Working Paper Series

Working Paper 76
The Job Generation Impacts of Expanding Industrial Cogeneration

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March 2014

ABSTRACT

Sustainable economic development requires the efficient production and use of energy. Combined heat and power (CHP) offers a promising technological approach to achieving both goals. While a recent U.S. executive order set a national goal of 40 GW of new industrial CHP by 2020, the deployment of CHP is challenged by financial, regulatory, and workforce barriers. Discrepancies between private and public interests can be minimized by policies promoting energy-based economic development. In this context, a great deal of rhetoric has addressed the ambiguous goal of growing "green jobs". Our research provides a systematic evaluation of the job impacts of an investment tax credit that would subsidize industrial CHP deployment. We introduce a hybrid analysis approach combining simulations using the National Energy Modeling System with Input-Output modeling. NEMS simulates general-equilibrium effects including supply- and demand-side resources. We identify first-order employment impacts by creating "bill of goods" expenditures for the installation and operation of industrial CHP systems. Second-order impacts are then estimated based on the redirection of energy-bill savings accruing to consumers; these include jobs across the economy created by the lower electricity prices that would result from increased reliance on energy-efficient CHP systems. On a jobs per GWh basis, we find that the second-order impacts are approximately twice as large as the first-order impacts

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1. Introduction

Many economic, environmental and political factors are driving a growing emphasis on the efficient and environmentally sustainable production and use of energy (Brown & Sovacool, 2011; Pollin et al., 2008). From climate change to foreign exchange, our current patterns of energy use in the United States and worldwide are severely stressing natural and social systems (Diamond, 2005; Rockstrom et al., 2009). U.S. energy demand is projected to continue to grow,[1] and concerns about the security and affordability of energy supply are literally front-page news.

Conflicts about the policy drivers of economic growth and job creation and anxieties about persistent structural under-employment are feeding debates over infrastructure investments and environmental policy. Regulatory policies that are feared to lead to the loss of jobs are easy political targets, uniting business owners and workers, even when health and other social benefits are large in comparison. Alternatively, regulatory or fiscal policies that can be shown to produce net job growth tend to be politically attractive.

Recent studies of "green jobs" have shown positive contributions of clean energy policy legislation to job creation and sustainable economic development (Laitner & McKinney, 2008; Pollin et al., 2008). However, these studies shed little light on the relationship between clean energy investments, energy market dynamics, and macroeconomic effects including both direct and indirect employment development. For example, analysis to date has not fully evaluated the second-order employment effects from the redirection of energy-bill savings accruing to participants in energy-efficiency programs (although in a different context, these expenditures have been considered by analysts of the "rebound effect" (e.g., Sorrell, Dimitropoulos, & Sommerville, 2009).

In addition, the literature has not examined the impact of lower energy prices economy-wide that could result from the lower energy use that occurs following energy-efficiency investments. With large-scale energy efficiency, competitive markets would see lower clearing prices for energy and price-regulated markets would experience lower marginal dispatch costs – in both cases, prices would benefit from decreasing reliance on the most expensive marginal generating equipment (Kim, Baer, & Brown, 2013; Kramer & Reed, 2012; Steinhurst & Sabodash, 2011). This "demand reduction induced price effect" (DRIPE) suggests that increased energy efficiency could reduce energy prices for all customer classes, generating jobs across the economy as the resulting savings are spent on goods and services that are more job-intensive than the capital-intensive industries associated with energy production.

This study assesses the employment impacts and energy market dynamics of a sizeable increase in the deployment of one key energy efficient technology – combined heat and power (CHP) systems – driven by a federal investment tax credit (ITC). CHP technology is often regarded as a transformational technology with potential for significantly improving energy efficiency by productively reusing waste heat (Shipley et al., 2008); indeed, a recent executive order has set a national goal of 40 GW of new industrial CHP by 2020, targeting a broad set of stakeholders including states, manufacturers, and utilities (The White House, 2012). Our analysis recognizes that subsidies can produce changes in energy consumption, production, and prices across the economy, including the industrial, residential, and

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[1] The U.S. Energy Information Administration (2012) forecasted that U.S. total energy consumption would grow by 0.3 percent per year from 2010 to 2035.

commercial sectors. By combining an Input-Output (I-O) model with the projections of an energy systems model (the National Energy Modeling System (NEMS), we develop a hybrid analytical tool to generate plausible estimates of the consequences of various policy, price, and technology scenarios.

2. Industrial CHP and ITC Policy

Also known as cogeneration, CHP is the production of electricity together with economically useful heat, for use in industrial processes and for heating and cooling buildings. By capturing energy that would otherwise be wasted, the efficiency of conversion can be increased from 45 percent in typical thermal power plants to as much as 70 percent in efficient natural gas CHP facilities (U.S. EPA CHP Partnership, 2008). In addition, while the main fuel of CHP systems is natural gas,[2] CHP can often be fueled with industrial waste products or with biomass, further reducing fossil fuel consumption and carbon dioxide emissions.

CHP is also a form of distributed generation, as CHP technologies allow end-users to generate electricity on site. The primary CHP technologies (so-called "prime movers") include gas turbines, reciprocating engines, and boiler/steam turbine combinations, which are combined into systems with electrical generators and heat recovery equipment. Such systems are tailored to available fuels, plant operating costs, the difference between electricity price and fuel costs,[3] and the on-site need for electrical power versus thermal energy (Sentech Inc., 2010). Deployment of CHP systems reduces electricity purchased through the grid from central utility stations and usually produces power to sell back to the grid. This onsite generation avoids energy losses from electricity transmission, and it can increase overall system resilience, as has been shown in the development of locational marginal pricing for distributed generation of all types (Lewis, 2010). These characteristics make CHP especially attractive for industrial users who want to enjoy the benefits of site-specific, strategic energy production to supply their electricity and thermal energy needs.

The industrial sector is the largest consumer of energy in the U.S., accounting for 31 percent of total energy consumption in 2010 (U.S. EIA, 2012). According to the *Annual Energy Outlook 2012*, industrial energy consumption is also expected to show the largest increase of any sector over the next 25 years. Therefore, improving energy efficiency in the industrial sector is a critical agenda item for policy-makers.

Despite the economic and environmental attractiveness of CHP, decision-makers in the industrial sector face financial, regulatory, information, and workforce barriers to what are generally considered to be cost-saving investments. Many studies have documented a gap between optimal and actual energy efficiency (Dietz, 2010; Hirst & Brown, 1990; Jaffe & Stavins, 1994). First of all, the economic challenges of CHP investments are the greatest barrier to viability (Chittum & Kaufman, 2011); although CHP promises long-term energy-bill savings, companies often feel a greater financial risk because CHP installations have high upfront costs and long payback periods compared to traditional equipment. The

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[2] Approximately two-thirds of industrial CHP systems in the U.S. are fueled by natural gas (ICF International, 2011).

[3] The estimated operating cost stream is called the "spark spread", which is the theoretical gross margin of a CHP-installed power plant from selling a unit of electricity. The spark spread is calculated as "price of electricity – [(cost of fuel)*(heat rate)]."

current economic downturn in the U.S. has caused companies to become increasingly conservative, with even greater aversion to longer payback periods compounded by difficulties securing financing (Chittum & Kaufman, 2011).

Second, utility monopoly power and utility rate structures also distort CHP economics. Many utilities discourage CHP facilities from acting as independent distributed generators who can sell excess power to nearby customers at retail or negotiated rates. In some states, utilities own and manage the transmission and distribution infrastructure and they discourage CHP users from selling their excess power back to the grid at a wholesale rate. Furthermore, utilities impose additional charges for private wire usage and for standby or back-up service (Chittum & Kaufman, 2011; Sciortino et al., 2011). These electricity rate structures reduce the money-saving potential of on-site generation.

Third, the enforcement of interconnection standards and environmental regulations can be substantial barriers to CHP investments, especially for smaller CHP projects. Although many states have developed interconnection standards that ensure stable utility service, the lack of uniformity in application processes has caused unnecessary project delays and has generated high transaction costs (Shipley et al., 2008; U.S. EPA, 2012). In addition to the costs of dealing with interconnection standards, various permits and regulations—such as input-based emission standards—can also increase upfront project costs. Satisfying the conventional emission regulations based on heat input (lb/MMBtu) or exhaust concentration (parts per million) can be challenging to CHP deployment at the beginning of a project's lifespan. CHP generally increases the emissions onsite, but due to its high efficiency, reduces the overall emissions of all pollutants in a given region as well as overall fuel consumption (Chittum & Kaufman, 2011). Many CHP studies argue that the transformation from current input-based emission standards to output-based standards can capture the total regional emissions benefits of CHP development (Shipley et al., 2008; Cox, Brown, and Jackson, 2011; Sciortino et al., 2011).

Lastly, as CHP has been utilized in quite varied sectors, the difficulty of effectively sharing lessons and information across industries can impede the process of diffusion and modernization of CHP projects (The Committee on Climate Change Science and Technology Integration, 2009). Given the uncertainties about the benefits and risks of CHP technology over a project's whole lifespan, the information incompleteness can be a substantial barrier to expensive capital investments. Subsidies that encourage the market penetration of CHP systems and continuing technology development may mitigate these information barriers.

