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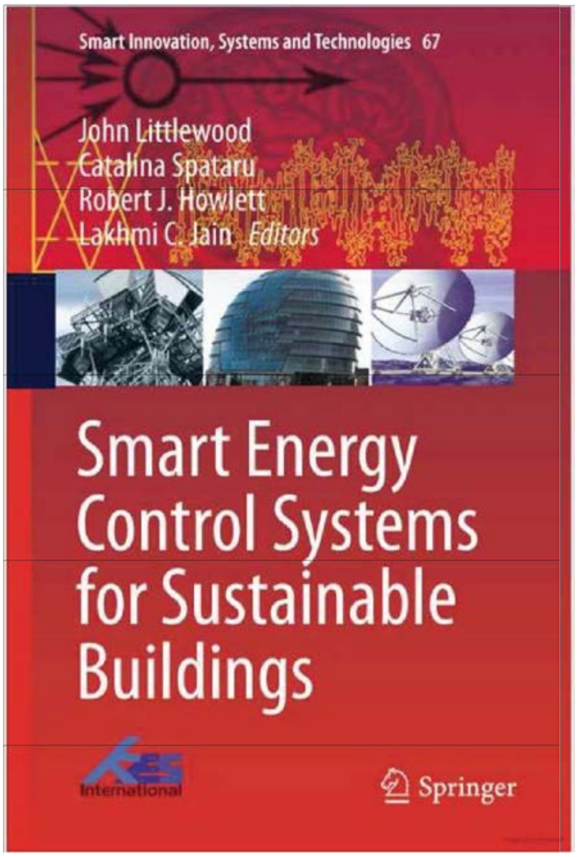

Development of a holistic method to analyse the consumption of energy and technical services in manufacturing facilities

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Abstract. This chapter describes the background to energy usage in production operations and sets out some principles, process steps and methods to provide a more holistic view of the Significant Energy Users (SEUs) and the related consumption of energy and technical services (Heat, Air, Water). A model based on direct and indirect energy analysis from a 'product' viewpoint is extended to identify waste or auxiliary energy in line with 'Lean' principles. The auxiliary energy identified represents the best opportunity to gain energy savings through operational and behavioral changes at the lowest possible cost. The proposed process mapping methodology (Value Stream Mapping (VSM)) effectively acquires production and energy data that can be modelled to provide both steadystate and dynamic energy consumption and potentially provide a multidimensional hierarchical view of this energy consumption and cost directly related to production equipment. The method is one that can be updated easily to reflect changes in the production environment and to provide a holistic view of the energy and technical services in the context of the varying production activity.

Keywords: Energy Efficiency in Industry, Significant Energy Users (SEUs), Technical Services, Value Stream Mapping (VSM).

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adfa, p. 1, 2011.

1 Energy in Industry

1.1 Introduction

Worldwide, industry consumes[1] almost one-half of all commercial energy used and is responsible for roughly similar shares of greenhouse gases. In the EU28 Countries, the industry sector still accounted[2] for about a quarter of the final energy consumption in 2012. In absolute terms industrial final energy consumption has decreased from 15.4 million TJ in 1990 to 11.8 million TJ in 2012. This is driven by energy efficiency improvement but also by the slowdown in world production since 2007.

The more industrialised nations naturally have higher percentage of consumption, for example, in Germany, industrial electricity consumption accounts[3] for approximately 46% of national energy usage. Similarly in the UK the DUKES Report[4] shows that in 2012 industry accounted for 31% of the total electricity consumed and 25% of the green house gas (GHG) emissions.

To stay competitive in the 21st Century, manufacturing companies need to include sustainability into their manufacturing optimisation schemes. Sustainable Manufacturing (SM) is the new paradigm[5] for manufacturing companies and involves the integration of all relevant dimensions that affect or have effects on third parties while conducting manufacturing operations, including energy, environmental impact and lifecycle analysis.

Hence, when designing or improving a manufacturing system an alignment with economic, ecological, and social goals has become an essential strategic objective of manufacturing companies[6]. An isolated consideration of traditional economic variables without evaluation of ecological and social impact is no longer acceptable and a balance between traditional material, equipment and personnel resources is required.

