# The Non-Energy Benefits for Industrial Electric Technologies

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## ABSTRACT

Energy Efficiency is viewed as an important motivation behind electrification of industrial end-use technologies. However, electric end-use measures might also yield additional advantages beyond the actual energy cost savings which can be classified under the bucket of non-energy benefits (NEBs). To achieve widespread electrification, the value of NEBs is considered as a driver to the adoption of electric end-use technologies. This paper will review the various NEBs, provide examples of their quantification methods, and demonstrate the tilt in the economic balance when comparing electric versus non-electric technologies. Examples include; reduced O&M costs, improved productivity, increased product quality, improved health and safety, and reduced environmental risks. Some of these benefits can be quantified and monetized, resulting in reduced payback time for a technology based on energy savings and NEBs. However, not all the benefits are easily quantifiable. The quantitative results show a clear economic benefit for electric technology examples chosen when including both energy costs and NEBs in the lifecycle cost analysis as opposed to the former alone. The methodology demonstrated in this paper can be used by electric utilities, equipment manufacturers and other interested parties for a long-term strategic approach for investment decision making.

## Introduction

The industrial sector is the largest energy consuming sector in the country, being responsible for 35% (EIA 2021) of the total U.S. energy consumption and accounting for 32% of U.S. end-use energy consumption. Most of today's industrial end-use processes rely heavily on the combusted fuels to supply heat. However, with the growing push to combat climate change, electrification of industrial end-use processes is gaining attention. Previous studies have shown that reduction in final energy consumption and $CO_2$ emissions are possible through the deployment of efficient electric technologies and a cleaner grid (IEA 2017, Ruud and Saygin 2014, Lechtenböhmer et al. 2016, Rogelj, J., et al. 2018). Technology advancements make it possible for very diverse manufacturing processes that cover a wide range of operating temperatures to be electrified, which translates to approximately 50% replacement of the final industrial energy consumption from fossil fuels (Roelofsen 2020). Despite this technical maturity, high costs of currently available, commercial electric technologies are a key barrier that prevents manufacturing companies from widespread adoption of those technologies in their plant sites. Even with comparable cost for like-to-like electric equipment versus the fuel-fired equipment, the electricity-to-gas price ratio needs to be sufficiently low in order for the energy costs and ultimately the lifecycle cost of the electric technology to be economically justifiable. One factor that is either not well understood or overlooked, but can substantially tilt the economic balance between the electric and the baseline fuel-fired technology, is the monetization of non-energy benefits (NEBs) (Nehler 2016) - defined as benefits that are "not part of the costs, or the avoided cost, of the energy from the utility" (Malone 2014).

While electrification of industrial technologies drives more energy efficiency and thus saves energy costs for an industrial plant, the NEBs of electric technologies can be an important driver for their adoption by the plant site managers. Hence, monetizing and including NEBs in industrial plant investment decisions could increase the potential of initial investment in electric technologies. At a high level, NEBs impact the following aspects of an industrial plant site; (a) production, (b) operation and maintenance, (c) working environment, (d) waste, and (e) emissions. For example, electrification has a significant role in decarbonizing the environment both because the electric technology is often more energy efficient than fuel-fired equipment, and because the grid is continually becoming cleaner. Further, the elimination of on-site emissions through electric technologies provides a safer work site. Increased productivity, improved product quality, and reduced maintenance have also been reported for multiple electric technologies. The reporting on the monetary value of NEBs for electrification, is however very scarce in the literature. Pye and McKane (2000) have stated these NEBs are equal or sometimes greater than the energy savings themselves. Spreading a quantitative awareness of NEBs for electric industrial technologies is a key motivation for the present work.

Apart from site managers of industrial plants, a clearer understanding of the NEBs is also of interest to electric utilities. They have the challenge of identifying which industrial subsectors and customers in their geographical territories have the best economic opportunities to electrify industrial processes, as that directly impacts their strategies around industrial electrification programs. The current work provides a methodology to quantify certain industrial NEBs through examples, and how the economic balance between competing technologies changes with the inclusion of those NEBs. As such they can be used by electric utilities to help their customers visualize the true, improved economic value that electric technologies offer.