CHP users, manufacturers, and service providers have advocated for expanding CHP-friendly tax credits to reduce market barriers to the expansion of CHP (ICF International, 2010). The federal government has established a 10 percent ITC for qualified CHP systems through 2016. The eligible system size is capped at 50 MW that exceeds 60 percent energy efficiency on a lower heating value basis.[4] Several states are beginning to tackle current regulatory barriers. Legislative proposals have suggested increasing the ITC from 10 percent to 30 percent for highly efficient CHP technologies[5] and removing the 50 MW capacity limit on qualified systems.[6] Increasing the ITC to 30 percent for all

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[4] The Database of State Incentives for Renewable Energy, www.dsireusa.org/

[5] H.R.4751 (2010) - sponsor: Rep. Tonko, P. (Source: www.govtrack.us)

[6] H.R.4455 (2009) - sponsor: Rep. Thompson, M.; S. 1639 (2009) - sponsor: Sen. Bingaman, J.; H.R.4144 (2009) - sponsor: Rep. Inslee, J. (Source: www.govtrack.us)

efficient CHP systems would increase CHP market penetration, improve energy efficiency, enhance operational reliability, and provide economic savings that would improve business cost-effectiveness. In this context, we examined three ITC scenarios that apply 10, 20, and 30 percent subsidies and remove the 50 MW cap through 2035. Prior analysis of a 30 percent ITC estimated the deadweight losses from such a federal tax subsidy, but these losses were more than offset by the social benefit produced by addressing the negative externalities of air pollution and climate change (Brown, Cox, and Baer, 2013).

3. Green Jobs: Key Concepts from the Literature

Although much academic evidence suggests otherwise, there remains a significant perception in the U.S. of a "jobs vs. environment tradeoff" (Claussen & Peace, 2007; Goodstein, 1999). To counter this perception, much effort has gone into promoting "green jobs," a vague term that generally refers to a wide range of economic activities aimed at mitigating environmental threats and improving energy security. Recently the Bureau of Labor Statistics introduced the following definitions of green jobs:

A. Jobs in businesses that produce goods or provide services that benefit the environment or conserve natural resources.

B. Jobs in which workers' duties involve making their establishment's production processes more environmentally friendly or use fewer natural resources.[7]

According to surveys they found about 3.4 million workers in "green goods and services" (definition A) in 2011, and about 850,000 workers who worked more than half time on "green technologies and practices" (definition B) (Bureau of Labor Statistics, 2013).

Even these definitions leave lots of ambiguity. On the one hand, it is clear that wind turbine installers hold green jobs; but what about the workers in the mine that produces the iron that goes into the steel for wind turbines? Would it matter if it was all one firm? Additionally there are regulators and the workers who monitor compliance with regulation – "green jobs" by many definitions but not directly productive of goods and services, thus not necessarily what one wants to maximize.

More importantly for our purposes, inasmuch as one goal of investments in ecological efficiency is to increase overall social welfare, the reduction of energy expenditures allows redirection of household income to more valued goods and services. One consequence of this is the "rebound effect" (actually a combination of price and income effects in economic terms), which offsets the initial efficiency gains to a greater or lesser extent; however, it also typically leads to employment gains as spending is redirected from the very highly capital intensive energy industries to more labor-intensive service and manufacturing industries. The jobs produced from this redirection are a benefit of efficiency improvements, and can be an important indirect consequence of environmental policies (Turner, 2009).

Since the American Recovery and Reinvestment Act of 2009 (ARRA), discussions of green job creation have increasingly focused on "energy-based economic development," a term coined by Carley et al. (2011) to capture the integration of policy-driven transformations of energy systems for environmental

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[7] http://www.bls.gov/green/overview.htm#Definition, accessed 2/24/2013.

and security goals with regional and national concerns for economic development and resilience. Domains of energy-based economic development include energy technology innovation, energy equipment manufacturing, installation and service, research and development, fuel economy, and electricity consumer's energy bills (Laitner & McKinney, 2008; Pollin et al., 2008; White & Walsh, 2008). Distinct from traditional economic development strategies, this approach adds a focus on clean energy to emerging sustainable economic development practices that care for both people and place by improving standards of living for all and sustaining local employment capacity (Blakely & Leigh, 2009).

Reflecting these various issues, a wide range of academic and consulting studies have used different kinds of models to estimate the employment effects of environmental and climate policies, including I-O models, Computable General Equilibrium (CGE) models, and what are often called "Analytic Models" that (typically in a spreadsheet) use various "bottom up" methodologies to estimate job creation (Wei et al., 2010). Even where similar methods are used, model projections vary widely, since they are dependent on baseline assumptions and model parameterizations. Furthermore, at a large scale, policies can actually drive economy-wide changes in prices and interest rates, and comprehensive modeling efforts must account for these general equilibrium effects endogenously.

Overall, energy policies promoting green jobs should be able to consider not only the employment that stems from the investment in energy technologies and R&D (the "direct, indirect and induced jobs" of conventional I-O analysis), but also the "second order" indirect and induced economic activities resulting from energy-bill savings due to price and demand changes. Using IMPLAN (IMpact analysis for PLANning) or similar I-O models, many studies have utilized an estimate of the national-scale multiplier effects of additional direct stimulus spending on energy efficiency (Geller et al., 1992; Laitner et al., 1998; Pollin et al., 2008). These studies have usually concluded a net positive return in job opportunities per installed capacity unit compared to business-as-usual. Job creation has commonly been attributed to the construction, installation, and operation of energy efficient technologies and other related services.

The job estimates in these studies are not fully comparable due to geographical and sectoral differences. Nevertheless, Laitner and McKinney (2008), Carley et al. (2011), and Wei et al. (2010) compared the job estimates of previous studies and provided average employment over the lifetime of facility (e.g. job-years/GWh) for each energy efficient technology. For example, Laitner and McKinney (2008), reviewing 48 reports from 1992 to 2008, conclude that a 20-30 percent energy efficiency gain within the U.S. economy might lead to a net growth of 0.5 to 1.5 million jobs by 2030; the average among all studies reviewed is a net benefit of 49 job-years per TBtu of savings. A more recent study estimated that doubling U.S. energy productivity[8] by 2030 could create 1.3 million jobs, while increasing GDP up to 2% (Houser, 2013). We compare the results of some of these studies with our own findings in Section 5.

Despite the strengths and applicability of I-O modeling, most studies have acknowledged the inherent limitations of the method. For example, Lehr et al. (2008) used survey data to amend I-O tables by applying key inputs and intermediary goods of the renewable industry, and the potential for expected employment. Such efforts, however, are still rare in employment studies of energy-efficiency programs. A comprehensive approach to assessing jobs from energy-efficiency promotion should cover complex

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[8] Energy productivity, measured in $output/unit energy, is the reciprocal of energy intensity.

impacts including not only supply-side (oil and gas, coal, nuclear, and renewable fuels) but also demand-side (residential, commercial, and industrial sectors) and energy conversion impacts (electricity markets). In this research, as described next, we track these comprehensive energy market paths by combining an I-O model with NEMS. We further discuss limitations and future extensions in Section 6.

4. Methodology: Hybrid Modeling

As noted, this study aims to assess the employment impacts of an increase in the deployment of CHP systems through a federal ITC policy. To investigate the relationship between energy-efficiency investments and energy market dynamics, unlike other green job studies, we developed an analytical model to combine energy market projections derived from NEMS with sectoral employment coefficients taken from I-O modeling.

4.1 National Energy Modeling System (NEMS)

Clean energy policies and investments are first modeled in NEMS, which can analyze energy consumption changes by fuel type[9] along with policy scenario and energy market assumptions. Since the model is run on Georgia Tech computers, we call it "GT-NEMS".[10] NEMS uses resource supply and price data based on federal, state, and local laws and regulations in effect at the time of the analysis. The NEMS integrating module ensures general market equilibrium fuel prices and quantities across all twelve modules including supply (oil and gas, coal, and renewable fuels), demand (residential, commercial, industrial, and transportation sectors), energy conversion (electricity and petroleum markets), and macroeconomic and international energy market factors. Specifically, we derive the baseline projections of GT-NEMS from the version of NEMS that generated EIA's *Annual Energy Outlook 2011*, which is regarded as a reliable representation of the U.S. energy market (U.S. EIA, 2011). A "policy case" produces changes in fuel prices and resource consumption when compared with the "reference case."

NEMS is well suited to projecting how alternative energy policies might impact energy markets over time, particularly with respect to CHP systems, because it has a detailed methodology for evaluating the market penetration of CHP technologies in different subsectors of industry. NEMS' "bottom-up" technology configuration enables an assessment of technology investments, energy prices, energy consumption and expenditures, carbon abatement, and pollution prevention over time and across regions of the U.S.

In this study, focusing on industrial CHP end-users, three policy scenarios were evaluated by GT-NEMS. The reference case already reflects the current 10 percent ITC subsidy for 50 MW or less-sized CHP through 2016. Three policy cases of expanded ITC are modeled, assuming subsidies of 10, 20, and 30 percent from 2015 to 2035 across all type of CHP systems. The results of each scenario run provide estimates of changes in CHP capacity, natural gas consumption, electricity purchased from the grid and

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[9] NEMS reports changes in electricity use and fuel used in electricity generation as well as direct fuel use.

[10] Even when the same NEMS code is used on two hardware systems with the supporting software, the results could be distinct from those of the EIA. The fact that the GT-NEMS Reference case nearly duplicates the EIA's Reference case indicates that the two models are essentially identical.

sales back to the grid, and energy prices by sector. The differences between the reference case and the three levels of ITC subsidy allow estimation of net jobs from installation and operation of additional CHP and the recycling of economy-wide energy-bill savings.