To allow for sustainability and to meet growing environmental legislative requirements, industry must be capable of understanding their energy requirements, their energy consumption and the manner in which this is managed, particularly in the production environment. Although there are various sustainability assessment tools available, these tools are complex, require large amounts of data and technical expertise to utilise[7].

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1 IEA, "World Energy Outlook," 2013.

2 Eurostat Statistical Database, 2014. http://ec.europa.eu/eurostat/data/database, Accessed 13/03/2015

3 K. Jens, “Energieeffiziente Produktherstellung,” Fraunhofer FUTUR Produktionstechnik für die Zukunft., vol. 12, pp. 12-13, 2010

4 Digest of United Kingdom Energy Statistics (DUKES), 2013 (Internet Booklet). Department of Energy and Climate Change, TSO. https://www.gov.uk/government/uploads/attachment_data/file/225056/DUKES_2013_internet_booklet.pdf, accessed May 2014

5 C. Herrmann, S. Thiede, and T. Heinemann, "A Holistic Framework for Increasing Energy and Resource Efficiency in Manufacturing," in 8th Global Conference on Sustainable Manufacturing, Abu Dhabi, 2011, pp. 267-273

6 European Commission, "Energy Efficiency in Manufacturing - The Role of ICT. Consultation Group on Smart Manufacturing. Publication of the European Communities, ISBN 97892-79-11306-2, Feb 2009

7 M. Paju, J. Heilala, M. Hentula, A. Heikkila, B. Johansson, S. Leong, et al., "Framework and Indicators for a Sustainable Manufacturing Mapping Methodology," in 2010 Winter Simulation Conference, Baltimore, USA, 2010, pp. 3411-3422

Hence, this chapter proposes a practical and less-complex methodology for the assignment of energy usage in technical services (water, HVAC) in Advanced Manufacturing Facilities. This methodology uses a combination of the lean manufacturing principle of Value Stream (VS) Mapping with energy management and on application to a standard manufacturing site, outlines the process flow, energy metering requirements, the technical utilities servicing the process and an identification of significant energy users. This methodology allows a manufacturing company to visualise their production process from an energy perspective and determine the next steps for improvement in energy management and consumption.

In productive industries some consumption of energy is necessary and indeed unavoidable as fundamental principles of energy conversion apply. The key principles[8] of energy reduction in industry are;

1. Avoid unnecessary consumption of energy.
2. Turn things off when they not needed to add-value and ensure that the workforce are engaged with and implement energy efficient operations.
3. Reduce the quantity of energy consumed during the production process
4. Re-design inefficient products and processes and reduce the supply of services in line with production activity.
5. Recover energy from the production process and reuse it.
6. Where waste cannot be eliminated, develop systems to re-use the energy either internally or externally.
7. Generate alternative energy sources (solar energy, wind turbines).

Rahimifard et Al describes[9] how a significant proportion of energy used in manufacturing is currently generated through fossil fuels and that in the foreseeable future, the rationalisation of energy consumption still provides the greatest opportunity for the reduction of greenhouse gases.

While the share of renewable energy production has grown at a greater rate (from 14% in 2004 to 25.4% in 2013) than the growth in overall energy production[10] and even though the adoption of renewable energy technologies may well be the long term solution, increasing the efficient use of energy can generate the greatest and most economical contribution to climate mitigation that industry can deliver.

As set out in the EU Factories of the Future (FoF) roadmap[11], the smart sustainable factory of the future will be one where there is full integration between the production activity and the associated energy used and where the operation of the factory can be optimised around its energy and ecological impact. Thus expected features would include; energy efficient plant and processes that are constrained by the available of energy (time/type), integrated on-site renewable energy generation with export capacity

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[8] Energy Savings Toolbox – an Energy Audit Manual and Tool, Natural Resources Canada, http://www.nrcan.gc.ca/energy/efficiency/industry/cipec/5161, Accessed 10th January 2015

[9] S. Rahimifard, Y. Seow, and T. Childs, "Minimising Embodied Product Energy to support energy efficient manufacturing," CIRP Annals - Manufacturing Technology, vol. 59, pp. 2528, 2010

[10] Eurostat Statistical Database, 2014. http://ec.europa.eu/eurostat/data/database, Accessed 13/03/2015

[11] FoF, 2010, Factories of the Future PPP, Strategic Multi-annual Roadmap, Publications Office of the European Union, Luxembourg, 2010, ISBN 978-92-79-15227-6

and integrated community based energy sinks/sources to avoid distribution losses and to eliminate waste heat/energy.

