EPA METHODOLOGY FOR POWER SECTOR-SPECIFIC EMPLOYMENT ANALYSIS

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Contents

Part I: Introduction and Overview of Methodology

Objective

Over the past decade, ICF has conducted numerous bottom-up employment analyses for EPA in support of several rulemakings. While the methodology specific to each analysis has been documented in conjunction with the relevant rulemaking, this document provides a comprehensive summary of the general methodology for estimating the impact on labor between any two modeling scenarios.

Scope of the analysis

EPA's labor analyses have focused on the potential impacts of air pollution regulations on the direct changes in the amount of labor needed in the power generation sector and directly related sectors (e.g., equipment manufacturing, fuel supply, and generating efficiency services). The same approach can be applied to estimate labor changes between any two modeling scenarios. In short, this approach converts changes in projections of the resources required for a certain scenario (e.g., pollution controls) to estimates of changes in labor demand. This approach does not address another potential change in labor demand, i.e. if a regulation causes marginal cost to increase, placing upward pressure on output prices, decreasing quantity demanded and production, this can cause a decrease in factor demands, such as labor.[1] Generally, this conversion of resource requirements relies on the translation of non-monetary units into monetary estimates, and subsequently those monetary estimates into labor demand.

This approach can 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 prices) that would be included in a more general equilibrium modeling context.

Overall Methodology: 4 Steps

The overall methodology for these analyses consists of four sequential steps:

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[1] Since electricity demand is relatively inelastic, and industry output may not change much, this output effect on labor demand may be small, overall, for the power sector. The distribution of labor demand changes may vary across facilities within the power sector.

1) Quantify the change in projected actions between two modeling scenarios.
2) Estimate the resources required for those actions based on EPA's engineering estimates of the per-unit resources required to implement those changes.
3) If resource needs are not already reported in terms of the labor required, estimate the labor needs under each analysis by converting the resource needs into a monetary value which is then converted to labor needs using labor productivity data.
4) Combine this information to generate the first-order labor impacts.

Each of these steps are summarized below and discussed in more detail in the numbered sections in Part II.

This approach estimates labor changes measured as the change in job-years in each analysis year. Job-years are not individual jobs, and they are not necessarily permanent or full-time jobs. Job-years are the amount of work performed by one full time equivalent (FTE) employee in one year. For example, 20 job-years may represent 20 full-time jobs or 40 part-time jobs in a given year, or any combination of full- and part-time workers such that total is equivalent to 20 FTE employees.

Step 1: Quantify projected actions from power sector modeling

The first step is to quantify the changes projected to occur between scenarios. To do so, we compare projections of a two or more scenarios in order to estimate the changes projected to occur. These actions typically include changes in pollution control retrofits, changes in new and existing generation capacity, and fuel use changes.

Step 2: Estimate changes in resource requirements

After the changes in projected actions are quantified, the next step estimates the resources required to implement these actions. These resources can be physical resources such as tons of steel, monetary inputs such as dollars required to install or run a compliance technology, or the labor hours required to implement a compliance change. In general, resource needs for many of the compliance changes are broken down into two main categories: those needed for construction or installation and those for operating the resources.

Construction-related resources are relevant for building new generation capacity or installing new retrofits. To estimate these resources, we use data and assumptions on the specific types of labor categories required (e.g., boilermakers) along with the physical quantities of total resources needed, such as total labor hours required for a specified capacity of the new equipment. In addition, we also use information on the indirect labor needs to construct and install new equipment, such as those for steel or initial catalyst load in certain types of pollution control equipment.

We also estimate the resources required to operate new generating capacity and retrofits. For new generation capacity, the cost of operation and maintenance is estimated based on the projected capacity increase. For pollution control retrofits, the physical resources required for operation are estimated based on assumptions regarding the necessary inputs for each type of control (e.g., tons/MWh of limestone used in scrubbers).

This step also involves estimating resource changes related to generator retirements. Under this step the resources no longer needed due to retirement are the reduction in operating and maintenance expenditures on the facility retiring; any employment impacts such a retirement has related to its fuel consumption are captured separately through our assessment of projected differences in total fuel consumption under the policy being analyzed.

Estimates of fuel use changes are based directly on differences in model projections. We also estimate the cost to construct additional pipeline capacity needed to accommodate projected increases in natural gas demand.

Step 3: Estimate Labor Impacts

The next step is to convert the estimated resource requirements into estimated labor impacts, if not already reported in terms of labor requirements. We first convert the estimated physical quantities of required resources into monetary amounts, where necessary, using market prices for the resource.

