MW)	Steel (0.069 tons/MW)	$827/ton	Steel
Typical ESP Upgrades	Capacity (MW)	Steel (0.173 tons/MW)	$827/ton	Steel
ESP Rebuild	Capacity (MW)	Steel (0.691 tons/MW)	$827/ton	Steel
Fabric Filter	Capacity (MW)	Steel (3.8 tons/MW)	$827/ton	Steel

Source: Resource Requirements: EPA 2002; See Appendix I for resource prices

VII. Operation of Pollution Controls

The labor required for production of the reagents and catalysts necessary for the operation of all pollution controls (both existing controls and those projected to be built) is estimated by using labor intensity ratios in conjunction with resource use and price estimates. The catalyst and reagent resource use for each control is estimated by multiplying the projected change in generation associated with that control by an estimate of the amount of resource required for each unit of generation (generally tons per MWh). Next, the total amount of the resource is multiplied by the price, and the resulting total expenditure is multiplied by the applicable LIR factor. For SCR controls, the projected amount of NOx removed is used to estimate the amount of ammonia required in a similar fashion. Additionally, new FF are estimated to require 4 labor hours per MW annually. See Table 20.

Table 20. Summary of Methodological Approach for Estimating Employment Impacts Related to Operation of Pollution Controls

Technology	Projection	Resource Usage	Resource Price	LIR Factor
ACI (with FF)	Generation (MWh)	Activated Carbon (0.0000615 tons/MWh)	$1,833/ton	Activated Carbon
ACI (wo FF)	Generation (MWh)	Activated Carbon (0.000615 tons/MWh)	$1,833/ton	Activated Carbon
Dry FGD	Generation (MWh)	Lime (Quick) (0.02088 tons/MWh)	$123/ton	Limestone
DSI	Generation (MWh)	Trona (0.01 tons/MWh)	$152/ton	Trona
SCR	Generation (MWh)	Operational Catalyst (0.00002 m3/MWh)	$3,676/m3	Catalyst
	NOx Removed (tons)	Ammonia (0.39 lbs/lb NOx Reduced)	$265/ton	Ammonia (NH3)
SNCR	NOx Removed (tons)	Ammonia (2.45 lbs/lb NOx Reduced)	$265/ton	Ammonia (NH3)
Wet FGD	Generation (MWh)	Limestone (0.036 tons/MWh)	$11.5/ton	Limestone

Source: Resource Usage: EPA 2002, Staudt 2001a; Resource Prices: see Appendix I

Additionally, for projected changes in new retrofit controls, the incremental labor associated with operating the new controls is accounted for by using the LIR factors. The projected FOM associated with each retrofit control type is multiplied by the LIR factor for Power Plant Operators.

VIII. Fuel Production

A. Coal

The labor associated with extracting the coal projected to be consumed is estimated using productivity factors published by EIA in the Annual Coal Report.[22] Table 21 of that report presents "Average Production per Employee Hour" by coal-producing region, and that value is multiplied by the projected amount of coal utilized by the electric power sector.[23] See Table 21.

[22] EIA's Annual Cost Report is available at https://www.eia.gov/coal/annual/
[23] This methodology assumes 2,080 hours is the equivalent of one job

Table 21. Summary of Methodological Approach for Estimating Employment Impacts Related to Coal Production

EIA Coal-Producing Region	EPA Coal Production Region (IPM)	EPA Projection	Average Production per Employee Hour, 2018 (short tons)
Alabama	Alabama	Coal Production (Million Tons)	2.15
Arizona	Arizona		6.53
Arkansas	Arkansas, North		-
Illinois	Illinois		6.82
Indiana	Indiana		4.8
Kentucky (East)	Kentucky, East		1.79
Kentucky (West)	Kentucky, West		3.71
Maryland	Maryland		2.23
Mississippi	Mississippi		6.99
New Mexico	New Mexico, San Juan		6.16
North Dakota	North Dakota		12.31
Ohio	Ohio		3.66
Oklahoma	Oklahoma		1.84
Pennsylvania (Anthracite)	Pennsylvania, Central		1.03
Pennsylvania (Bituminous)	Pennsylvania, West		4.74
Tennessee	Tennessee		1.23
Texas	Texas		6.73
Utah	Utah		4.57
Virginia	Virginia		2.07
West Virginia (Northern)	West Virginia, North		4.76
West Virginia (Southern)	West Virginia, South		2.14
Colorado	Colorado		5.25
Montana	Montana		14.46
Wyoming	Wyoming		26.63
Refuse Recovery	Waste Coal		4.56