1.2 Sustainable Manufacturing

Sustainable manufacturing is a term that is commonly used in industry. It is basically the process of lowering the use of energy and utilities while producing the same level or greater of product. The US Department of Commerce's Sustainable Manufacturing Initiative[12] sums it up as:

"The creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound".

The OECD[13] has set out a seven step plan to increased levels of sustainable manufacturing in industry, although it is stressed that the seven steps are not necessarily a one way journey. Sustainable manufacturing is not about a final destination or result but rather is about continuous learning, innovation and improvement.

- Step 1: Map impact and set priorities
- Step 2: Understand data needs and choose indicators
- Step 3: Measure inputs used in production
- Step 4: Assess the operations of the facility
- Step 5: Evaluate the product design
- Step 6: Understand the results
- Step 7: Take action to improve performance

Step 1: Map impact and set priorities

It is necessary to understand the overall impact of the factory in terms of environmental impacts from the consumption of electricity, fossil-based fuels, biomass and water. At the highest level possible in the organisation it is necessary to clearly set out the business expectations and the level of priority for energy reduction activities. In larger organisations this commitment is often evidenced through the appointment of an Energy Manager and the creating of appropriate reporting structures to senior management.

Step 2: Understand data needs and choose indicators

It is necessary to gather the data required to achieve your goals. Once the organisation priorities have been identified a data collection process needs to be established. Basically this means that the company must decide what to compare against what and how they are going to measure it. The appropriate metrics (Key Performance Indicators (KPIs) / Energy Performance Indicators (EnPIs)) need to be selected to best represent

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[12] The U.S. Department of Commerce's Sustainable Manufacturing Initiative and Public-Private Dialogue. Available: http://trade.gov/competitiveness/sustainablemanufacturing/ June, 2013 Accessed 20/01/2015

[13] OECD Sustainable Manufacturing Toolkit – Seven Steps to Environmental Excellence, http://www.oecd.org/innovation/green/toolkit/48661768.pdf. Accessed 20th May 2014

the company priorities and available data. Both specific energy consumption (Energy Intensity) indicators and absolute energy indicators should be developed.

Step 3: Measure inputs used in production

To clearly understand the drivers of energy consumption in production it is necessary to understand the variation in inputs to production and the units of production output that are measurable in the organisation. It is best to select indicators and a method of normalisation of data that will be consistent across value stream and through changes in seasons, weather, production patterns and production volumes. This ensures that over the period of a number of years of historical data all the years are measured using the same KPIs thus ensuring uniformity and accurate comparison of the data.

Step 4: Assess the operations of the facility

It is necessary to review the existing processes and to determine which operations can be modified in order to reduce energy consumption. Establishing a list of Significant Energy Users (SEUs) and a quantified and prioritised Register of Opportunities is standard practice under most energy management systems.

Step 5: Evaluate the product design

It is necessary for the company to critically evaluate their products and to review if changes can be made to the product design, product assembly steps and /or production processes to see if lower impact can be designed into the facility based on a better understanding of the facility operations. This is easier to achieve in industries with regular change-overs in product design and may not be possible in some regulated industries such as medical devices or pharmaceuticals.

Step 6: Understand the results

After completing the previous steps it is very important to use the figures found as a benchmark for future revision. It is difficult to know if results are good or bad without having something to measure against. This benchmarking the results gives you a powerful tool in the future to check and compare results against. Where possible results should be compared against any available external benchmarks.

Step 7: Take action to improve performance

Once the steps have been set out it is important to develop an action plan to improve efficiency and put a team together to do so. For continued success the action plan must contain concise actions for each member of the team as well as clearly defined timelines. Improvements in energy efficiency are unlikely to be maintained unless there is appropriate energy management tools, metrics and systems in place to provide regular review and control.

1.3 Energy Efficiency Potential

Energy Efficiency is the relationship between production output and energy input. Increasing energy efficiency results in increased production for the same amount of energy or a reduction in the amount of energy required for a production unit.