4.2 Input-Output Model and First Order Impacts

Any employment study, whether focused on a project or a policy, has to specify the boundaries of the analysis and the pathways of employment impacts (positive or negative) that will be included. In spite of the numerous methodologies that have been used to analyze employment impacts and macroeconomic impacts more broadly, no single terminology exists for describing the relevant pathways. I-O modeling has developed a conventional language referring to direct, indirect, and induced employment, where direct employment is based on additional final demand for products from particular sectors, indirect employment is based on expenditures for intermediate goods by the sectors seeing increased final demand, and induced employment is based on the additional expenditure by persons earning wages and profits from the additional production (Miller and Blair, 2009). We classify all of these as *first order* impacts, as they are based on partial-equilibrium effects in which all prices and technological coefficients are assumed to stay constant.

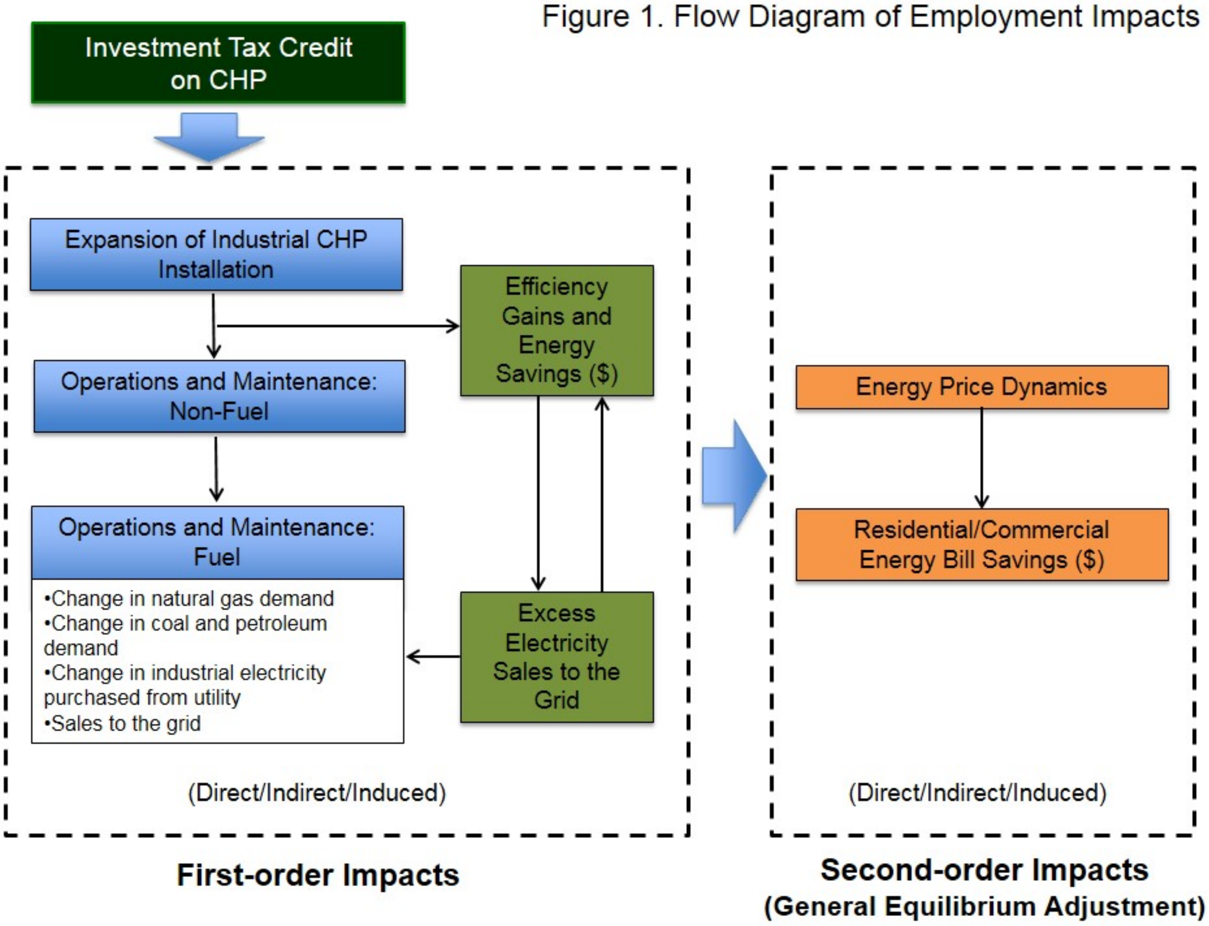
4.3 Second Order Impacts

In addition, we consider *second order* impacts, in which general equilibrium effects such as changes in energy prices due to increased efficiency (that is, DRIPE effects) propagate through the economy. Models such as NEMS can calculate employment effects directly; however, because the linkages in NEMS between changes in sectoral demand and changes in employment are quite opaque, we use the changes in energy expenditures as an output from NEMS to calculate second order impacts based on I-O employment coefficients taken from IMPLAN. Further details of our methods are given below.

4.4 Subsets of First-Order Impacts

We model three different categories of first-order impacts: construction and equipment installation purchases, non-fuel CHP operating expenditures, and changes in industrial energy purchases (in this case, increased purchase of natural gas and decreased purchases of electricity, coal and petroleum products) (Figure 1). These in turn are subdivided into one-time jobs in construction, installation and manufacturing (CIM), and “permanent” (or “annual”) jobs based on the operation of the new capacity and the corresponding changes in energy purchases. Ultimately we aggregate these into full-time-equivalent jobs.

Figure 1. Flow Diagram of Employment Impacts



4.5 Assumptions Regarding Second-Order Impacts

Modeling second-order impacts using NEMS' energy market projections requires a number of strong assumptions. Second-order impacts derive from redirection of energy bill savings by residential consumers, commercial businesses, and industry (Figure 1). If the scale of efficiency investment is large enough, it will cause economy-wide changes in supply and demand, and thus prices, for energy. This in turn changes the expenditures of various actors. Businesses, whether in the industrial or commercial sector, could pass their energy bill savings on to customers through lower prices, or maintain prices and increase profits or wages, or some combination. We assume businesses would count their energy bill savings after amortizing new CHP investment costs. The amortization schedule assumes a 20 years payback of new construction and equipment investments at a 3% interest rate.[11] As energy bill savings recycle through the economy, additional employment impacts are expected when expenditures shift from capital-intensive sectors like utilities to more labor-intensive sectors like services, manufacturing and construction.

As a simplifying assumption, we treat all energy bill savings as direct savings to consumers

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[11] According to the Federal Reserve's survey of terms of business lending, compounded average interest rates for commercial and industrial loans were a range of 1.64% to 2.46% depending on the degree of risk (Source: http://www.federalreserve.gov/releases/e2/current/#fn4).

(assuming that changes in prices, wages, and dividends all eventually accrue to households), and that they are re-spent in direct proportion to the existing distribution of household expenditures[12]. Furthermore, we assume that savings accrue to households in proportion to the existing distribution of household income; while this is unrealistic for a variety of reasons, the employment coefficients for household expenditures by different income brackets vary relatively modestly (about 8% between the highest and lowest). Using this procedure, we calculate a weighted employment multiplier of 15.5 jobs per million dollars of energy bill savings across all sectors in 2009 (see Figure 2 for comparison with other sectors); as with all of our multipliers it is "discounted" over time to account for economy-wide productivity increases.[13]

4.6 IMPLAN Employment Coefficients

To estimate employment impacts, NEMS outputs (e.g., additional CHP capacity, sectoral energy consumption, etc.) are combined with I-O employment coefficients (sometimes imprecisely referred to as "multipliers") that are derived from IMPLAN. The I-O model is based on annual tracking of the national gross output of the transactions among diverse industries and government agencies, and then provides the estimation of direct, indirect, and induced employment coefficients between pairs of industries (Miller & Blair, 2009). The employment coefficients were calculated for six components of the CHP technology life-cycle and the associated economy-wide impacts: new construction and equipment installation (which is developed by bills of goods); non-fuel operation and maintenance (O&M); three energy sectors (electric utilities, natural gas, and the coal and petroleum sectors together); and all other sectors affected by energy bill savings in the residential and commercial sectors.

4.7 Bills of Goods

To estimate the jobs associated directly with the construction and operation of new facilities, we identify the industrial sectors contributing to the CHP systems using the concept of a "bill of goods". Our bill of goods for CHP systems involves selecting industrial sectors taken from IMPLAN's 440 sectors, the associated employment coefficients also taken from IMPLAN, and a set of estimated weights reflecting each sector's expenditure share. We began with a review of the literature to identify the relevant industrial sectors and their respective proportion of installation costs. We selected ten categories of industrial sectors and estimated the weights for each category. We then conducted an expert survey to validate our estimates. Four of ten experts contacted provided complete responses; two for natural gas-based systems and two for biomass-based systems. Since the fractions are fairly similar, we used the average proportion of all four responses. Table 1 includes the results of each expert's response and the average weights that we applied for the final employment coefficients calculation.

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[12] The household respending multiplier is calculated by adding a unit of income to households in the IMPLAN model, but adjusting for the fact that there are no income taxes when "income" is actually savings.