## Challenges in Quantifying the Non-Energy Benefits (NEBs)

NEBs for electric technologies are process-and product-specific. One characteristic that distinguishes the industrial sector from other sectors is that the manufacturing processes between industrial sub-sectors are extremely diverse. For example, the average operating temperatures and grade of heat varies significantly between say, the food processing industry uses low-temperature heat <100 ºC (Law 2013) and the iron and steel, cement and glass production industries use high-temperature heat of more than 500 ºC for several processes (Buhlera 2019). Even within an industrial subsector, there are multitude products that require customized equipment sizes and usage styles. Apart from the challenge presented by the nature of the industry, some of the NEBs are very abstract in nature. For example, microwave heating for food processing has been shown to yield food products with better taste, but taste is a very subjective parameter to be accurately measured and represented monetarily. Despite these challenges, this study aims to fill the gaps in quantitative representation of NEBs by providing a calculation methodology. Table 1 illustrates the level of ease/difficulty in quantifying NEBs monetarily, clearly some of them are easier to quantify than others. For example, $CO_2$ is calculated from energy usage and the generation mix value whereas other compounds such as VOCs require measurement. The ability to quantify NEBs also depend on the data and resources available to perform empirical analysis. However, we believe that by increasing the awareness of NEBs, there will be more R&D to solve the challenges and complexity related to data collection.

Table 1. Summary of the industrial Non-energy Benefits

| Non-energy Benefits | Example | Quantifiability |
|---|---|---|
| **Production** | | |
| Productivity | Improve/ Increase productivity | ● |
| Reduced production cost | Operations and maintenance | ● |
| Reduced processing time | Shorter process cycle time | ● |
| **Product Quality** | | |
| Product Output | Lower defects | ◐ |
| | Increased yield | ◐ |
| Improved Quality | Improve product taste and appearance | ○ |
| **Health and Safety** | | |
| Workplace Hazards | Air quality (carbon dioxide $CO_2$) | ◐ |
| | Comfort | ○ |
| | Health Impacts | ○ |
| **Environment** | | |
| Pollutants | $CO_2$ | ● |
| | Volatile Organic Compounds (VOCs) | ○ |
| | Toxic Air Pollution (Benzene) | ○ |

● The quantification is easy ◐ The quantification is somewhat easy ○ the quantification is difficult. *Source:* EPRI, 2019.

In the following sections, we illustrate the methodology for calculating NEBs for two electric technologies, one applied to the food processing industry and the other applied to the primary metals industry. As mentioned above, these are two industries that vary widely in terms of the operating temperature spectrum and having large values of shipments (Table 2). Currently, the primary energy source for both these industries is natural gas.

Table 2. Energy use and economics for the food processing and primary metals subsectors in the U.S.

| Industrial Sector | Electricity (million kWh) | Natural Gas (billion cubic feet) | Shipment value (billion USD) |
|---|---|---|---|
| Food Processing | 91,975 | 650 | 794 |
| Primary Metals | 112,848 | 658 | 240 |

*Source:* (EIA 2018 and U.S. Census Bureau 2021)

## Methodology for Calculating NEBs

In conventional calculation methods, the lifecycle cost of an industrial equipment is a function of its upfront cost, annual energy costs and maintenance costs[1]. The NEBs can be viewed as a cost-reducer, that is, they lower the effective lifecycle cost of the equipment that a customer would have otherwise paid for. Hence, in our proposed method, a monetary value is first calculated for the NEBs of a particular electric equipment, and this value is then subtracted from the lifecycle cost calculated using the conventional method. The economic likelihood of adoption of the electric technology is evaluated by comparing the lifecycle cost of the baseline fossil-fuel equipment against the revised lifecycle cost of the electric technology calculated above. Two NEBs, namely the raw material savings and increased productivity due to reduced cycle time have been chosen to illustrate this methodology. Both NEBs have been monetized for the food processing industry (showing the NEB analysis for infrared heating equipment) and the primary metals industry (showing NEB analysis for induction furnace melting equipment).

### Examples for the food processing industry

For the food processing industry, we specifically look at infrared heating technology applied to the drying/processing of fruits, vegetables, and nuts. Dr. Pan (UC Davis webpage) has shown that application of infrared drying to peel tomatoes and pears result in around 10% lower peeling loss. Peeling loss is a wastage of raw material, so infrared technology essentially reduces the amount of raw material lost in a tomato or pear processing plant. The reduced production cost due to the lesser requirement of raw material can be calculated using Eq. (1) below:

Raw material cost savings = Loss reduction (%) x Raw material price ($/ton) x Plant capacity (tons) (1)

For the example of tomato peeling, a 10% reduction in loss of tomatoes procured at hundred dollars per ton results in a cost savings of ten dollars for each ton of tomato processed. The same 10% reduction in peeling loss of pears saves thirty-five dollars per ton of pears, assuming a per ton cost of three-hundred and fifty dollars.