Next, we apply labor productivity values to the estimated monetary amounts in order to estimate labor impacts. We derive labor productivity values based on the North American Industry Classification System (NAICS)-based sectors that produce the relevant resources estimated in the previous step. Labor productivity quantifies the amount of labor required to produce a dollar amount of output. In addition, because labor estimates are being made for future years, labor productivity growth rates were also calculated based on historical data. These growth rates are used to project labor productivity to future years.

Step 4: Aggregate Labor Estimates

The final step combines the information developed in the previous steps to create the labor estimate representing the first-order policy impact as direct labor changes resulting from projected actions.

Part II: Detailed Methodology

1. Quantify Projected Actions

The following table contains a list of all outputs obtained from the power sector modeling that are used as inputs to this analysis.

Table 1: Power Sector Modeling Outputs

Modeling Output Category	Technology	Units
New Generation Capacity	Biomass	**Cumulative GW**
	Solar	
	Wind	
	Coal	
	Natural Gas Combined Cycle (CC)	
	Natural Gas Combustion Turbine (CT)	
Retirements	Natural Gas Combined Cycle	Cumulative GW
	Coal	
Pollution Control Retrofits	FGD	Cumulative GW
	SCR	
	SNCR	
	ACI	
	DSI	
	HRI	
	Combustion Control	Installation Costs
Fuel Consumption	Appalachian Coal	Million tons
	Interior Coal	
	Western Coal	
	Waste Coal	
	Natural Gas	Trillion cubic feet

1.1. Retrofit Capacity

One of the largest drivers of employment growth in policies analyzed to date is the installation of new pollution control equipment. Retrofit technologies evaluated to date include:

- Flue gas desulfurization, or “scrubbers” (FGD)[2]
- Selective Catalytic Reduction (SCR)
- Selective Non-Catalytic Reduction (SNCR)
- NO_X Combustion Controls
- Activated Carbon Injection (ACI)
- Dry Sorbent Injection (DSI)
- Fabric Filters (FF)
- Electrostatic Precipitators (ESP)
- Heat rate improvements (HRI)

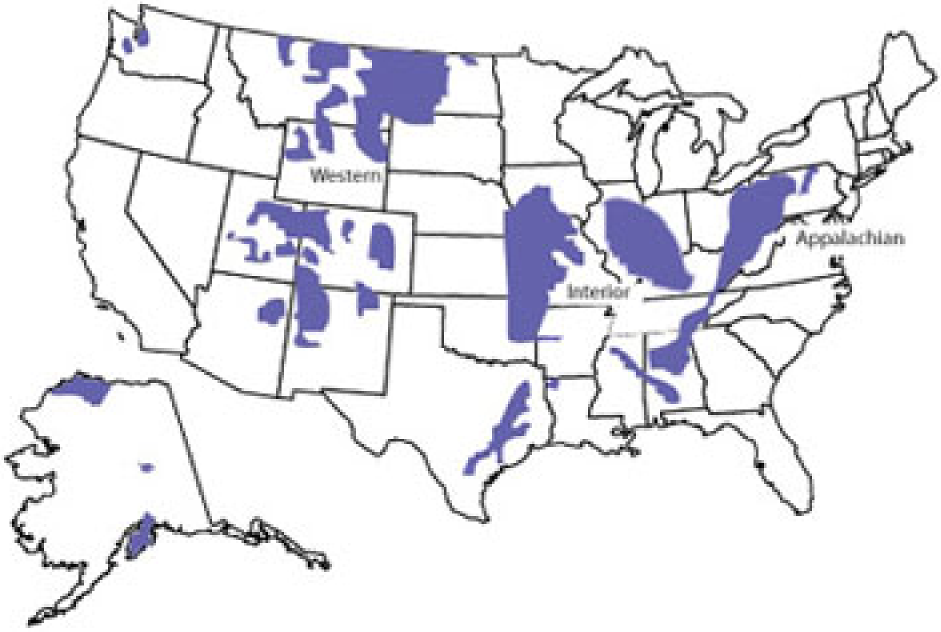
1.2. Changes in new generation capacity

Projected changes in new electric generating capacity might include coal steam, natural gas combined cycle, natural gas combustion turbine, solar, wind, and biomass.

1.3. Fuel use changes

We account for changes in coal demand regionally because Appalachian and Interior coal require more labor to mine the same amount of coal as Western coal, such that they have notably different, labor productivity values (that are applied regionally in the following step).

Figure 1: Regional Coal Production in the U.S.



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[2] Note that this labor analysis does not make a distinction between wet and dry scrubbers.