[13] We assume that productivity in all sectors increases at a 1.84% annual rate, the economy-wide average for the years 2007-2011.

Table 1. Weights of New CHP Construction and Installation Expenditures: Preliminary Estimation vs. Experts Survey

CATEGORY	Respondents				Results from Experts Elicitation	Preliminary Estimates Base on Literature
	NG-based Company 1	NG-based Company 2	Biomass-based Company 3	Biomass-based Company 4		
Primary Generation (Turbine and Power Boiler)	56%	39%	37%	36%	39%	25%
Construction	11%	20%	22%	25%	20%	20%
Electrical Equipment	11%	6%	4%	6%	7%	10%
Machinery and Fabricated Metal	6%	5%	11%	7%	9%	15%
Electronic Components (Controls)	3%	1%	3%	3%	4%	10%
Environmental Equipment	3%	10%	5%	5%	6%	7%
Other Materials	0%	2%	8%	3%	3%	3%
Scientific and Technical Services	11%	9%	7%	7%	8%	5%
Finance and Insurance	0%	8%	2%	8%	4%	5%
Other	0%	0%	1%	0%	0%	0%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Table 2 shows the final combination of bills of goods and IMPLAN employment coefficients. This analysis produced an estimate of 14.5 first-order jobs created per 1 million dollar ($2009) investment in CHP system installation and construction.

Table 2. Selected IMPLAN sectors and Employment Coefficients for CHP Installation

IMPLAN Code and Industrial Sector		Weights (%)	Jobs per $2009M
Installation		**100%**	**14.48**
1. Primary generation		**39%**	**12.58**
222	Turbine and turbine generator set units manufacturing		11.34
188	Power boiler and heat exchanger manufacturing		13.42
2. Construction		**20%**	**18.04**
35	Construction of new nonresidential manufacturing structures		**18.04**
3. Electrical Equipment		**7%**	**11.56**
266	Power, distribution, and specialty transformer manufacturing		11.23
267	Motor and generator manufacturing		11.23
268	Switchgear and switchboard apparatus manufacturing		10.76
269	Relay and industrial control manufacturing		11.50
272	Communication and energy wire and cable manufacturing		10.02
275	All other miscellaneous electrical equipment and component manufacturing		14.62
4. Machinery and Fabricated Metal		**9%**	**13.74**
171	Steel product manufacturing from purchased steel		12.74
174	Aluminum product manufacturing from purchased aluminum		10.37
186	Plate work and fabricated structural product manufacturing		14.98
193	Hardware manufacturing		13.34
194	Spring and wire product manufacturing		14.19
195	Machine shops		18.94
196	Turned product and screw, nut, and bolt manufacturing		15.09
198	Valve and fittings other than plumbing		12.52
201	Fabricated pipe and pipe fitting manufacturing		13.71
202	Other fabricated metal manufacturing		14.79
207	Other industrial machinery manufacturing		15.82
226	Pump and pumping equipment manufacturing		12.71
5. Electronic Components		**4%**	**11.09**
234	Electronic computer manufacturing		8.57
235	Computer storage device manufacturing		11.26
236	Computer terminals and other computer peripheral equipment manufacturing		13.37
244	Electronic capacitor, resistor, coil, transformer, and other inductor manufacturing		16.39
6. Environmental Equipment		**6%**	**13.05**
214	Air purification and ventilation equipment manufacturing		14.68
216	Air conditioning, refrigeration, and warm air heating equipment manufacturing		12.45
250	Automatic environmental control manufacturing		14.57
7. Other Materials		**3%**	**11.27**
127	Plastics material and resin manufacturing		9.59
136	Paint and coating manufacturing		11.44
144	Plastics pipe and pipe fitting manufacturing		11.40
151	Rubber and plastics hoses and belting manufacturing		13.36
160	Cement manufacturing		11.78
8. Scientific and Technical Services		**8%**	**22.08**
369	Architectural, engineering, and related services		22.17
374	Management, scientific, and technical consulting services		20.75
375	Environmental and other technical consulting services		23.15
9. Financial and Insurance Service		**4%**	**14.80**
357	Insurance carriers		11.33
358	Insurance agencies, brokerages, and related activities		20.31
359	Funds, trusts, and other financial vehicles		15.50

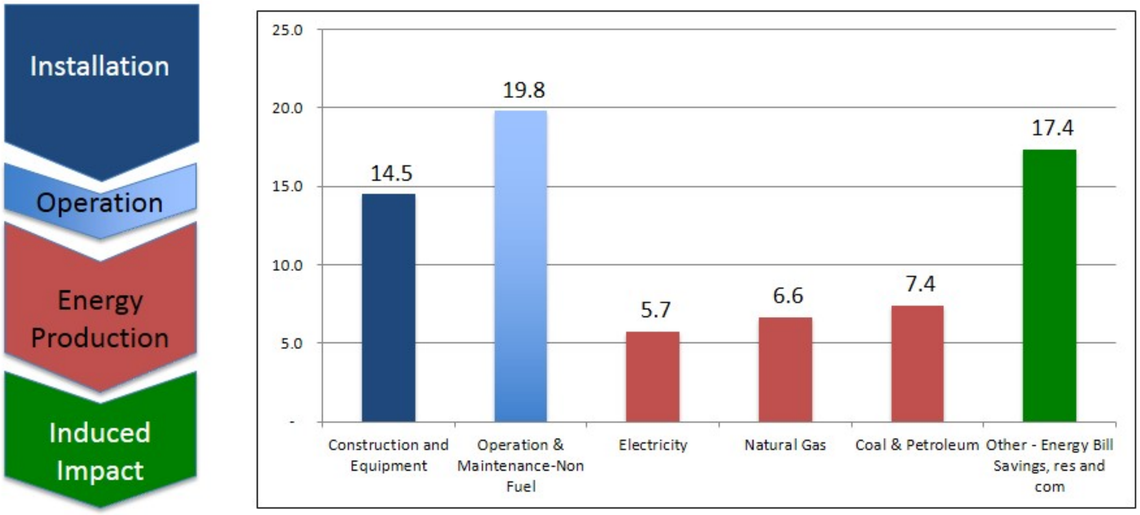
We also identified industrial sectors for long-term O&M employment impacts and applied their employment coefficients from IMPLAN. Table 3 shows the employment coefficients for non-fuel and fuel sectors for operation and maintenance.

Table 3. Selective IMPLAN sectors and Employment Coefficients for Operation and Maintenance

IMPLAN Code and Industrial Sector		Weights (%)	Jobs per $2009M
Operation & Maintenance - NON FUEL		100%	19.80
39	Maintenance and repair construction of nonresidential structures		20.08
385	Facilities support services		21.55
416	Electronic and precision equipment repair and maintenance		17.77
417	Commercial and industrial machinery and equipment repair and maintenance		19.96
Operation & Maintenance - Electricity		100%	5.71
31	Electric power generation, transmission, and distribution		5.71
Operation & Maintenance - Natural Gas		100%	6.64
32	Natural gas distribution		6.64
Operation & Maintenance - Coal & Petroleum		100%	7.43
21	Mining coal		10.83
115	Petroleum refineries		5.12
119	All other petroleum and coal products manufacturing		6.82

Figure 2 shows the aggregated employment coefficients for all six categories of employment market sectors. The non-fuel O&M sector would be the most labor-intensive sector of job generation throughout the life cycle of CHP systems. The second-order employment impacts that result from switching households' spending from energy bill payments to other consumption goods or services would be significant with the second highest employment coefficient, 15.5 jobs per million dollars of investment/expenditure. As a result, the deployment of CHP systems would generate significant employment impacts in the long-term, in addition to the short-term, one-time jobs created during the construction phase. The second-order impacts would be spread across a wide band of economic sectors, roughly proportional to the current distribution of household consumption spending.

Figure 2. Employment Coefficients by Sector (Jobs/$2009M)



5. Results

This section further explains the estimated energy market impacts from GT-NEMS modeling and the employment impacts estimated by the hybrid energy system/I-O modeling.

5.1 Scenario Modeling Results

Major components of our GT-NEMS results are summarized in Figures 3 to 7. They show increases of CHP capacity and generation (Figures 3 & 4) from the three levels of ITC subsidies compared to the reference case, decreases of industrial electricity purchases from the grid (Figure 5), increases of electricity sales back to the grid (Figure 6), and increases of industrial natural gas consumption (Figure 7).

Our reference case (modified slightly from the 2011 Annual Energy Outlook[14]) predicts that the nation's CHP capacity will expand at rates significantly greater than in the last few years, reaching 50 GW in 2020 and 80 GW in 2035. With ITC subsidies, CHP is estimated to grow by an additional 6.1 GW

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[14] Note that our reference case projection is somewhat greater than the AEO 2011 projection of 43.5 GW of industrial capacity in 2020 due to a correction of the CHP installation cost database, which had an incorrectly high price for the largest and most efficient CHP systems.