The infrared equipment has also been shown to reduce the processing time of drying nuts (Pan et al. 2019). In the conventional hot air roasting method, forced hot air above 150°C is passed over nuts like almonds. Through this process, they are agitated to deliver finished product with better color and flavor. However, hot air roasting is a time-consuming process (Bagheri, H., 2020). In comparison, infrared heating quickly raises the temperature of the nuts and removes moisture to yield finished product at reduced processing time. In the study conducted by Pan et al. (2019), the roasting time of almonds reduced by 39% while the drying time for walnuts was reduced by 14-27%. This means more nuts can be processed per day of operation of the plant, yielding higher overall productivity. The increased productivity can be quantified using Eq. (2):

Productivity due to reduced processing time = Total annual plant cycle (hours) x Time saved (%) x Labor rate ($/hour)/Annual production capacity of equipment (tons) (2)

[1] In many instances, reduced maintenance costs can be considered as a non-energy benefit.

Assuming a 6000-hour production cycle annually in a plant that produces dried walnut, a 20% time savings and average labor rate of $100/hour yields cost savings of twenty dollars per ton of finished walnuts in a plant that produces 6000 tons annually.

**Example from the primary metals industry**

A key process seen in foundries during the steel making process is melting of iron. This is conventionally accomplished using a fuel-fired cupola furnace. However, the electric induction furnace has been reported as a cleaner and energy-efficient method to accomplish this process (Yilmaz et al. 2012). The technology comes with NEBs like controllability (i.e. improved precision and product control) and lean manufacturing capability, but productivity is arguably the biggest NEB. Rapid heating speeds produce faster throughput in the induction melting process, and for this reason it is estimated that induction heating is ten times faster than cupola-based direct melting method (SWEPCO). Another reason that is attributed to the faster melting is about 30% higher melting effectiveness seen in the induction furnace-based operation (Wick et al. 1998) (melting effectiveness is defined as the ratio between the theoretical energy needed to melt the charge components in the furnace and the energy actually used by the furnace). Productivity improvement through higher production rates can be quantified using the same Eq. (2) above.

Assuming an 8000-hour production cycle annually in an assembly line that produces 4,000 tons of steel annually, a 10%-time savings and an average labor rate of $100/hour yields cost savings of twenty dollars per ton of steel.

As also mentioned, very precise heating of local areas can be maintained when the electromagnetic field of induction furnace is applied on the steel parts. This is because of the high controllability of the output energy level of electric induction furnace. This NEB of improved precision improves product quality and reduces scrap and necessary repairs. If we use Eq. (1) to monetarily express the reduced scrap requirement, assume a 1% scrap reduction and $600 per ton as the average price of steel, then the cost savings is six dollars per ton.

The above is but two very specific examples of quantifying NEBs for two electric technologies in two different industries. Since both the food processing industry and the primary metals industry have a broad range of industrial products and processes, the same technology can be applied differently to yield NEBs in different ways. Even for the specific parameters of productivity improvement and raw material reduction that have been quantified, there can be other ways in which these two NEBs can be achieved and hence the total monetary value of these NEBs can be higher. A single operating characteristic can also yield multiple NEBs. For example, in the peeling loss reduction example considered above, there is not only reduction in raw material but there is also a productivity improvement because less raw material needs to be processed to yield the same amount of final product. Moreover, the way in which a certain NEB manifests for an electric equipment depends also on the specific application. For example, when infrared heating is applied to preheat potato chips before frying, the raw material reduction occurs due to reduced oil requirement for frying, as opposed to the earlier tomato processing example where the reduced need for tomatoes itself was seen. All of this is to say that the industry and processes need to be deeply understood while attempting to accurately quantify the non-energy benefits of an electric technology.

## Results

To illustrate how the monetary quantification of the NEBs can impact the economic potential for customer adoption, lifecycle costs were first calculated for a representative electric infrared heating equipment and induction furnace equipment. The equipment costs, energy use and maintenance costs used for the lifecycle cost calculations are shown in Table 3 below. The cost data for infrared and convection oven equipment were adapted from Ratti & Majumdar (2006), and adjusted for time-based inflation using the U.S. Bureau of Labor Statistics (U.S. Department of Labor, webpage) data, while the costs for electric induction furnace and natural gas furnace were adapted from Unver & Unver (2014). It is worth noting in Table 3 that for the food processing industry, the lifecycle cost of the infrared electric drying equipment is lower than the natural gas convection oven. This already renders the electric technology economically favorable without accounting for NEBs, and the inclusion of monetary value of the NEBs will further strengthen the economic potential of the electric equipment, and additionally reduce its higher installed cost barrier.