Source: EIA Annual Coal Report, Table 21 “Coal Mining Productivity by State and Mine Type” (November 2019)

B. Natural Gas

The labor associated with projected changes in natural gas extraction is estimated based on a factor developed using information available from 2020 USEER and EIA. This factor is based on the change in employment in production between 2018 and 2019, and is the ratio of the change in natural gas employees to the change in total natural gas production over that time. See Table 22.

Table 22. Natural Gas Production and Employment, 2018-2019

	2018	2019	2018-2019 Change
Gas Production (MMCF)	30,588,702	33,657,046	3,068,344
Gas Production (MMBtu)	31,322,830,848	34,464,815,104	3,141,984,256
Total Employees	270,626	275,924	5,298
Employees per TBtu	8.64	8.01	1.69

Sources: Gas Production: EIA (https://www.eia.gov/dnav/ng/ng_sum_lsum_a_EPG0_FPD_mmcf_a.htm); Employment: 2020 USEER. A heat content conversion factor is 1024 Btu/CF is assumed.

An alternative approach to estimating the labor associated with projected changes in natural gas extraction could rely on labor intensity ratios developed using the 2017 economic census values for NAICS 21113 (Natural Gas Extraction). This factor, about 0.4 employees per million dollars, is roughly equivalent to the factor developed in Table 22.[24] This methodology uses the USEER data because it is the most recently-available data and requires fewer assumptions to convert employment to an output-based factor that is consistent with modeling projections.

Additionally, labor associated with natural gas pipeline construction is estimated using a LIR factor for Pipeline Construction. The projected incremental amount of natural gas use is multiplied by a cost estimate of $215 MM/TCF,[25] and that total estimated expenditure is multiplied by the LIR factor to yield an estimated total employment change.

C. Nuclear Fuels

An estimate of employment related to the amount of fuel produced for nuclear generation is based on information available in the 2020 USEER and total generation data from US EIA. A factor of 11.2 employees per billion kWh of nuclear generation is applied to the projected change in nuclear generation to estimate the impact on employment. For more detail on development of this factor, see Appendix II.

IX. Projecting Potential Impacts

Sections IV through VIII above detail the different approaches for estimating the labor associated with projected changes to various aspects of the electric power sector. In order to evaluate the potential labor impacts of a policy, it is necessary to first estimate changes to elements such as capacity and generation, and then apply the factors and equations discussed above to those changes. Table 23 below summarizes the model projections that are necessary as inputs to the methodology described above.

[24] Applying this alternate factor to the change in gas production in 2018-2019 and an average citygate gas price of $4.02/MMBtu over that time results in an equivalent factor of about 1.6 employees per TBtu.
[25] $215MM/TCF is an EPA estimate is based on assumptions utilized in EPA's IPM Reference Case v.5

Table 23. Summary of Required Model Projections for Employment Analysis

Power Sector Impact	Methodology Section	Required Model Projections
Construction of New Generators	Section IV	Capacity (MW)
		Generation (MWh)
		Capital Costs ($)
		FOM Costs ($)
Change in Operation of Generators	Section V	Capacity (MW)
		Generation (MWh)
		FOM Costs ($)
Construction of New Pollution Controls	Section VI	Capacity (MW)
		Capital Costs ($)
Operation of Pollution Controls	Section VII	Generation (MWh)
		NOx Removed (tons)
Fuel Production	Section VIII	Coal Production (Million Tons)
		Gas Production for Power Sector (Btu)
		Nuclear Generation (MWh)

Note: Required model projections for each impact may vary by technology. See methodology sections above for a comprehensive documentation.