(8% above the reference case forecast for 2035) for the 10% ITC policy, 13.6 GW (a 17% increase) for the 20% ITC, and 22.5 GW (a 28% increase) for a 30% ITC (Figure 3). As noted earlier, a recent executive order has set a national goal of 40 GW of new industrial CHP by 2020; assuming that 23% of this future capacity will be in the petroleum refining industry (as it is today), this would imply a goal of 31 GW of new capacity by 2020 in the non-refining industrial sectors that we model here.[15] The reference case of NEMS forecasts that the nation's industrial CHP capacity would meet only 47% of the executive goal by 2020 (a 15 GW increase in non-refining industrial CHP from 2012 to 2020). The three ITC policies would bring the industrial sector closer to achieving the goal, though they still fall short, meeting only 53% of the goal with the 10% ITC, 61% with the 20% ITC, and 70% with the 30% ITC by 2020. The goal is achieved with the 30% ITC by 2023.

The expanded industrial CHP capacity enables a significant increase in electricity generation in the industrial sector (Figure 4). The growth rates of CHP electricity generation are 1-3% higher than the rate of CHP capacity growth, which means that industrial plants tend to utilize the CHP system to generate electricity in an efficient way, with higher-than-average "capacity factors."

Since expanded CHP capacity would allow industry to consume electricity from its own on-site generation, manufacturers would not need to purchase as much electricity from the central utility. (Even if they could meet all of their on-site electricity needs, industrial plants still benefit from being connected to the grid for standby and back-up power.) Figure 5 shows the reduction of industrial electricity consumption purchased from the grid. The reference case shows the large decrease in purchased electricity consumption that occurred during the economic recession between 2007 and 2009, and forecasts a recovery to prior levels of consumption by 2014, followed by a gradual decline over the subsequent 20 years. The policy scenarios show greater declines in purchased electricity. In 2035, industrial electricity purchases are forecast to gradually drop by an additional 30.7 billion kWh (4% of the reference case) with the 10% ITC, 66.5 billion kWh (8%) with the 20% ITC, and 105.5 billion kWh (12%) with the 30% ITC (Figure 5).

On the other hand, the CHP-generated electricity sold back to the grid grows as shown in Figure 6. Both the growth of on-site generation electricity sales and the reduction of electricity purchased from the grid would lead to overall energy bill savings for industrial CHP users; however, industrial CHP users would also consume more natural gas, the fuel for approximately two-thirds of CHP systems in the U.S. that are coupled with gas turbines or gas-fueled steam turbines. NEMS forecasts that industrial natural gas consumption will grow by 4% in 2035 (relative to the reference case) for the 10% ITC policy, by 10% for the 20% ITC, and by 17% for the 30% ITC, as shown in Figure 7.

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[15] The petroleum refining industry is modeled in a separate module of NEMS, and is not treated in this paper.

Figure 3. Total Industrial CHP Capacity

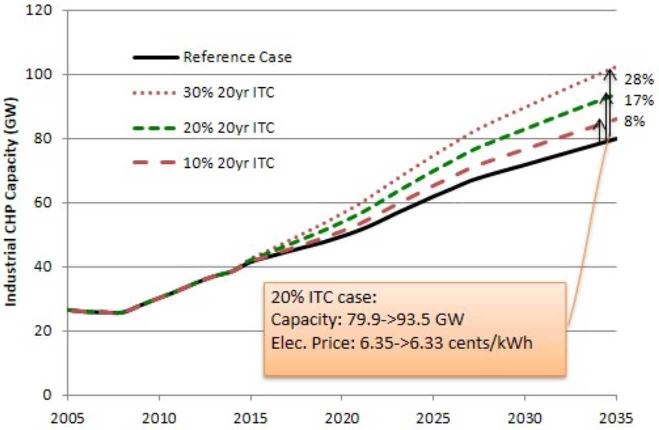


Figure 4. Total Industrial CHP Generation

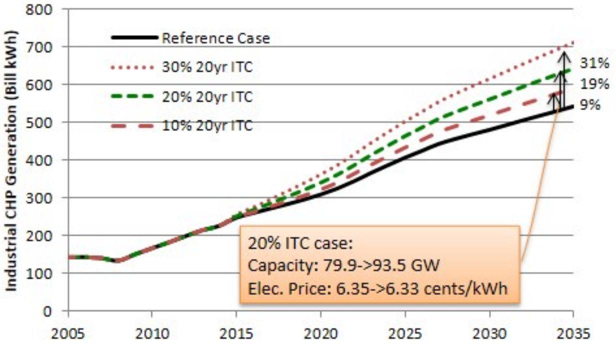


Figure 5. Industrial Purchased Electricity Consumption

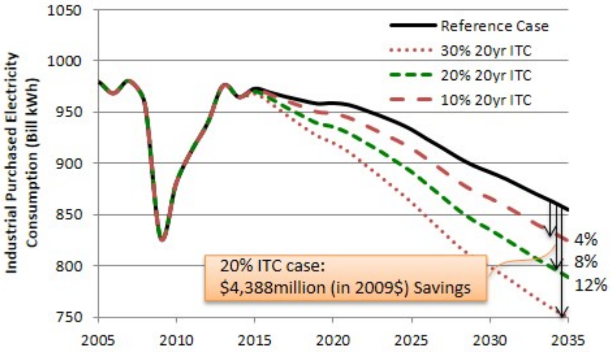
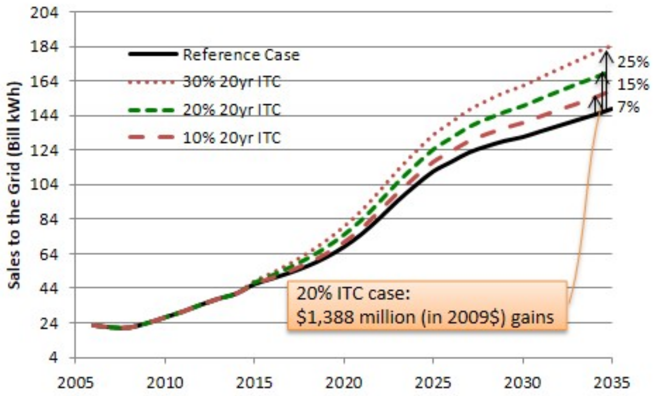
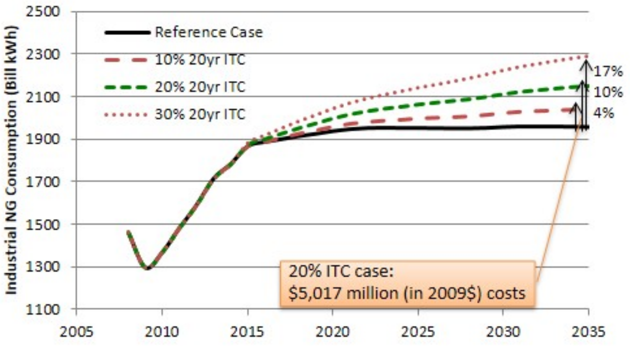


Figure 6. Industrial Sales to the Grid



20% ITC case:
$1,388 million (in 2009$) gains

Figure 7. Industrial Natural Gas Consumption



20% ITC case:
$5,017 million (in 2009$) costs

5.2 Investment Increases

The macroeconomic analysis of the three ITC scenarios was developed in a way that converted all changes of CHP capacity and energy consumption into market investment increases and energy bill savings. These investment costs and energy savings were matched to sectoral employment coefficients derived from IMPLAN, as discussed in Section 4.

The additional investment in CHP systems is proportional to the net growth of CHP capacity spurred by the ITC policy. The investment cost is calculated by converting the net growth of CHP capacity to dollar value added over the reference case, using the unit of total installation cost for typical gas turbines that is identified by Sentech (2010) and included in NEMS input files. This typical CHP system has a capacity of 25 MW, and an efficiency of 0.71 in 2010 increasing to 0.74 in 2035. The average total installation cost is the equipment cost excluding O&M and service costs. The equipment cost projections gradually decrease over time, from a high of $1,080/kW in 2010 to a low of $905/kW in 2030, reflecting economies of scale, learning by doing, and R&D.

Table 4 shows the estimated investment costs for the three ITC policies relative to the reference case. In the reference case, investment costs are forecast to decline over the next two decades from $2.4 billion in 2010 to $1.55 billion in 2035, reflecting both declining CHP system prices and the slightly declining rate of capacity growth shown in Figure 3. In 2020, the total investment costs could grow by 18% above the reference case with a 10% ITC, by 42% with a 20% ITC, and by 70% with a 30% ITC. The investments in 2035 increase by 16-52% in our three ITC policy scenarios.

Non-fuel O&M costs typically include operating labor, routine inspections, scheduled repairs, and preventive maintenance, which are sources of long-term job creation. According to EPA's CHP Partnership (2008), total O&M costs range from $0.004/kWh to $0.011/kWh for typical gas turbines and are less than $0.005/kWh for steam turbines. Our O&M costs are calculated by applying $0.005/kWh and an 80% capacity factor for the new CHP systems.