We evaluate projected changes in natural gas consumption at a national level. Additionally, since increases in natural gas demand likely correlate with new pipeline demand, in this step we also estimate potential pipeline construction that could accompany projected increases in natural gas demand.

1.4. Changes in Existing Capacity

In order to estimate employment changes related to plant closures, we assume that the fixed operating costs (FOM) that are no longer paid for retired units can be used as a proxy for ceased economic output due to retirements.[3]

2. Estimate Resource Requirements for Changes in Projected Actions

In this step, "resource" refers to any inputs associated with changes in projected actions between modeling scenarios. These resources can be physical resources such as tons of steel, monetary inputs measuring cost of installing or running a pollution control device, or the direct labor hours. This section describes the resources that are estimated, assumptions made, and details how projected changes are converted into resource requirements. This section covers the two main types of resources: resources for construction and resources for operation.

2.1. Construction of New Generation Capacity

The resource requirements for new capacity are expressed in terms of the costs of equipment, material, labor, and special technical services, such as engineering and construction management. Calculating these resource requirements occurs in two steps. The first step converts projections of annual capacity (MW) into the cost of construction. Next, the total construction cost value is broken down into shares for equipment, material, labor, and specialized labor.

For each technology, estimates about construction cost and time to completion are based on EPA's assumptions as documented in EPA (2018). To estimate an annual cost, the total construction cost was divided by the number of years assumed to complete construction.

The annual construction costs of new generation capacity can be summarized as:

$$Annual\ Construction\ Cost = \frac{Capacity\ (MW)\ x\ Capital\ Cost\ \left(\frac{\$}{kW}\right) x\ 1000}{Build\ Duration\ (years)}$$

The assumed capital cost ($/kW) and build duration values are presented in the table below.

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[3] FOM costs are treated as a proxy for retirement-related job losses occurring at the power plant only.

Table 2 Capital Cost and Build Duration Assumptions:

New Capacity Type	Capital Cost (2016$/kW)	Build Duration
Combined Cycle	1,081	3 Years
Combustion Turbine	662	2 Years
Onshore Wind	1,404	3 Years
Solar PV	1,034	3 Years

Source: EPA (2018)

The total construction costs for each generation technology are then divided into the specific capital and labor components for expenditures on equipment, material, labor, and engineering and construction management. The breakdown into these categories is provided in the table below.

Table 3: Capital and Labor Contents for New Generation Capacity

New Capacity Type	Equipment	Material	Labor	Engineering and Construction Management
Renewables + Biomass	54%	6%	31%	9%
Combined Cycle	65%	10%	18%	7%
Combustion Turbine	65%	10%	18%	7%

Sources: EPA (2002) and Staudt (2011)

Dividing the annual construction costs into the constituent categories results in estimates of expenditures on equipment, material, and labor required for construction of new generation capacity.

For illustrative purposes, an example calculation to estimate the resources required for a 500-MW combined cycle unit is presented in the table below.

Table 4: Estimate Required Resources: New Generation Capacity Example (500-MW Combined Cycle)

Assumptions		Calculation			Resource Estimate
1,006 $/kW	3 Year Build Duration	$\frac{1{,}006\frac{\$}{kW}*500\ MW*1{,}000}{3\ Years}$	= $167,666,667 per year	65% Equipment	= $108,983,333
				10% Material	= $16,766,667
				18% Labor	= $30,180,000
				7% Engineering and Construction Management	= $11,736,667

2.2. Operation of New Generation Capacity

The operation of new generation capacity requires resources that can be estimated based on the annual cost of operation and maintenance. We estimate annual resource requirements for operating new generation capacity based on these annual fixed operating and maintenance (FOM) costs. These assumptions are summarized in the table below.

Table 5: New Generation Capacity Fixed Operation and Maintenance Cost Assumptions

New Capacity Type	FOM Cost (2016$/kW-yr)
Combined Cycle	9.9
Combustion Turbine	6.8
Onshore Wind	49.46
Solar PV	11.35

Source: EPA (2018)

Using the above FOM cost assumptions, we estimate operating costs by multiplying the FOM cost by the projected capacity of new generation for each technology. The table below illustrates this calculation for a 500 MW new combined cycle unit.

Table 6: Estimate Required Resources: New Capacity Operation Example (500 MW Combined Cycle)

Assumption	Calculation	Resource Estimate
15 $/kW-yr FOM	$15\ \$/kW-yr\ *\ 500\ MW\ *\ 1{,}000$	= $7,500,000 Annual FOM Cost

2.3. Installation of New Pollution Control Retrofit Technology

Resources required for installation of pollution control retrofits consist of both the labor hours required to install a retrofit (by specialized labor category) as well as other resources required to install the retrofits (such as steel and any relevant reagent). In order to estimate these hours and resources, the quantity of projected new retrofit capacity is combined with technology-specific assumptions discussed below. The methodology for performing these steps differs depending on the retrofit technology.