APPENDIX I. Resource Price Assumptions

Based on: “Estimating labor impacts of generation technology deployment and heat rate improvement methods (Draft),” Memo to EPA from James Staudt, Tara Stout, and David Sellers (3/26/19):

Table 24. Resource Price Assumptions

Resource	Price Estimate	Unit	Year
Steel	827	$ per metric ton	2012
Lime (Quick)	123	$ per metric ton	2017
Lime (Hydrated)	149	$ per metric ton	2017
Limestone	11.5	$ per metric ton	2017
Ammonia (NH_3)	265	$ per metric ton	2017
Catalyst	3,676	$ per cubic meter	2016
Activated Carbon	1,833	$ per metric ton	2017
Trona (Soda Ash)	152	$ per metric ton	2017

Steel: A yearly steel price was averaged from bimonthly prices provided from SteelBenchmarker™, an “index of the current ‘standard’ or ‘base’ transaction prices for use by participants in the steel industry” (see steelbenchmarker.com). Around 950 providers submit anonymous steel prices for hot-rolled band, cold-rolled coil, rebar, and plate steel twice a month. In 2012, there weren’t enough participants submitting rebar information (at least ten providers must submit prices for the information to be published) so that kind of steel was excluded from the average.
Source: SteelBenchmarker™. World Steel Exchange Marketing, 2018, http://steelbenchmarker.com/.

Lime, Limestone, Ammonia, Trona: These commodity prices were all sourced from USGS Mineral Commodity Summaries. All prices are FOB at the mine or plant. The crushed stone commodity in the USGS survey also references prices of other stone types, however 70% of the category is identified as limestone so this cost was still relevant.
Sources: U.S. Geological Survey, Mineral Commodity Summaries, January 2018 (LIME, STONE (CRUSHED), and NITROGEN (FIXED)—AMMONIA, and SODA ASH)

Catalyst: Catalyst bids received by municipal utility SCRs are public information and can be available on line. This catalyst cost estimate is based on bids for an SCR project for Lakeland Electric’s McIntosh Power Plant in 2016. The bids included prices for new and regenerated layers. Only the new layer prices from three vendors were averaged to estimated catalyst cost, although the plant decided to regenerate their existing catalyst (the more economical option).
Source: City of Lakeland Memorandum: Approval to Procure Services with SCR-Tech to Regenerate Catalyst Layers for McIntosh Power Plant Unit 3 SCR Reactor System, January 2016. Available: http://www.lakelandgov.net/portals/CityClerk/City%20Commission/Agendas/2016/01-04-16/X-C-1%20-%20SCR-TechAgmt.pdf

Activated Carbon: In 2006, two U.S. producers filed a petition with the United States International Trade Commission (USITC) claiming that imports of activated carbon from China were being sold at less than

fair value (LTFV). To determine fair value, U.S. companies submitted price information to the USTIC, with the most recent data submitted in 2017. The USTIC reported that the average unit value (dollars per pound) of U.S. supplier shipments of activated carbon was $1.01 in 2017. The Table 4 estimate converts this value to dollars per metric ton.
Source: U.S. International Trade Commission. Certain Activated Carbon from China: Second Review (Investigation No. 731-TA-1103). Washington D.C., June 2018.

APPENDIX II. Nuclear Power Plant Staffing Assumptions

Based on: "Estimating labor impacts of generation technology deployment and heat rate improvement methods (Draft)," Memo to EPA from James Staudt, Tara Stout, and David Sellers (3/26/19):

Employment relating to nuclear power is assessed in this appendix. According to the USEE report staffing associated with nuclear generating in 2017 was 64,743 workers, with about 66% at utilities, 20% in professional services 6.4% in manufacturing, 4.6% in trade 3.1% in construction. In addition, nearly 9,000 workers were employed in supply of nuclear fuels.[26]

In 2017, nuclear plants supplied 805 billion kWh of electricity from 60 commercially operating plants and 98 nuclear reactors with a total capacity of 102 GW.[27] Using the above employment data, there are roughly 0.62 workers per MW and about 1079 workers per plant and 660 per reactor. This includes on-site utility workers, professional service contractors, manufacturing workers, construction and trade workers, and a small number of off-site utility workers. Excluding manufacturing workers, this equates to 0.58 workers per MW, 1011 per plant, and 619 per generating unit. For fuels, the roughly 9,000 workers in the fuel supply area equates to 11.2 workers per billion kWh of electrical generation.