Potential reductions in energy[14] of 20% and in GHG emissions[15] of 30% have been identified on industrial sites where there is an in-depth understanding of energy flows in the manufacturing process and a clear analysis of energy usage. However, to achieve these potential reductions some changes in business practices are needed.

A study[16] conducted by the IEA in 2007 concluded;

"that manufacturing industry can improve its energy efficiency by an impressive 18 to 26 %, while reducing the sector's CO2 emissions by 19 to 32 %, based on proven technology. Identified improvement options can contribute 7 to 12 % reduction in global energy and process-related CO2 emissions."

Similarly, a study[17] from 2010 on the energy savings potential in Danish industries found that with a maximum two year payback time requirement, 10% of the final energy consumption could be saved through well proven technologies and energy efficient behaviour. If the payback time requirement is extended to 4 years then the potential savings increased to 15 %.

Other studies[18,19] have shown that where large industries effectively implementing an energy management system (EnMS) that they can reduce their energy use by between 10 % and 40 %.

In the US, multiple studies[20,21] have found that industrial facilities could costeffectively reduce their energy use and GHG emissions by 14–22 percent by 2020. Manufacturers who participated in these energy efficiency programmes also experienced significant additional cost savings[22]. These Non-Energy Benefit (NEBs) included improved production, cleaner environments, improved moral and more reliable operation. Previous research[23] has shown that if NEBs are included, the true value of the energy efficiency projects might be up to 2.5 times higher than if looking at the energy efficiency improvements alone. It is important to attempt to capture any such NEBs and their size to provide better justification and wider implementation of energy efficiency projects.

Despite the efforts made over the last 20 years, the research[24,25] suggests that there remains an important potential to reduce energy consumption in energy intensive industry by 15–25%. The same research indicates that energy management and behavioral changes can achieve up to half of this remaining energy efficiency potential. Several articles[26,27] show that only a limited number of companies actually focus on

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14 Costello, G. J., Lohan, J. and Donnellan, B., 2010, Mobilising IS to support the diffusion of Energy Management Practices outside of Ireland's LIEN (Large Industry Energy Network), Proceeding of The 15th Annual Conference of the Association Information et Management (AIM 2010), IDDS, May 2010, La Rochelle, France

15 The UK Carbon Trust - Industrial Energy Efficiency Accelerator (IEEA) Programme, 2014, http://www.carbontrust.com/client-services/technology/innovation/industrial-energyefficiency-accelerator. Accessed May 2014

16 Tracking industrial energy efficiency and CO2 emission, IEA, June 2007, ISBN: 978-92-6403016-9

17 Besparelser i erhvervslivet; Viegand & Maagøe for the Danish Energy Agency; February 2010

18 IEA and IIP 2012; IEA (International Energy Agency) and IIP (Institute for Industrial Productivity). 2012. Energy Management Programmes for Industry: Gaining through saving.

managing energy and that cost-efficient energy efficiency measures are not always implemented, explained by the existence of barriers[28]. The main reasons given for not

Paris, France: IEA Publications. https://www.iea.org/publications/freepublications/publication/policypathwaysindus¬try.pdf Accessed 25th June 2014

19 Duarte, C., Acker, B., Grosshans, R., Manic, M., Van Den Wymelenberg, K., and C. Rieger. 2011. Prioritizing and Visualizing Energy Management and Control System Data to Provide Actionable Information for Building Operators. Western Energy Policy Research Conference, Boise, ID, U.S.: August 25–26

20 National Academy of Sciences (NAS). "Real Prospects for Energy Efficiency in the United States." National Academy of Sciences, Washington, DC. 2010

21 McKinsey & Company. "Unlocking energy efficiency in the US economy," June 2009. http://www.mckinsey.com/client_service/electric_power_and_natural_gas/latest_thinking/unlocking_energy_efficiency_in_the_us_economy. Accessed 13/03/2015

22 Regional Greenhouse Gas Initiative. 2012. "Regional Investment of RGGI CO2 Allowance Proceeds, 2012." http://www.rggi.org/design/program-review, Accessed 13/03/2015