For FGD, SCR, and ACI, assumptions regarding construction labor are based on a 2002 EPA study that analyzed the resource requirements for installing various pollution control equipment (EPA, 2002). For DSI and FF, assumptions are based on a memo from Andover Technology Partners (ATP), the author of which was also one of the contributors of the 2002 EPA study (Staudt, 2011a). To derive estimates for DSI, ATP scaled the labor requirements for ACIs found in the EPA (2002). Installation labor was further sub-divided into different labor categories, such as boilermakers, engineers and "other installation labor," based on EPA (2002), and similarly scaled for DSI and FF.

In addition to construction labor, we also estimated the additional labor necessary to produce the steel required by these retrofits. The increased steel demand is estimated by multiplying the per-MW steel demand from EPA (2002) by the estimated increases in retrofit pollution control capacity. For DSI and FF, the same proportionality assumption was taken from Staudt (2011a) for installation labor to estimate the steel needed for installation. In addition to steel, SCRs also require an initial load of their catalyst at installation. Similar to the calculations for steel, this initial load was calculated based on per-MW values. The per-unit labor needs, labor category breakdown, and physical resource requirements for FGD, SCR, ACI, DSI, and FF technologies are presented in the table below.

Table 7: New Retrofit Capacity Resource Assumptions

Resource Needs (Units in parenthesis)	FGD	SCR*	ACI	DSI	FF
Total Labor (labor hours/MW)	760	700	10	44	398
Boilermaker (%)	40%	45%	50%	50%	45%
Engineering (%)	20%	7%	17%	17%	7%
Other Installation Labor (%)	40%	48%	33%	33%	48%
Steel (tons/MW)	2.25	2.5	0.35	2.20	1.42

Source: EPA, 2002 and Staudt, 2011a

**SCR also requires a catalyst initial load of 1.2 m^3/MW, in addition to steel.*

To illustrate how these assumptions are used to estimate the required resources to install a retrofit, the following table has an example calculation for a 500-MW FGD unit.

Table 8: Estimate Required Resources: New Retrofit Example (500 MW FGD)

Assumptions	Calculation			Resource Estimate
760 labor hours per MW	$760 \frac{labor\ hours}{MW} * 500\ MW$	= 380,000 labor hours	40% Boilermakers	= 152,000 Hours
			20 % Engineering	= 76,000 Hours
			40% Other Installation Labor	=152,000 Hours
2.25 Tons Steel per MW	$2.25 \frac{Tons}{MW} * 500\ MW$			=1,125 Tons of Steel

Resource requirements for HRI and NO_X combustion controls were determined using a slightly different methodology due to a lack of more detailed labor requirement data for those technologies. For both HRI and NO_X combustion controls, we estimate the annual cost of installation and then estimate constituent capital and labor components.

For HRI, total labor and capital estimates were broken down into two specialized labor categories as well as the equipment and material required for installation. These breakdowns were applied to the estimated average cost of available HRI installations. [4] We assumed a 4-year duration for HRI changes (Staudt, 2014) and thus estimated the annual cost as one-fourth of the total cost for these improvements.

Table 9: Annual Labor and Capital Breakdown for Heat Rate Improvement

Category	HRI
Cost ($/kW)	$25/kW
Boilermaker/General Construction	40%
Management/Engineering	20%
Equipment	30%
Materials	10%

Source: Staudt (2014) Note that these are illustrative annual costs over a period of 4 years.

To illustrate how resource requirements are estimated, the table below demonstrates the calculation of a HRI at a 500 MW unit.

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[4] The ability to improve heat rates and the cost of doing so is dependent on various unit-specific factors and varies across the existing fleet. In a 2015 analysis, EPA assumed $100/kW, and presents that assumption here for illustrative purposes.

Table 10: Estimate Required Resources: New Retrofit Example (500 MW Heat Rate Improvement)

Assumption	Calculation		Resource Estimate
25 $/kW Annual Cost	$25\frac{\$}{kW} * 500\ MW * 1{,}000$	40% Boilermaker/General Construction	= $5,000,000
		20% Management/Engineering	= $2,500,000
		30% Equipment	= $3,750,000
		10% Materials	= $1,250,000

For NO$_X$ combustion controls, estimates of required resources are based on the capital and labor content of projected installation costs. Note that this differs from other controls, for which we use capacity projections. The labor and capital components of total installation costs are based on analysis of McAdams (2001), which estimates the capital cost and labor requirements to upgrade to state-of-the-art NO$_X$ combustion controls. In that report, the costs of installing flue gas recirculators and ultra-low NOx burners were estimated to be $400,000 for capital and $180,000 for labor. These cost estimates were used to derive the capital and labor content at approximately 70 percent and 30 percent, respectively.