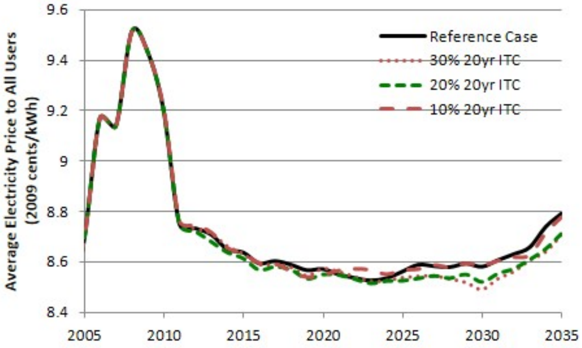
Table 4. Annual Investment Cost Increases in $2009M

	2010	2020	2035
Reference	2,419	1,776	1,550
10% ITC		2,102	1,796
Private		1,682	1,257
Gov. Subsidy		420	539
Difference from Reference		326	246
% Growth		18%	16%
20% ITC		2,526	1,975
Private		2,021	1,383
Gov. Subsidy		505	593
Difference from Reference		750	425
% Growth		42%	27%
30% ITC		3,020	2,363
Private		2,416	1,654
Gov. Subsidy		604	709
Difference from Reference		1,244	813
% Growth		70%	52%

5.3 Energy Price Impacts

NEMS calculates equilibrium energy prices and quantities across energy fuels and across sectors of end-use demand. Figure 8 shows how the three ITC policies affect electricity price dynamics across all consumers. Compared with the reference case, the three policies generally lead to decreases in electricity rates, ranging from 0.001 cents/kWh to 0.1 cents/kWh. The effect is variable, however, so for example in some years a 10% ITC policy is shown to slightly increase electricity rates (particularly between 2020 and 2025). These price increases, and the non-linear response more generally, derive from complex market responses modeled in NEMS such as rebound effects from the electricity price declines and the dynamics of the timing of coal plant retirements caused by the reduction in utility grid sales superimposed on increasing environmental regulations.

Figure 8. Average Electricity Price to All Users



Volatile electricity and natural gas prices are a sustained source of financial pain for industrial end-users. Energy-efficient CHP systems can be a strategic option to reduce such market threats. At the same time, CHP systems are increasingly cost-competitive with today's glut of shale gas and the forecast for cheap natural gas prices over at least the next several years. In 2012, US natural gas electric power prices dropped to a 10-year low of $2.79 per Mcf (thousand cubic feet) in April; then, reflecting its historic volatility, prices increased by about 50% to $4.36 per Mcf in December.[16] Electricity price declines from the expansion of CHP systems can also provide wide economic benefits to residential and commercial end-users. This means that the national market would expect to see induced effects from re-spending of energy cost savings in other sectors of the economy.

5.4 Energy Cost Savings

Changes in industrial energy expenditures are calculated from industrial energy consumption and energy price changes (Table 4). Industrial CHP users would benefit from reduced costs from purchased electricity, coal and petroleum, and from increased revenues from selling excess power to the grid. In contrast, they would spend more on natural gas, the most common fuel for industrial CHP. By comparing Tables 3 and 4, it can be concluded that a 10% and 20% ITC would generate net benefits because total energy cost savings exceed total investment costs (private and public). The 30% ITC is less cost-effective with incremental investment costs exceeding energy savings in both 2020 and 2035. However, when the subsidies are removed as a component of investment costs, reflecting the CHP developer's perspective, the return of energy savings to private investments is nearly favorable in 2020 and clearly favorable in 2035 even in the 30% ITC scenario. The industrial energy savings are less in the 30% ITC scenario because its larger natural gas consumption causes gas prices to rise more aggressively, and these additional costs are offset only slightly by the industrial sector's decreased purchase of electricity and its increased grid sales.

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[16] EIA, U.S. Natural Gas Electric Power Price: http://www.eia.gov/dnav/ng/hist/n3045us3m.htm.

Table 4. Annual Industrial Energy Savings in $2009M

Annual Energy Costs	2010	2020	2035
Reference	81,135	93,741	98,696
Purchased Electricity	56,825	57,849	54,315
Sales to the Grid	- 1,732	- 4,080	- 9,384
Natural Gas Demand	18,975	30,793	44,249
Coal & Petroleum Demand	7,068	9,179	9,517
10%ITC		93,230	98,212
Purchased Electricity		57,068	52,388
Sales to the Grid		- 4,237	- 10,082
Natural Gas Demand		31,225	46,410
Coal & Petroleum Demand		9,174	9,497
Annual Energy Savings		511	484
% Savings		0.5%	0.5%
20%ITC		92,916	97,896
Purchased Electricity		56,275	49,926
Sales to the Grid		- 4,498	- 10,772
Natural Gas Demand		31,963	49,265
Coal & Petroleum Demand		9,176	9,477
Annual Energy Savings		825	800
% Savings		0.9%	0.8%
30%ITC		93,139	98,537
Purchased Electricity		55,529	47,483
Sales to the Grid		- 4,790	- 11,691
Natural Gas Demand		33,224	53,300
Coal & Petroleum Demand		9,176	9,443
Annual Energy Savings		602	160
% Savings		0.6%	0.2%

5.5 Jobs Estimation

Figure 9 presents the comprehensive results of the I-O-based jobs analysis of the three ITC policy scenarios. The sectors of construction and CHP equipment installation, non-fuel O&M, and natural gas are all sources of job creation. While the number of one-time jobs in construction and CHP installation slows over time, the number of jobs in O&M and the natural gas sector increase with the expansion of CHP capacity.

Furthermore, the potential job creation from energy cost savings in the residential and commercial sectors and industrial cost savings would be sources of substantial benefits for the national economy. These second-order impacts broadly track electricity price changes.[17] In general, electricity prices are lower in all sectors in all three of the ITC policy cases compared to the reference case, though there is considerable variability over time. In the 10% ITC policy scenario, electricity prices exceed those in the reference case between 2020 and 2025 (Figure 8), leading to negative second-order impacts in those years; in the 20% and 30% ITC policy scenarios, electricity prices are essentially identical to the reference case in the 2020-2025 period and are significantly below the reference case in other time frames, leading to the second-order job gains shown in Figure 9.

In contrast, the electric utility sector and (to a much smaller extent) the coal and petroleum production and distribution sectors would experience job losses resulting from enhancing industrial

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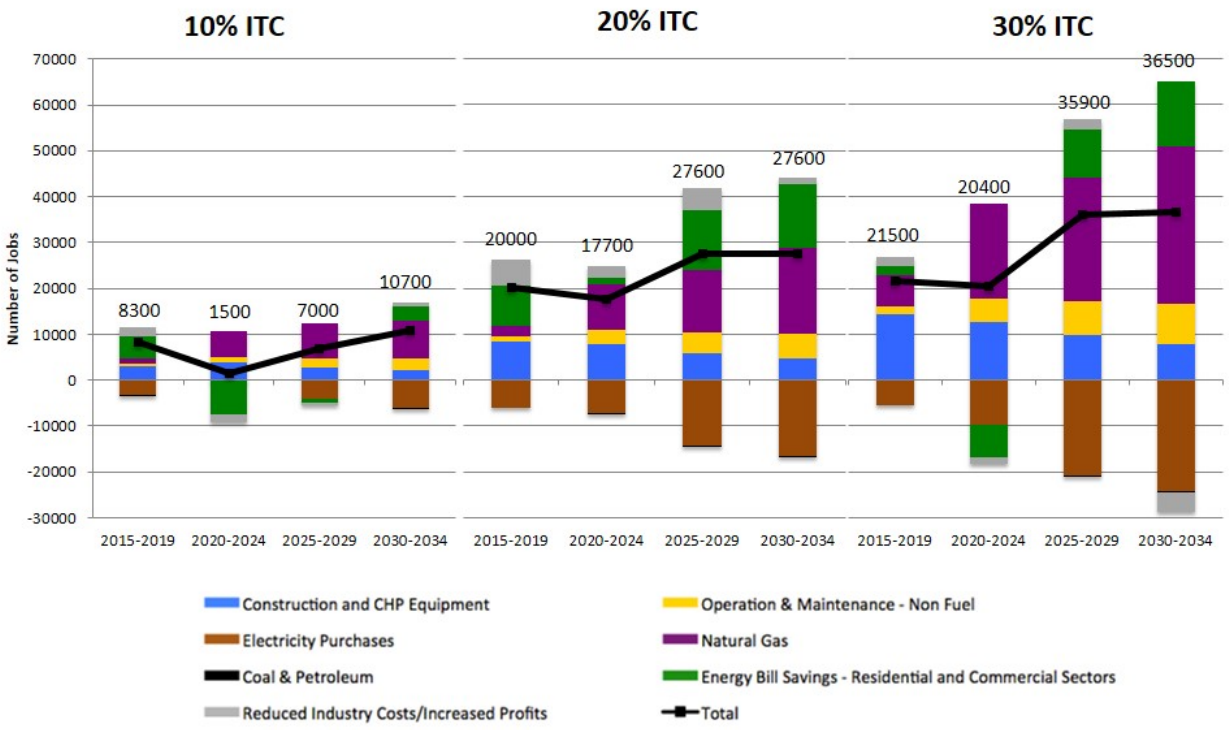
[17] More precisely they track energy bill savings (or increases) after amortizing new CHP investment costs, but because the income elasticity of energy consumption is low in NEMS, and electricity prices change more than gas or other fuel prices, the electricity price changes dominate the second-order job impacts.

energy efficiency as well as switching fuel consumption to natural gas. Overall, however, these effects are much smaller than the job creation in other sectors; as a result, the net annual increase in jobs (averaged between 2030 and 2035) is estimated to be 10,700 with a 10% ITC, 27,600 with a 20% ITC, and 36,500 with a 30% ITC.