23 Non-energy benefits from commercial and industrial energy efficiency pro-grams: Energy efficiency may not be the best story; Paper presented at the Energy program evaluation conference 2003, Seattle, Nick P. Hall & Johna A. Roth, Tec-Market Works, 2003

24 Jollands, N., Tanaka K., Gasc, E., Wescott, W., "Energy Management Action NetworK (EMAK)-A scoping study investigating the establishment and support of an international and domestic action network of energy management in industry", International Energy Agency, France, 2009

25 Granade, C., G., Creyts, J., Derkach, A., Farase, P., Nyquist, S., Ostrowski, K., "Unlocking Energy Efficiency in the U.S. economy", McKinsey & Company, USA, 2009

26 Christoffersen, L., B., Larsen, A., Togeby, M.," Empirical analysis of energy man¬agement in Danish industry", Journal of Cleaner Production, Vol 14 (5), 516–526, 2006

27 Thollander, P., Ottosson, M., "Energy management practices in Swedish ener¬gy-intensive industries", Journal of Cleaner Production, Vol 18 (12), 1125–1133, 2010

28 Thollander P., Palm J., 2012. Improving energy efficiency in industrial energy systems – an interdisciplinary perspective on barriers, energy audits, energy management, policies & programs. Springer. ISBN 978-1- 4471-4161-7

managing energy is lack of time, lack of resources, lack of knowledge and a primary focus on production.

Seow and Rahimifard[19] conclude that despite the number of commercial tools being used to track and monitor energy use in a factory and across various workstations, the detailed breakdown of energy consumption within various processes and, more

19 Y. Seow and S. Rahimifard, "A Framework for Modelling Energy Consumption Within Manufacturing Systems," CIRP Journal of Manufacturing Science and Technology, vol. 4, pp. 258-264, 2011

importantly, its attribution to total energy required for the manufacture of a unit product is not well understood.

1.4 Energy Efficiency Results

Where companies have engaged with energy audit and management scheme, good results have been reported, however the actual results are considerably smaller that the potential outlined above.

In Belgium, over 4,000 companies participated, between 2005 and 2014, in a voluntary Benchmarking and Auditing Covenant which is a state run programme on energy efficiency that targets medium sized enterprises. The analysis[20] of the results showed an 8–10% improvement in energy efficiency over the period. Of note, 59% of the energy saving measures stemmed from process-related activities.

In Sweden, a study[21] based on data from 58 industrial firms in the spring of 2012 returned an analysis that they had achieved an energy efficiency improvement of 12% on average. This stemmed from both technology and energy management measures and in absolute numbers provide energy savings of 1,100,000 MWh/year.

In the US, a New York State programme supports Energy Audits of large and medium industries through provision of 50% funding. The audits provide a prioritised list of quantified investment grade energy efficiency measures. Analysis[22] of 303 companies who participated in the programme showed that only 25% of the proposed measures were adopted within the first year. More promisingly, approximately 65% of the proposed measures were installed by the end of the 4th year and there was evidence that the audit report was still being used for guidance more than 6 years after delivery.

2 Industrial Energy Classification

2.1 Production versus facilities

The traditional approach to energy management tends to view a factory in terms of its functional units, i.e. production operations and facilities operations, see table 1. Responsibility for the cost of energy generally lies with the facilities function and thus the greatest focus on energy efficiency is driven by facilities. This is evident in research[23] which highlights the relative priorities of the different functions in industry.

Table 1. Traditional Approach to Energy Classification

Production Operations	Facilities Operations

[20] Cornelis E., Lessons learnt from two long-term agreements on energy-efficiency in industry in Flanders, Belgium. Proceedings of the ECEEE 2014 Summer Study on Energy Efficiency in Industry. Arnhem, 3-5 June 2014

[21] Backlund S., Paramonova S., Thollander P., Rohdin P., Karlsson M., A regional method for increased resource-efficiency in industrial energy systems, Proceedings of the ECEEE 2014 Summer Study on Energy Efficiency in Industry. Arnhem, 3-5 June 2014

[22] Perkins, J., & Maxwell, J., Energy audit impacts delivering sustained savings, Proceedings of the ECEEE 2014 Summer Study on Energy Efficiency in Industry. Arnhem, 3-5 June 2014