Table 11: Capital and Labor Costs of Combustion Control Equipment

	Capital	Installation Labor
Flue gas recirculation (FGR)[5]		
Forced draft and FGR ductwork	$150,000	
New forced draft/FGR fan	$50,000	
Forced draft/FGR fan installation		$100,000
Next-generation low NOx burner[6]		
Burners	$200,000	
Installation		$80,00
Sum	**$400,000**	**$180,000**
Total Cost	$580,000	
Percentage of Total	70%	30%

Capital and labor were then further split into boilermakers and general construction, management and engineering, equipment, and material using the same ratios as for HRI (a 2:1 ratio of boilermakers and general construction to management and engineering). The table below summarizes the breakdown of total NO$_X$ combustion control costs into specialized labor and capital components.

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[5] Ibid., Table 2

[6] Ibid, Table 7

Table 12: Labor and Capital Breakdown for Combustion Control Equipment

Category	Percentage
Boilermakers/General Construction	20%
Management/Engineering	10%
Equipment	52%
Materials	18%

2.4. Operation of Newly Installed Retrofits

Resources required for operating pollution control retrofits included materials such as limestone, catalyst, ammonia, activated carbon, and others. As with resources required for construction of pollution controls, the resources required for operation of pollution controls is based largely on EPA (2002) and Staudt (2011a). These resource estimates were multiplied by an estimated level of generation for each type of pollution control in order to estimate the total (physical) quantity of resources needed during operation.[7]

Table 13: Resource Need Assumptions for Retrofit Operation

Pollution Control Type	Resource (Units in parenthesis)	Usage Estimates
FGD	Limestone (Tons/MWh)	0.036
SCR	Ammonia (lbs/lb NO_X Reduced)	0.39
	Operational Catalyst (m3/MWh)	0.00002
DSI	Sodium Bicarbonate / Trona (Tons/MWh)	0.03
ACI	Activated Carbon (tons/MWh)	0.000074 (with FF) 0.000914 (with ESP)
FF/ESP	Baghouse Material (Annual VOM Costs)	$95,000,000**

Sources: Usage: EPA (2002. DSI and FF: Staudt (2001a)
Ammonia: Development of Supply Curves for Abatement of GHG from Coal-fired Utility Boilers, Air Pollution Prevention and Control Division, US-EPA, RTP and NC State University, 2009
Catalyst: EPA Air Pollution Control Cost Manual, Sixth Edition, January 2002.
Sodium Bicarbonate: Communication with Andover Technology Partners, Feb 7 2011
***For Fabric filters, we used the projected VOM cost and converted this to labor hours using the direct workers per million dollars output for the relevant manufacturing industry sector.*

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[7] Total generation was estimated based on the total capacity of each type of retrofit and an assumed 85 percent capacity factor. For ammonia, the usage was calculated based on the total predicted NO_X reduced, consistent with the EPA (2002) approach.

In addition to the resources required for operating newly installed retrofits, under certain situations, there may also be additional resources required for incremental changes in operating *existing* retrofits. These changes are reflected in EPA's labor analyses as projected changes in variable operating and maintenance costs.

The following table illustrates the calculation of resource requirements for a scrubber retrofit.

Table 14: Estimate Required Resources: New FGD Retrofit Operation Example (500 MW, $1 Mil FOM, FGD)

Assumption		Calculation	Resource Estimate
0.036 Limestone Tons/MWh	0.85 Capacity Factor	500 MW * 0.85 * 8760 Hours * 0.036	134,028 Tons of Limestone
$1 Million FOM		----	$1 Million FOM

2.5. Retirements

Projected retirement of existing capacity results in a decrease in required resources in operating these units. To estimate resource requirements associated with these projections, the projected change in generation capacity is multiplied by FOM costs. In order to convert retired capacity into potential reductions in labor needed, we assumed that changes in operating costs for electricity generation can be used as a proxy for the ceased economic output due to fossil retirements. To convert projected retirement capacity into total changes in resource requirements, we use the FOM ($/kW-yr) values in the table below.