Other sources of data include a benchmarking study by the Electric Utility Cost Group (EUCG) of utility employees and contractors.[28] This study provided a breakdown of years 2004-2008 nuclear plant labor by three categories – onsite employees, offsite employees, and contractors. The average per plant for each of the years is shown in Figure 1. This appears to be generally consistent with the data from the USEE report. An advantage of this data is that it lets us examine the effects of plant size. A summary of the data is shown in Table 25

. A median is typically more representative than average because a median value is less susceptible to very high numbers that might be the result of unusually old or unusually small plants. Analysis of this data shows a strong relationship between plant total MW and the number of total onsite employees. This effect is shown in Figure 2 (total employees versus plant capacity) and Figure 3 (employees per MW capacity versus plant capacity). For labor categories other than utility onsite employees the relationship with capacity is much weaker. Utilities also use contractors on site. These include maintenance and technical personnel and may also include contracted engineering services.

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[26] Energy Futures Initiative for the National Association of State Energy Officials, "US Energy and Employment Report", May 2018

[27] US Energy Information Administration

[28] Peltier, R., "Benchmarking Nuclear Plant Staffing", Power Magazine, April 1, 2010, Contractors would include contractors that regularly work at the utility premises. It is not unusual for utilities to utilize contractors for some engineering or service functions. Data from the Nuclear Committee of the EUCG

Figure 1. Average employment per nuclear plant by worker type for years 2004-2008[29]

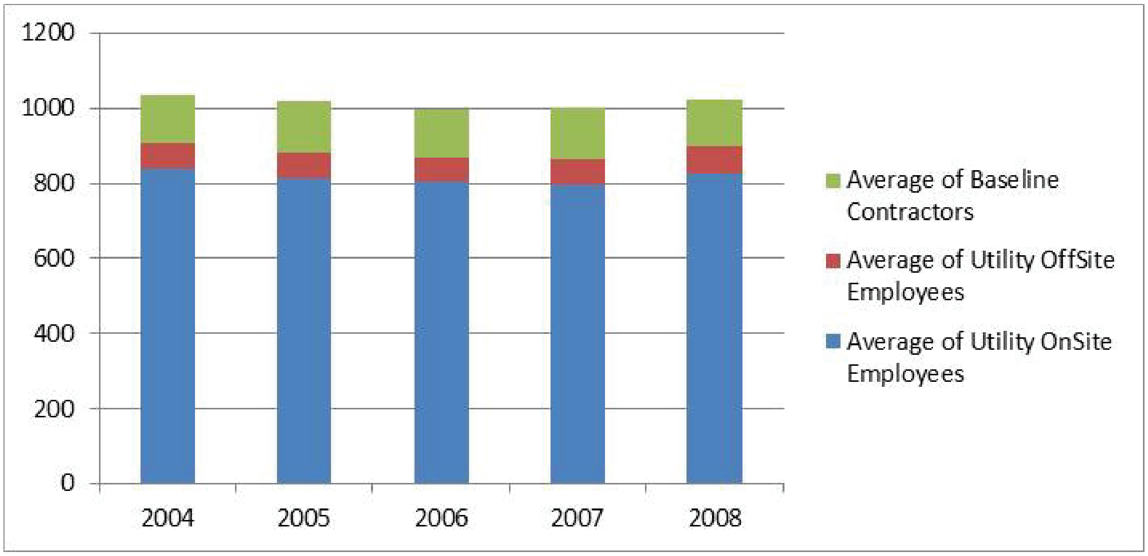


Table 25. Summary of data for nuclear power plant staffing 2008[30]