[23] Müller, E. and Löffler, T. 2009. Improving energy efficiency in manufacturing plants case studies and guidelines. In 16th CIRP International Conference on Life Cycle Engineering(LCE 2009), pages 465–471. Department of Factory Planning and Factory Management, Chemnitz University of Technology, Saxony, Germany

Production Machines	Electrical Utility Supply
In-process Heating	Heating, Ventilation and Air Conditioning (HVAC)
	Compressed Air
	Process cooling/Chilled Water
	Process / Di-ionised Water
	Process Heating /Steam Production
	Combined Heat and Power
	Canteen
	Factory Lighting
	Office Computing / IT Systems

An alternative approach[24] that views energy consumption in terms of how it impacts a product passing through a factory would suggest a different break-down of energy consumption with the costs more fairly assigned to the different functions, as in table 2 below. A clear decision point is whether that specific consumption of energy would be necessary if there is no active production.

A UNIDO working paper[25] classifies end-use energy consumption in the industrial sector as either Process or Generic. Process refers to energy used directly in the production process, whereas Generic refers to energy used for non-core applications such as heating, ventilation and air conditioning (HVAC), lighting and information technology. However, they state that the boundary between these two categories is not always clear.

Table 2. Product Centred Approach to Energy Classification

Production Operations	Facilities Operations
Process	Generic
Production Machines	Electrical Utility Supply
In-process Heating	Heating, Ventilation and Air Conditioning (HVAC)
Compressed Air	Combined Heat and Power
Process cooling/Chilled Water	Canteen
Process / Di-ionised Water	Factory Lighting
Process Heating /Steam Production	Office Computing / IT Systems

[24] Y. Seow and S. Rahimifard, "A Framework for Modelling Energy Consumption Within Manufacturing Systems," CIRP Journal of Manufacturing Science and Technology, vol. 4, pp. 258-264, 2011

[25] Sorrell S., Mallett, A,. and Nye, S., Barriers to industrial energy efficiency: a literature review, United National Industrial Development Organisation (UNIDO), Development Policy, Statistics and Research Branch, Vienna, 10/2011

As stated, there may be blurred divisions in some areas which in specific factories may warrant a variation on the proposed approach, e.g. vacuum extraction from production may be integrated with the overall factory ventilation systems or may be separated out as a significant production energy users in the case of a semi-conductor fab. The supply of chilled water may be integral to the facility HVAC and the operation of the CHP in terms of the heat availability may be directly linked to the need for heat in the production process.

The correct assignment of the significant energy users to the respective production operation is the first step in allocating the cost of energy consumed to the production function and to the specific value streams (VS). Management of specific energy consumption at a value-stream level present the opportunity for the value-stream manager and operators to have an input into the efficient operation of their area and to benefits from improvements they make in energy cost reduction.

A detailed review[26] of industrial facilities in Ireland showed that correctly attributing the direct and indirect energy consumption in a large high-volume manufacturing facility gave a split of 57% direct (process) energy consumption and 43% indirect (generic) energy consumption.

In a similar study[27] in the US the analysis states that the majority of energy at larger industrial sites is used by equipment that is associated with the manufacturing process.

2.2 Significant Energy Users (SEUs)

Manufacturing facilities, in addition to basic facility end uses, have a number of very specialized energy systems. Some of these – known as cross-cutting technologies[28] – are common to many or most industries while others are process- or industryspecific. The major cross-cutting technologies include compressed air, steam systems, fan and pump systems, process heating, process cooling, refrigeration, and specialized process space conditioning. Because of their prevalence and energy intensity these end-use systems have been the subject of considerable interest.

Various Sustainable Manufacturing projects are currently been run by medium to large industries to tackle the increasing cost of energy in production and to develop and disseminate best practice in energy management. Each of these projects has identified the critical energy consuming aspects of their industries or what are normally referred as Significant Energy Users (SEUs). These are listed in table 3 below.