Figure 9. Estimated Employment Impacts by Scenarios



6. Demand Reduction Induced Price Effects (DRIPE)

The results presented in Section 5 are based on three subsidy scenarios and on the energy market dynamics specific to those scenarios. In order to provide a more general and scale-independent analysis of the impacts of CHP deployment, and in particular of the second-order impacts related to the DRIPE effect, we developed a statistical analysis relating the quantity of new capacity and generation to the changes in spending patterns and associated employment impacts. This allows us to estimate the employment impacts of new CHP in the baseline, as well as to compare the results of our analysis to similar assessments of the job-creation associated with the deployment of renewables and efficiency technologies.

The statistical analysis is based on assessing the relationships between new CHP capacity and the reduction in utility power generation and increased industrial natural gas consumption, and the associated changes in gas and electricity prices across the economy.[18] At a theoretical level, the relationships can be described quite simply. Reduction in purchases of utility electricity by industrial consumers, increases in sales back to the grid, and increased purchases of natural gas lead to price changes for gas and electricity in all sectors (Figure 8). These in turn lead to changes in energy demand and energy expenditures, taking into account the feedbacks in a general equilibrium system. In the real world, or even a model of the real world such as NEMS, the impacts would be much more complex, as industrial electricity purchases are typically based on long term contracts, residential and commercial rates are governed by a wide range of regulatory structures, and the underlying system is based on discrete physical infrastructure such as power plants, transmission lines and pipelines.

For our purposes, however, we abstract away from these complexities, and treat the variation from the reference case for each year for each variable as independent data points in a simplified economic model. To provide additional comparisons with the reference case, we ran three scenarios in which symmetrical price increases of 10%, 20% and 30% were applied to the capital costs ($/kW) of new CHP installations. While plainly this is an imperfect statistical treatment – each scenario is a time series with its own auto-correlation, for starters – in the context of a modeling analysis, we believe it provides a more comprehensive basis for a scenario-independent estimation.

The results of the statistical analysis are shown in Table 5 below. Many of the correlations are quite tight; the least explanatory correlation is between changed natural gas consumption and changed natural gas pricing.

Using the statistical relationships calculated from the NEMS output and the employment coefficients derived from the IMPLAN data, we are able to generate estimates of the per unit employment impacts of new CHP capacity and generation. CHP facilities are assumed to operate at 80 percent of their nameplate capacity and have a 20-year operating life, with a non-fuel O&M cost of 0.5 cents/kWh. As in the ITC scenario analysis, changes in industrial costs and revenues and commercial energy bills are assumed to be passed on to households as price reductions or increases in dividends. To generalize over the period during which the investments and operation take place, we take average expenditures in each sector over the 2015-2035 period as the base against which to calculate changed expenditures due to price changes; we use the midpoint (2025) level to estimate CHP capital costs for our prototype system ($948/kW) and productivity increases in the various sectoral employment coefficients.

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[18] There are also changes in industrial consumption of coal and petroleum but they are so small in these scenarios that we ignore them.

Table 5. Regression Analysis of New CHP Generation

Relationship	Slope	R-Squared
Change in industrial electricity purchases per unit of new CHP generation (Quad Btu/Billion kWh)	-0.002	0.997
Changes in industrial electricity sales to grid per unit of new CHP generation (Billion kWh/Billion kWh)	0.222	1.000
Change in industrial gas consumption per unit of industrial CHP generation (Quad Btu/Billion kWh)	0.007	0.999
Change in industrial electricity price per unit of new CHP generation ($ per Million Btu/Billion kWh generation)	-0.001	0.549
Change in industrial gas price per unit change of industrial gas consumption ($ per Million Btu/Quad Btu)	0.032	0.223
Change in residential electricity price per unit change of industrial electricity price	1.648	0.910
Change in commercial electricity price per unit change of industrial electricity price	1.191	0.952
Change in residential gas price per unit change of industrial gas price	1.356	0.807
Change in commercial gas price per unit change of industrial gas price	1.325	0.828

Based on these relationships and assumptions, we can estimate the changes in expenditures in the industrial, residential and commercial sectors, and the employment impacts of those expenditure changes. The cost changes in the industrial sector generate what we call first-order jobs, although they include direct, indirect and induced jobs in the jargon of I/O analysis. The net change in industrial costs is then included as a change (increase) in household income. Changes in commercial energy costs are also assumed to be passed to households; and household energy bills change directly through changes in the prices of natural gas and electricity in the residential sector. As noted previously, we assume that the respending of these savings is proportional to average household spending across all income groups, as reported by IMPLAN. Table 6 shows that for every billion kWh of new generation electricity by industrial CHP, the next expenditure change is about a four million dollar decrease in the industrial sector, about a 13 million dollar decrease in the commercial sector, and about a 7.5 million dollar decrease in the residential sector, leading to a net decrease in expenditure/increase in income of about 24 million dollars to all households.

Table 6. Expenditure Changes (in Millions Of Dollars Per Billion kWh of New CHP Generation)

	Industrial	Commercial	Residential	Net Household
Amortization	8.0			
O&M	5.0			
Gas	40.1	1.0	1.4	
Electricity Purchased	-43.4	-13.8	-8.0	
Electricity Sales	-13.6			
Net Annual	-3.9	-12.8	-7.5	-24.2

* Note: Net annual expenditures in each sector are summed to provide net change in household income/expenditures (negative numbers are decreases in expense or increases in income).

Using these figures with the IMPLAN coefficients described above, we can calculate the net employment impacts. As shown in Table 7, around 0.9 first order jobs (full-time, 20-year-equivalent) are created per GWh of new generation, and about 0.23 second order jobs from the respending of household energy bill savings and changes in industrial/commercial costs or dividends passed through to households. Job losses are concentrated in the electricity industry, while job gains accrue in the gas industry and in the remainder of the economy across which consumer purchases are spread. Note that the net second-order impacts are roughly twice as large as the net first-order impacts.

Table 7. Employment Coefficients and Net Employment Impacts (First Order, Second Order and Total) Per GWh of Additional CHP Generation

	Employment coefficients (jobs per $million expenditure)	Industry (First Order)	Household and Commercial (Second Order)	Total
Construction (converted to FTE)	0.6	0.08	0	0.08
O&M	17.4	0.09	0	0.09
Electricity	5.0	-0.33	-0.11	-0.45
Natural Gas	5.8	0.25	0.014	0.26
Consumer Respending	13.6	-	0.33	0.33
TOTAL		0.09	0.23	0.31

7. Jobs per GWh Comparison with other studies

Direct comparison with other studies is difficult for a variety of reasons. Like installation and operation of other electrical generating equipment, investment in CHP leads to jobs changes in the directly affected sectors. However, precisely because CHP also produces efficiency gains, it generally leads to lower projected prices and thus to energy bill savings and household and business re-spending. Most other studies of jobs from adding renewables do not attempt to estimate these second-order effects. Thus while on the one had, comparison of CHP with renewables would seem to be more appropriately based on only the first-order jobs which both types of studies generally include, this excludes the efficiency benefits which motivate CHP in the first place.

Similarly, comparing job estimates from CHP with estimates from the deployment of efficiency-improving technologies (typically in jobs/GWh saved) is complicated because capacity and generation from new CHP is what is reported, not the energy directly saved through efficiency gains. However, since the redirection of spending from energy bill savings is a fundamental driver of employment changes from efficiency investments, comparable studies of efficiency do typically address what we call second-order jobs.

Table 8 shows summary data from a variety of previous studies, based on a similar table in Carley et al. (2011) and on Wei et al. (2010). Typical values for renewables range from a low of 0.03 jobs/GWh to over 1 or even 2 jobs/GWh of generation.

Table 8. Previous Studies

Sources	Technology	CIM	O&M and fuel processing	Total
		(Job-years/GWh)		
Laitner and McKinney (2008)	Energy Efficiency			0.17
Simons and Peterson (2001)	Wind	0.03	0.09	0.13
	Geothermal	0.01	0.21	0.22
	Biomass	0.01	0.21	0.22
	Solar thermal	0.07	0.06	0.13
	Solar PV	0.16	0.07	0.23
	Small hydro	0.03	0.33	0.35
Kammen et al. (2006)	PV1	0.71	0.14	0.85
	PV2	0.66	0.55	1.21
	Wind1	0.05	0.03	0.08
	Wind2	0.29	0.03	0.32
	Biomass-high estimate	0.05	0.28	0.32
	Biomass-low estimate	0.05	0.04	0.09
	Coal	0.03	0.08	0.12
	Gas	0.03	0.08	0.11
Moreno and Lopez (2008)	Wind	0.17	0.07	0.23
	Solar PV	0.79	1.54	2.33
	Biomass-electric	0.01	0.02	0.03

8. Discussion and Conclusions

Many of the limitations of this type of study are well known, and for obvious reasons the results should not be taken as firm predictions. Plainly it would be desirable to perform a range of sensitivity and uncertainty analyses; however our goal here was to develop both a reproducible analytic method and a practical toolkit for this type of analysis. In addition, we sought to examine the job impacts of a federal ITC policy.

The expanded 30% ITC policy modeled in this study suggests that industrial CHP capacity could be increased by 22.5 GW in 2035, compared with the reference case, which represents a 28% growth of the total CHP capacity forecast by the reference case in that year. Such a policy would nearly meet the 2012 executive order goal in 2020; we estimate that by 2023, the ITC would meet the expansion target for industrial CHP. These policy effects on industrial energy efficiency would be technologically transformational and economically broad. While direct fuel expenditures would rise and more capital would be required for these energy-efficiency upgrades (on the order of $1 billion each year), the enhanced energy independence from the central utility would deliver more than $800 million in additional energy bill savings in 2035 with a 20% ITC; this benefit would drop to $160 million in 2035 with a 30% ITC because gas prices rise significantly, and these additional costs are offset only slightly by the industrial sector's decreased purchase of electricity and its increased grid sales.