	Utility OnSite Employees	Utility OffSite Employees	Baseline Contractors	Total	Plant Capacity MW
Total (all plants)	53,637	4,161	7,954	65,752	99,986
Median	723	62	113	913	1,598
Average	825	72	126	1,012	1,538
Median employee/MW	0.547	0.040	0.081	0.719	
Average employee/MW	0.604	0.045	0.096	0.745	

[29] Ibid
[30] Ibid

Figure 2. Total employees per plant as a function of total plant MW capacity[31]

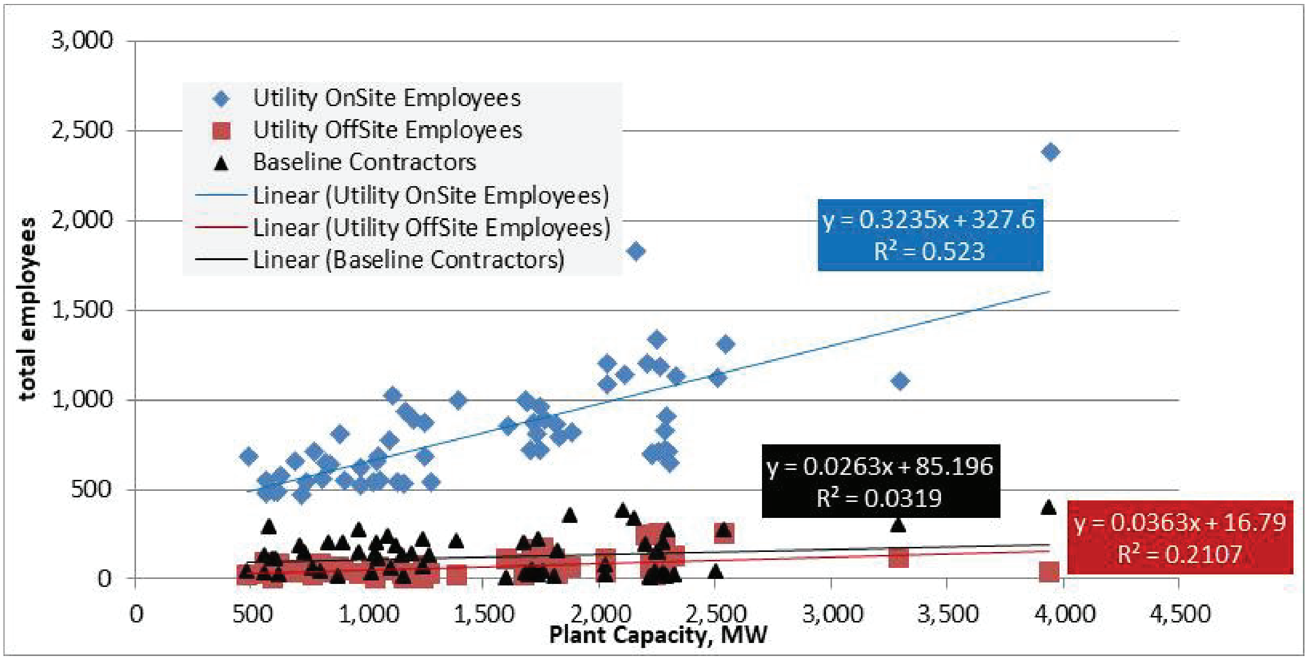
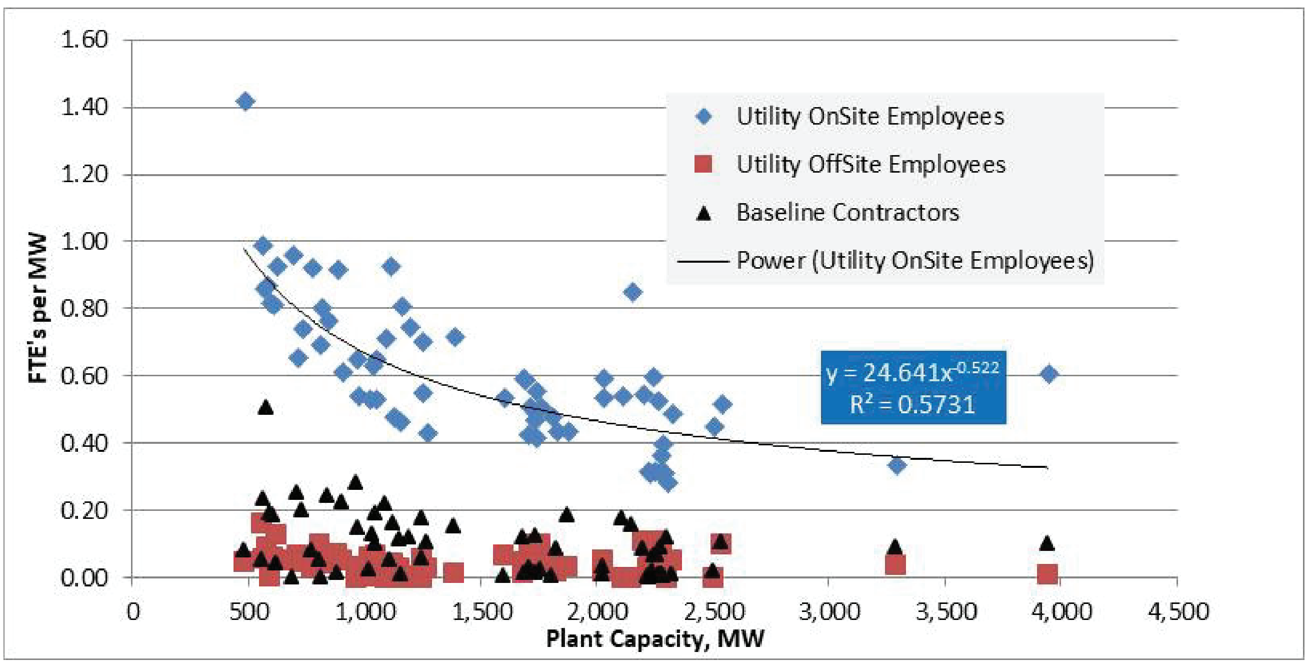