The Industrial Innovation for Energy Efficiency (I2E2) Centre[29] is an Irish government sponsored Technology Centre, established to facilitate research which will have a direct impact on industry. The I2E2 research focus is on energy efficiency

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[26] Harrington, J., Cosgrove, J., & Ryan P., A Strategic Review of Energy Management Systems in Significant Industrial Sites in Ireland", Conference on Energy Efficiency in Industry, European Council for an Energy Efficient Economy (ECEEE). Arnheim, NL. 3-5 June 2014

[27] Epstein G., D'Antonio M., Neiman L., & Perkins J., Large industrials: serious engagement for deep savings, Proceedings of the ECEEE 2014 Summer Study on Energy Efficiency in Industry. Arnhem, 3-5 June 2014

[28] Sorrell S., Mallett, A,. and Nye, S., Barriers to industrial energy efficiency: a literature review, United National Industrial Development Organisation (UNIDO), Development Policy, Statistics and Research Branch, Vienna, 10/2011

[29] I2E2 – Industrial Innovation for Energy Efficiency, http://www.i2e2.ie/ Accessed 15/03/2015

improvements in factories, plant, equipment and buildings. Based on feedback from over 30 large industrial sites they have established priority areas for action including compressed air systems, HVAC, heat recovery and production machines.

The EU Intelligent Energy funded Project[30] entitled Sustainable Energy Savings for the European Clothing Industry (SESEC) is driven by the textile industry across Europe. They have identified the non-existence of partial energy meters as a common problem as typically only the main meters from the utility companies are present, i.e. only global energy is measured. They also state that companies are still suffering from historical low interest in energy efficiency mainly due to the low ratio of energy costs / total costs and low internal knowledge on this area.

The EU funded Project entitled SurfEnergy[31] - Path to Energy Efficiency is driven by the Electronics Assembly Industry across Europe. Their members have reported the largest savings in the development of waste heat and energy recovery, improvements to boilers and the use of CHP. They also point to the significant benefits from Energy systems integration and adoption of best practice.

In India, a report[32] on the best practices in energy efficiency adopted by the Indian manufacturing sector, sets out the most common energy efficiency measures and practices adopted between 2007 and 2011 by the automotive, cement and consumer goods manufacturing sectors. The most popular initiative involved the installation of VSDs on motors. Across all the energy saving measures implemented the average payback period was between 1.5 and 1.6 years.

The University of Daytona Industrial Assessment Centre (UD-IAC) is a comprehensive resource[33] for energy efficiency in manufacturing and industry. It contains over 100 assessment recommendations selected from over 900 industrial energy assessments performed by the UD-IAC since 1981. Their goal is to help small and medium-sized industries to reduce costs and stay competitive. Recipients of their assessments report saving an average of about 10 % on their energy costs.

As part of the TEMPO Project[34] in Ireland a detailed survey of the energy profile of six large manufacturing sites was undertaken. The study highlighted the exemplar energy efficiency projects completed by the companies between 2011 and 2013. The largest number of projects were undertaken on compressed air, HVAC and facility lighting.

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[30] SESEC, Sustainable Energy Savings for the European Clothing Industry (SESEC), http://euratex.eu/pages/sesec Accessed 20th January 2015.

[31] SurfEnergy - Path to Energy Efficiency, ec.europa.eu/energy/intelligent/projects/en/projects/surfenergy Accessed 20th January 2015

[32] Deshpande A., Kumar S., and Tulsyan A., An analysis of the best practices in energy efficiency adopted by the Indian manufacturing sector, Conference on Energy Efficiency in Industry, European Council for an Energy Efficient Economy (ECEEE). Arnheim, NL. Sept 2012

[33] University of Daytona Industrial Assessment Centre (UDIAC), https://www.udayton.edu/engineering/centers/industrial_assessment/index.php Accessed 20th June 2013

[34] Harrington, J., Cosgrove, J., & Ryan P., A Strategic Review of Energy Management Systems in Significant Industrial Sites in Ireland", Conference on Energy Efficiency in Industry, European Council for an Energy Efficient Economy (ECEEE). Arnheim, NL. 3-5 June 2014

In Canada, the state body - Natural Resources Canada - have produced an Energy Savings Toolbox[35] to guide industry on energy efficiency. Besides a focus on the SEUs below they also include a large number of measures in the building envelope. This in not as apparent in other studies and may have greater relevance in Canada due to their harsh winters.