Table 15: Resource Assumptions for Generator Retirements

Retirement Type	FOM Cost (2016$/kW-yr)
Coal (Average)	40
Oil and Natural Gas (Average)	26

Source: EPA 2018

These FOM costs in $/kW-yr are then multiplied by the incremental change in capacity in order to estimate total incremental FOM costs related to projected retirements. An example of this calculation is found in the table below.

Table 16: Estimate Required Resources: Retired Capacity Example (500 MW Combined Cycle)

Assumption	Calculation	Resource Estimate
23 $/kW-yr	$23\ \$/kW - yr\ *\ 500\ MW\ *\ 1{,}000$	= $11,500,000 Annual FOM Cost

2.6. Fuel Production and Pipeline Construction

Projected changes in fuel use and price are modeled directly, and do not require an intermediate estimation of required resources. However, a significant projected increase in natural gas use may require additional pipeline capacity. To estimate the resources required for pipeline construction we multiply the projected change in natural gas use (TCF) by the capital cost of pipeline capacity expansion, assuming that additional pipeline capacity is needed is linearly proportional to the projected increase in natural gas consumption. Using data from EPA's power sector modeling assumptions, we estimated the incremental capital cost for constructing new pipeline capacity to be about $215 million per TCF of incremental gas capacity in any given year. The resulting capital cost for pipeline construction is subsequently converted into labor estimates using the labor productivity value for pipeline construction found in Table 18.

3. Estimate Labor Impacts

This section describes the other economic variables that are needed to estimate the final employment impacts. These variables enable us to convert the estimated resource requirements in the previous step to estimated impacts on labor. The economic variables used in the labor analysis are job-years, product prices, and labor productivity.

3.1. Annual Job-Year

We assume 2,080 labor hours per year is the equivalent of one job. For the resource estimates in the previous step that are estimated in labor hours, we divide total labor hours by 2,080 to estimate total job-years.

3.2. Product Prices

Product prices are necessary to convert resource requirements estimated in physical units into dollars. Where applicable, product prices used for each resource are summarized in the table below. Product prices are multiplied by the resource estimates in the previous step to estimate the dollar amount of each resource.

Table 17: Product Price Assumptions

Resource	Price
Steel	\$550 per ton
Limestone	\$75 per ton
Ammonia (NH_3)	\$150 per ton
Catalyst	\$8,475 per m^3
Activated Carbon	\$1,120 per ton
Trona	\$120 per ton

Sources: *Steel: Platts, Steel Markets Daily, Vol 3 Issue 209, October 29, 2009.*
Limestone: FGD Tech Evaluation, March 2007.
Ammonia: Development of Supply Curves for Abatement of GHG from Coal-fired Utility Boilers, Air Pollution Prevention and Control Division, US-EPA, RTP and NC State University, 2009.
Catalyst: EPA Air Pollution Control Cost Manual, Sixth Edition, January 2002.
Activated Carbon: Preliminary Cost Estimate of ACI for Controlling Hg Emission, US DOE, NETL, November 2003.
Sodium Bicarbonate: Communication with Andover Technology Partners, Feb 7, 2011.

3.3. Labor productivity

In order to convert the estimated resource requirements into actual labor demand, we first estimate labor productivity for each of the relevant resources or sectors. Estimating labor productivity requires estimating both a base (historical) year labor productivity, as well as a future year labor productivity. Since labor productivity generally increases over time (as the number of workers needed to obtain a unit of output generally decreases over time), it is important to adjust labor productively based on historical data to account for these changes when evaluating impacts on future years.

3.3.1. Labor Productivity: Base year

This section includes the sources of base labor productivity estimates and the formulas used to calculate them. It also describes how different sectors have different values and how NAICS-based sector definitions are matched with the relevant sectors and their respective productivity estimates.

To determine base year labor productivity, we first connect all resource estimates to their North American Industry Classification System (NAICS) sectors. Each type of resource is matched to a NAICS sector based on the types of goods produced by that sector. Once the NAICS sector is identified, we collect value of shipments and total employees from the Economic Census and Bureau of Labor Statistics (BLS) for each relevant sector. The NAICS sectors for each resource, value of shipments and total employees data, the year that data was collected (data vintage), and calculations used to determine labor productivity are presented in the table below.