Figure 3. Total FTEs per plant MW as a function of total plant MW capacity[32]



[31] Ibid
[32] Ibid

Additional information on the breakdown of staffing can be drawn from an IAEA report.[33] This report examines staffing from member states, including several plants outside of the United States and is 20 years old. So, the information may have some disadvantages in terms of accuracy; however, it does provide a relative breakdown of employees for the types of functions within departments at nuclear plants (labor, technicians, management, etc.). For one case study, there were a total of 454 people in operations, 81 in admin, 52 in common functions like corporate management and legal, and 137 in licensing and engineering. This excludes some of the contractors that might be employed, especially short term contractors. The report also provided information on the breakdown of staff by function. It is assumed that Tech Support and Maintenance in Operations are labor and other functions are engineers or management.

The IAEA report is useful in helping estimate the breakdown between labor and management/engineering. The labor portion is limited mainly to the Operations department and comprises roughly 44% of the onsite staff. Using the total staffing from the EUEC study and the breakdown estimated from the IAEA report, it is recommended that employment be modelled as follows:

Utility onsite employees per plant:

- FTE = 328 + 0.3235 x (plant MW)
  (employees per plant with 66% managers or engineers and 44% labor)

Utility offsite employees per plant:

- FTE = 17 + 0.0363 x (plant MW)
  (employees per plant with 100% management or engineers)

Contractors per plant:

- FTE = 85 + 0.0263 x (plant MW)

Number of persons that are employed in the production of nuclear fuels:

- FTE = 11.2 x generation in billion kWh

[33] International Atomic Energy Agency, “Nuclear power plant organization and staffing for improved performance: lessons learned”, IAEA-TECDOC-1052, 1998, especially see Annex E, pp. 41-57

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