Table 3. Installation costs of electric and gas fired equipment used in adoption modeling

| Application | Drying in food processing industry | | Melting in primary metals industry | |
|---|---|---|---|---|
| Technology | Infrared Heating | Convection Oven | Induction Furnace | Gas Furnace |
| Lifetime (years) | 15 | 15 | 30 | 30 |
| Installed Cost | \$215,000 | \$130,000 | \$600,000 | \$200,000 |
| Annual Energy Cost | \$30,000 | \$45,000 | \$720,000 | \$540,000 |
| Annual Maintenance Cost | \$22,000 | \$13,000 | \$60,000 | \$120,000 |
| Lifecycle cost | \$995,000 | \$1,000,000 | 24,000,000 | 20,000,000 |

Our analysis then calculated the economic likelihood of adoption for the electric equipment based on the above lifecycle costs under three scenarios: (1)With no NEBs included, (2)With NEBs included whose monetary value is 40% of the lifecycle cost in Table 3, (3)With NEBs included whose monetary value is 120% of the lifecycle cost in Table 3. We believe that most industrial electric technologies will fall under scenarios 2 and 3, since the monetization of multiple non-energy benefits such as reduced O&M costs, improved productivity, increased product quality, improved health and safety, and reduced environmental risks can result in a total monetary value that is either less than or more than the lifecycle cost of the equipment. A logistic regression model (Logistic regression, Wikipedia) was used to calculate the probability of customer adoption of electric technology for each of these three scenarios. The lifecycle cost results for the three scenarios are shown in Table 4 below and the resulting economic potential for customer acceptance of the technology is shown in Figure 1.

## Discussion

Economic potential of the electric equipment is significantly impacted upon inclusion of the NEBs. As shown in Table 4, for scenario 1 where the percentage of customer adoption was calculated using the conventional lifecycle cost calculations and the logistic regression model described above, the adoption level was found to be roughly equal between the electric infrared and the baseline fossil fuel convection equipment for the food processing industry (51 percent versus 49 percent). This is obvious, since when the customer must choose between two equipment based on the economics, if the cost of the two options are equal then there is roughly equal chance for either equipment to be picked. The corresponding percentages for the melting equipment in the primary metals industry were 30% for the induction furnace and 70% for the fossil fuel furnace. However, when the “hidden” monetary value of NEBs is factored in (scenarios 2 and 3), these percentages change significantly. For scenario 2 where NEBs being 40% of the lifecycle cost, the adoption percentage for electric equipment rises to 97% for the infrared equipment and 89% for the induction furnace equipment, because the “true” lifecycle cost of the electric equipment decreases by 40%. For scenario 3, where NEBs equal 120% of the lifecycle cost, the adoption potential of electric equipment based on economics is obviously 100%. Note that in this scenario of NEBs exceeding the lifecycle cost of the equipment, the “true” lifecycle cost of electric equipment is calculated as zero (Table 4) even though the mathematical calculations will result in a negative lifecycle cost.

The inference is that the inclusion of NEBs with electric technologies has a significant impact in the adoption of those technologies by customers and should be considered and promoted by equipment vendors and electric utilities strongly in order to advance market maturity. The research question that needs to be answered is: what fraction of the lifecycle cost can the non-energy benefits realistically expected to be? The answer to this question depends on the specific technology and the specific application being evaluated. Wick et al. (1998) estimated a 27% cost savings for the electric induction furnace compared to the Cupola furnace due to increased melting effectiveness. Similarly, Lung et al. (2006) mentions that an advanced blanching process leads to 40% cost savings through productivity NEB alone, though this quantification was performed for making the blanching process more energy, i.e. it wasn’t a direct electrification effort. Similarly, Lilly and Pearson (1999) examined five industrial projects and showed that the payback period reduces by 50% when including NEBs in the cost. These numbers should give confidence to industrial site managers who would benefit from NEB evaluation of their specific electric equipment applications using the methods described herein.