Table 18: Assumptions to Calculate Base Labor Productivity

Resource	NAICS Sector	Value of Shipments ($ Million)	Total Employees	Labor Productivity (Direct workers per $ Millions of Output)	Data Vintage
		A	B	A / B	
Steel	33121	$13,818	26,196	1.9	2012
Limestone	32741	$1,876	4,369	2.3	2007
Ammonia (NH_3)	325188	$22,829	35,801	1.6	2007
Catalyst	331419, 331492	$13,911	19,666	1.4	2007
Activated Carbon	325998	$17,129	35,956	2.1	2007
Trona	212391	$1,708	3,711	2.2	2007
FF Resource	325211	$85,232	71,216	0.8	2007
Power Plant Construction (Including HRI and combustion controls)	237130	$44,270	222,684	5.0	2012
Equipment Manufacturing	333	$407,669	1,063,392	2.6	2012
Engineering	54133	$211,936	994,363	4.7	2012
Power Plant Operators	22111	$14,311	142,240	9.9	2012
Pipeline Construction	237120	$41,153	172,311	4.2	2012

For estimated changes in fuel consumption we use labor productivity estimates that are production-based. For coal, we use EIA data on regional coal mining productivity (in short tons per employee hour).[8] [9] For natural gas, labor productivity per unit of natural gas was unavailable. Since most secondary data sources (such as Census and EIA) provide estimates for the combined oil and gas extraction sector, we use an adjusted labor productivity estimate for the combined oil

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[8] From US Energy Information Administration (EIA) Annual Energy Review, Coal Mining Productivity Data. Used 2008.

[9] Unlike the labor productivity estimates for various equipment resources which were forecasted to future years using BLS average growth rates, for fuel sectors we use the most recent historical productivity estimates (i.e., without forecasting to the future). In general, labor productivity for the fuel sectors (both coal and natural gas) showed a significantly higher degree of variability in recent years than the manufacturing sectors, which would have introduced a high degree of uncertainty in forecasting productivity growth rates for future years.

and gas sector that accounts for the relative contributions of oil and natural gas in the total sector output (in terms of the value of energy output in MMBtu).[10]

Table 19: Fuel Use Labor Productivity Estimates

Fuel Type	Labor Productivity
Coal by Region (Short Tons/labor hour)	
Appalachia	2.32
Interior	4.73
West	17.09
Waste Coal	5.19
Natural Gas (MMBtu/labor hour)	122

Notes: US national coal productivity is used for waste coal.

3.3.2. Labor Productivity: Estimating Future Labor Productivity

Since we are evaluating impacts of future policies, the base productivity estimates are adjusted for future years in order to account for productivity growth. To do this, labor productivity growth rates are estimated using historical trends in sectoral productivity growth rates (from BLS and Census data). To calculate these growth rates, labor productivity estimates are calculated for each sector from 1992 through the year of data that informs the productivity factors (see Data Vintage column in Table 18). Calculated growth rates for each resource are presented below.

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[10] We converted 2012 EIA data for natural gas production (29.5442 TCF) and Crude Oil Production (2,377,806,000 barrels) into MMBtus of natural gas (30,194,172,400 MMBtu) and oil (13,793,274,800 MMBtu). The resulting sum of MMBtu values were divided by the number of total employees in the oil and gas extraction sector (173,281 based on 2012 economic census data) to calculate MMBtu per labor-year. This value was divided by 2,080 hours to estimate MMBtu/labor-hour value of 122.

Table 20: Estimated Annual Productivity Growth Rates by Resource / Sector

Resource / Sector	Growth Rate
Steel	1.0%
Limestone	2.0%
Ammonia (NH_3)	3.3%
Catalyst	1.9%
Activated Carbon	3.1%
Trona	1.3%
FF Resource	4.2%
Power Plant Construction (Including HRI and combustion controls)	0.0%
Equipment Manufacturing	2.7%
Engineering	0.8%
Power Plant Operators	1.7%

To estimate labor productivity for a given year the following formula is used:

$$LP_T = \frac{LP_V}{(1 + LP_T)^{Y_T - Y_V}}$$

Where:
LP_T = Labor Productivity in Year T
LP_V = Labor Productivity in Year of Data Vintage
Y_T = Year T
Y_V = Year of Data Vintage

4. Aggregate Labor Impact Estimates

The final step in the employment analysis estimates the total impact on labor by combining outcomes from the previous steps to produce an estimate of labor impact. This section discusses how this is implemented for each type of projected compliance change.

4.1. New Generation Capacity

New generation capacity labor estimates are derived from demand for labor needed to produce the materials and equipment used in construction as well as the labor to construct and operate the new capacity. In Step 1 we quantified the amount of new capacity, then converted that capacity amount into the total construction cost and the capital and labor components in Step 2. In Step 3 we estimate the labor productivity values for appropriate sectors to convert Step 2 costs into labor needs. This final step combines these previous steps to produce final labor needs. The schematic of the steps involved in these calculations are shown in the graphic below.