In both the reference case and with an ITC policy, our analysis indicates that energy consumption in industrial plants would continue to grow, but the efficiency of CHP systems would result in slower energy consumption growth in the ITC scenarios. Employment growth would be significantly higher in the ITC scenarios: by about 36,500 FTEs in 2035 relative to the reference case. Furthermore, these employment impacts include significant second-order impacts, which are often overlooked in estimates of job growth. The declining average electricity prices enable energy bill savings in the residential, commercial, and industrial sectors, which generate induced jobs.

The job estimates per GWh of new generation provide interesting insights to assess the cost-effectiveness of ITC policies by sectors. The ITC investment would provide positive sources of job creation in the first-order CIM (0.08 FTE/GWh) and O&M (0.09 FTE/GWh) processes for the increased CHP generation. It would also establish more substantially the widespread impacts for fuel processing in electricity (-0.46 job-years/GWh) and natural gas (0.26 job-years/GWh) as well as the second-order jobs from household and commercial respending (0.33 job-years/GWh).

Acknowledgements. The authors gratefully acknowledge the support for this research that was provided by Oak Ridge National Laboratory (Melissa Lapsa, Project Manager), the Department of Energy, and Georgia Institute of Technology's Institute of Paper Science and Technology (IPST). The advice of Norman Marsolan, Director of the IPST was particularly valuable in addressing our case study of the pulp and paper industry and combined heat and power. The views expressed in this paper, and any errors, are attributable entirely to the authors.

References

Blakely, E. J., & Leigh, N. G. (2009). Planning Local Economic Development: Theory and Practice (Fourth Edi.). Sage Publications, Inc.

Brown, M. A., & Sovacool, B. K. (2011). Climate Change and Global Energy Security, Chapter 6. MIT Press.

Marilyn A. Brown, Matt Cox, and Paul Baer. 2013. "Reviving manufacturing with a federal cogeneration policy." *Energy Policy*. 52 (2013) 264–276.

Bureau of Labor Statistics. (2013). Green Goods and Services News Release. U.S. Department of Labor.

Carley, S., Lawrence, S., Brown, A., Nourafshan, A., & Benami, E. (2011). Energy-based economic development. Renewable and Sustainable Energy Reviews, 15(1), 282–295. doi:10.1016/j.rser.2010.08.006

Chittum, A., & Kaufman, N. (2011). Challenges Facing Combined Heat and Power Today : A State-by-State Assessment (Vol. 20045). Retrieved from http://www.uschpa.org/files/public/ie111.pdf

Claussen, E., & Peace, J. (2007). Energy Myth Twelve - Climate Policy will Bankrupt the U.S. Economy. In B. K. Sovacool & M. A. Brown (Eds.), Energy and American Society - Thirteen Myths (pp. 311–340). Springer.

Cox, M., Brown, M., & Jackson, R. (2011). Regulatory Reform to Promote Clean Energy: The Potential of Output-Based Emissions Standards. Proceedings of the ACEEE Summer Study on Energy Efficiency in Industry (pp. 1–57 – 1–67). Niagara Falls, NY.

Diamond, J. (2005). Collapse: How Societies Choose to Fail or Succeed. Penguin Books.

Dietz, T. (2010). Narrowing the US energy efficiency gap. Proceedings of the National Academy of Sciences of the United States of America, 107(37), 16007–8. doi:10.1073/pnas.1010651107

Geller, H., DeCicco, J., & Laitner, S. (1992). Energy Efficiency and Job Creation: The Employment and Income Benefits from Investing in Energy Conserving Technologies. Washington, D.C.

Goodstein, E. (1999). The Trade-off Myth: Fact and Fiction about Jobs and the Environment. Washington, D.C.: Island Press.

Hirst, E., & Brown, M. (1990). Closing the efficiency gap: barriers to the efficient use of energy. Resources, Conservation and Recycling, 3(4), 267–281. doi:10.1016/0921-3449(90)90023-W

Houser, T. (2013). American Energy Efficiency: The Economic, Environmental and Security Benefits of Unlocking Energy Efficiency.

ICF International. (2010). Effect of a 30 Percent Investment Tax Credit on the Economic Market Potential for Combined Heat and Power.

ICF International. (2011). Combined Heat and Power Installation Database. 2011. Retrieved from http://www.eea-inc.com/chpdata/

Jaffe, A. B., & Stavins, R. N. (1994). The energy-efficiency gap: What does it mean ? Energy Policy, 199422(10), 804–810. Retrieved from http://www.hks.harvard.edu/fs/rstavins/Papers/The Energy Efficiency Gap.pdf

Kim, G., Baer, P., & Brown, M. A. (2013). The Statewide Job Generation Impacts of Expanding Industrial CHP. Proceedings of the American Council for an Energy Efficient Economy (ACEEE) Summer Study on Energy Efficiency in Industry. Niagara Falls, NY: American Council for an Energy Efficient Economy.

Kramer, C., & Reed, C. (2012). Ten Pitfalls of Potential Studies. Energy Future Group.

Laitner, J. A. “Skip”, & McKinney, V. (2008). Positive Returns: State Energy Efficiency Analyses Can Inform U.S. Energy Policy Assessments. Washington, D.C.

Laitner, S., Bernow, S., & Decicco, J. (1998). Employment and other macroeconomic benefits of an innovation-led climate strategy for the United States. Energy Policy, 26(5), 425–432.

Lehr, U., Nitsch, J., Kratzat, M., Lutz, C., & Edler, D. (2008). Renewable energy and employment in Germany. Energy Policy, 36(1), 108–117. doi:10.1016/j.enpol.2007.09.004

Lewis, G. M. (2010). Estimating the Value of Wind Energy Using Electricity Locational Marginal Price. Energy Policy, 38, 3221–3231.

Miller, R. E., & Blair, P. D. (2009). Input-Output Analysis: Foundations and Extensions (Second Edi.). Cambridge: Prentice Hall.

Pollin, R., Garrett-Peltier, H., Heintz, J., & Scharber, E. (2008). Green Recovery: A Program to Create Good Jobs and Start Building a Low-Carbon Economy. Center for American Progress.

Rockstrom, J., Steffen, W., Noone, K., Persson, A., Chapin, F. S., Lambin, E. F., Lenton, T. M., et al. (2009). A Safe Operating Space for Humanity. Nature, 461, 472–475.

Sciortino, M., Neubauer, M., Vaidyanathan, S., Chittum, A., Hayes, S., Nowak, S., Molina, M., et al. (2011). The 2011 State Energy Efficiency Scorecard (Vol. 20045). Retrieved from http://www.aceee.org/sites/default/files/publications/researchreports/e115.pdf

Sentech Inc. (2010). Commercial and Industrial CHP Technology Cost and Performance Data Analysis for EIA. Washington, D.C.

Shipley, A., Hampson, A., Hedman, B., Garland, P., & Bautista, P. (2008). Combined Heat and Power: Effective Energy Solutions for a Sustainable Future. Oak Ridge, TN. Retrieved from http://www1.eere.energy.gov/manufacturing/distributedenergy/pdfs/chp_report_12-08.pdf

Sorrell, S., Dimitropoulos, J., & Sommerville, M. (2009). Empirical Estimates of the Direct Rebound Effect: A Review. Energy Policy, 37, 1356–1371.

Steinhurst, W., & Sabodash, V. (2011). The Jevons Paradox and Energy Efficiency. Cambridge, MA: Synapse Energy Economics, Inc.

The Committee on Climate Change Science and Technology Integration (CCCSTI). (2009). Strategies for the Commercialization and Deployment of Greenhouse Gas Intensity-Reducing Technologies and Practices. Washington, DC. Retrieved from http://www.energetics.com/resourcecenter/products/studies/samples/Documents/strategies_greenhouse_report.pdf

The White House. (2012). Executive Order - Accelerating Investment in Industrial Energy Efficiency. Office of the Press Secretary. Retrieved from http://www.whitehouse.gov/the-press-office/2012/08/30/executive-order-accelerating-investment-industrial-energy-efficiency

U.S. Energy Information Administration. (2012). Annual Energy Outlook 2012 with Projections to 2035.

U.S. Energy Information Administration (EIA). (2011). Annual Energy Outlook 2011: with Projections to 2035. Outlook (Vol. 0383). U.S. Energy Information Administration.

U.S. Environmental Protection Agency (EPA). (2012). Combined Heat and Power: A Clean Energy Solution. Retrieved from http://www1.eere.energy.gov/manufacturing/distributedenergy/pdfs/chp_clean_energy_solution.pdf

U.S.Environmental Protection Agency Combined Heat and Power Partnership. (2008). Catalog of CHP Technologies. Retrieved from http://www.epa.gov/chp/documents/catalog_chptech_full.pdf

Wei, M., Patadia, S., & Kammen, D. M. (2010). Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US? Energy Policy, 38(2), 919–931. doi:10.1016/j.enpol.2009.10.044

White, S., & Walsh, J. (2008). Greener Pathways – Jobs and Workforce Development in the Clean Energy Economy. Retrieved from http://www.cows.org/pdf/rp-greenerpathways.pdf