Table 4. Lifecycle costs of industrial drying and melting equipment under various NEB scenarios.

| Application | | Drying equipment: Food processing | | Melting equipment: Primary Metals | |
|---|---|---|---|---|---|
| Scenario | Calculated item | Infrared Heating | Convection Oven | Induction Furnace | Gas Furnace |
| 1: No NEBs included | Lifecycle Cost | $995,000 | $1,000,000 | $24,000,000 | $20,000,000 |
| | Adoption Potential | 51% | 49% | 30% | 70% |
| 2. NEBs = 40% of lifecycle cost | Adjusted Lifecycle cost | $595,000 | $1,000,000 | $14,000,000 | $20,000,000 |
| | Economic Potential | 97% | 3% | 89% | 11% |
| 3. NEBs = 120% of the lifecycle cost | Adjusted Lifecycle cost | 0 | $1,000,000 | 0 | $20,000,000 |
| | Economic Potential | 100% | 0% | 100% | 0% |

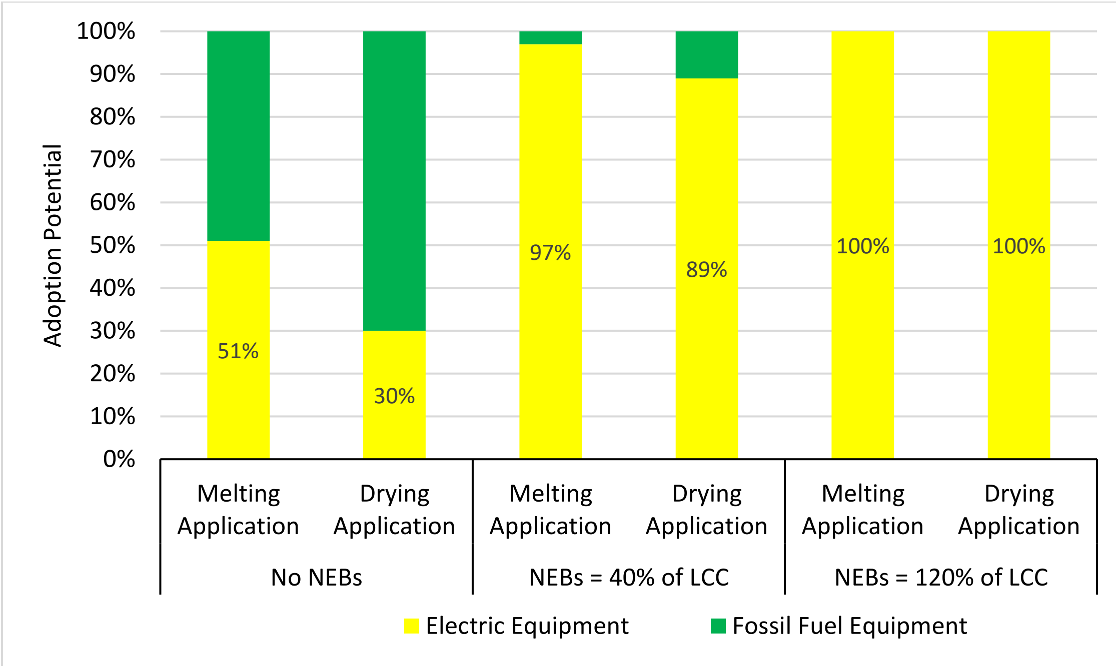


Figure 1: Likelihood of adoption of industrial drying and melting equipment under different NEB scenarios.

## Conclusion

A methodology to monetize certain non-energy benefits of electric industrial technologies has been described in this paper for infrared drying and induction melting technologies in two industries, namely the food processing industry and the primary metals industry. When factoring in the increased productivity and reduced raw material costs, there does appear to be a non-trivial, positive impact on the lifecycle cost of the electric equipment. Three scenarios evaluating customer adoption of the electric equipment based on economic value of the product was calculated, two of which included the additional value of NEBs that would not have been otherwise captured in a conventional economic adoption model. It was seen that a 40% reduction in the lifecycle cost improved the chances of adoption by 45-60%, while greater NEB values will tilt the probability of adoption entirely in favor of the electric equipment. The work performed herein can be expanded upon by calculating the monetary value for other NEBs for the same equipment and application. This can reveal the total lifecycle cost benefit through NEBs for the drying and melting application using the infrared equipment and the electric induction furnace equipment. Case studies can also be performed by the energy service provider on their current electric equipment customers to validate the methodology and the results arrived at in this paper, and in the process educate the customers about the true value of their industrial electric equipment. Finally, the role of non-energy benefits could be a possible influencer to consider during the adoption of electric technologies especially in those industries where energy savings do not command as much attention due to their lower impact on final product value.

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