Table 21: Estimating Final Labor Needs for New Generation Capacity

Step 1 (Quantify Compliance Change)	**Step 2 (Estimate Required Resources)**		**Step 3 (Estimate Labor Need)***	**Step 4**
MW of New Generation Capacity	Construction Costs	Equipment	LP Equipment Manufacturing	**Labor for Construction**
		Material	LP Steel	
		Construction Labor	LP Power Plant Construction	
		Engineering/ Management	LP Engineering	
	Operating Costs (FOM)		LP Power Plant Operators	**Labor for Operation**

*LP refers to labor productivity

4.2. New Pollution Retrofits

For pollution control retrofits, we evaluate the labor necessary to both construct and operate these controls. The quantity of new pollution control retrofits was estimated in Step 1. Under Step 2 the installation resource requirements were calculated as a function of the required amount of steel and the labor hours required for construction. In Step 3 we convert labor hour to labor estimates, convert other resources estimated under Step 2 into dollars, and estimate labor productivity values for industries associated with producing retrofit input material. This last step combines these results to estimate the final labor necessary to produce the required resources, install the retrofits, and operate the retrofits.

Table 22: Estimating Final Labor Needs for Retrofits

Step 1 (Quantify Compliance Change)	**Step 2 (Estimate Required Resources)**		**Step 3 (Estimate Labor Need)***		**Step 4**
MW of New Retrofits	Installation Costs**	Equipment	LP Equipment Manufacturing		**Labor for Installation**
		Material***	LP Steel***		
		Construction Labor	LP Power Plant Construction		
		Boilermakers	LP Boilermakers		
		Engineering/Management	LP Engineering		
MWh of Retrofit Operation	Resource Usage (physical quantity)		Resource price ($/Phys. Qty.	LP for Resource Sector	**Labor for Operation**
	FOM Costs		LP Power Plant Operators		

* LP refers to labor productivity.

**For some technologies we calculate resource needs in terms of labor hours. For these we assume 2,080 hours of work per year in Step 3 to derive final labor demand under Step 4.

***For SCRs, material also consists of initial catalyst load which uses the catalyst price to convert to expenditures and then Labor Productivity for catalyst to convert expenditures into required labor

4.3. Fuel Use Changes

Projected changes in fuel use were quantified under Step 1 and included an evaluation of coal and natural gas. It was not necessary to complete step 3 since the projections were already a measure of required resources (tons or MMBtu). In order to convert the physical quantities of fuel into labor estimates in Step 3, we determine physical labor productivity estimates for coal and natural gas. Under Step 4 we combine the previous steps to generate final labor estimates.

Table 23: Estimating Final Labor Needs for Fuel Use Changes

Step 1 (Quantify Compliance Change)	Step 2 (Estimate Required Resources)	Step 3 (Estimate Labor Need)		Step 4
Coal (Tons)	----	Regional Coal Productivity (tons per labor hour)	2080 Hours	**Labor for Coal**
Natural Gas (MMBtu)	----	Natural Gas Productivity (MMBtu per labor hour)	2080 Hours	**Labor for Natural Gas**

4.4. Pipeline Construction

In addition to labor to produce the fuel, we also estimate the labor required to build the pipeline infrastructure necessary to deliver additional natural gas. In Step 1 we quantify the change in natural gas consumption. In Step 2 we estimate the cost of constructing additional pipeline capacity for the natural gas. These construction costs were then converted into labor impacts using estimated labor productivity values for pipeline construction estimated in Step 3.

Table 24: Estimating Final Labor Needs for Pipeline Construction

Step 1 (Quantify Compliance Change)	Step 2 (Estimate Required Resources)	Step 3 (Estimate Labor Need)*	Step 4
Natural Gas (TCF)	Construction Costs ($MM)	LP Pipeline Construction	**Labor for Pipeline Construction**

* LP refers to labor productivity.

4.5. Changes to Existing Capacity

The total capacity of retirements is estimated in Step 1 and that capacity is converted into reduced expenditures using FOM in step 2. Labor productivity values for power plant operators are estimated in step 3, and in step 4 we convert expenditures to labor using the labor productivity factors.

Table 25: Estimating Final Labor Needs for Generator Retirements

Step 1 (Quantify Compliance Change) ➡	Step 2 (Estimate Required Resources) ➡	Step 3 (Estimate Labor Need)* ➡	Step 4
Coal (MW)	FOM Costs	LP Power Plant Operators	Labor for Coal Retirements
Natural Gas and Oil (MW)	FOM Costs	LP Power Plant Operators	Labor for Natural Gas and Oil Retirements

* LP refers to labor productivity.

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