Table 3. Critical Areas of focus / SEUs

I2E2	SESEC	SurfEnergy	India Industry	UDIAC	Tempo	Canada
Compressed Air Systems	Compressed air	Conserve Compressed Air	Com- pressed Air	Compressed Air	Compressed air systems	Compressed Air
HVAC	HVAC. Vacuum	Enclosed Hot Air Dryers		HVAC	HVAC	Heating and Boiler Plant
Low Grade	Heat (boiler		Waste heat	Combined	Direct	Process
Heat Recovery	and gas/fuel supply)		recovery	heat and power. Process heating. Steam. Fluid flow.	/indirect process heating. Steam production/system.	Heating /Heat Distribution. Hot Water Service.
Manufacturing Equipment	Production machines	Process Improvements operations and maintenance	Variable Speed Drives	Motor Drives	Direct process - machine drives	
	Lighting		Lighting control systems	Lighting	Lighting	Lighting
				Process cooling	Direct process – cooling /refrigeratio n	Cooling Plant /Cooling Distribution
		Reduce peak demand	Grid voltage regulation	Electrical		Electrical Power Distribution

[35] Energy Savings Toolbox – an Energy Audit Manual and Tool, Natural Resources Canada, http://www.nrcan.gc.ca/energy/efficiency/industry/cipec/5161, Accessed 10th January 2015

		Benchmark-ing	Energy efficiency awareness programmes			Food Areas
	Logistics		Renewable energy			Water Service

From this matrix it is possible to draw up a prioritised list of SEUs that industry should pay attention to in order to achieve energy reductions.

Generic Set of SEUs – Priority list

- Heating Systems for facility and provision of hot water/steam for production processes
- Compressed Air systems
- CHP and waste heat recovery
- Provision of chilled water and di-ionised water
- Facility internal and external lighting
- Electrical tariffs, structures and conversion/distribution
- Production machines and conveyors
- Operating Procedures / Employee Behaviour
- Air Conditioning / Vacuum Extraction

2.3 Electric Motors

Across many of the SEUs identified above, the primary conversion of electricity into mechanical force (pumps, fans, compressors, machines) is through electric motors and thus manufacturing industry should have a clear strategy on the use of energy efficiency motors, on the correct sizing of motors, on the use of variable speed drives (VSDs) and on the use of advanced control systems to optimise performance.

An International Energy Agency (IEA) report[36] shows that Electric Motor Systems account for between 43% and 46% of all global electricity consumption and there is potential to cost-effectively improve energy efficiency of motor systems by roughly 20-30%, reducing global electricity demand by up to 10%.

In a US study[37], it is estimated that three phase AC induction motors below 500 horsepower will consume 1,224 TWh of electricity in 2015, which represents about 30% of the total projected U.S. electricity use. The study shows that these motors are projected to represent 72% of the total electricity consumption of the industry sector.

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[36] Brunner, C., Waide, R.: Energy Efficiency Policy Opportunities for Electric Motor-Driven Systems, Working Pager, IEA, OECD, 2011, Paris

[37] US Dept of Energy .Annual Energy Outlook 2011. US Energy Information Administration, US Dept of Energy

An analysis[38] at 25 industrial and infrastructure plants in Switzerland has shown that 87.8 % of the total electricity consumption of a plant is due to motor systems. This high number may be due to the inclusion of infrastructure plants (Water / Waste Water treatment) where motive power is prevalent. This study also highlighted that in an analysis of 4,142 motors in use in these industries, over 50% of them were older than their rated operating life expectancy. On average, these motors were run twice as long as their expected lifetime. Less than 20% of the motors assessed had variable frequency drives to control their load and of a sample of 100 motors that were analysed in further detail, 68% were oversized compared to their load (average load factor below 60 %). The key barriers identified in failing to address motor energy efficiency in industry was that industrial users lacked human resources, time, responsibility, technical know-how and financial resources necessary for the implementation of motor systems efficiency projects.

3 Production Centered Energy Management

Production processes consume raw materials and transform them into products and wanted or unwanted by-products and use a significant amount of energy to do so. Some of this energy is used for value-added activities embodied into the form and composition of products, while the rest of the energy is wasted in terms of heat losses and emissions. Hence, manufacturing processes generate a significant environmental impact through energy consumption with related resource depletion and GHG emissions[39]. To understand the consumption of energy in a production environment, it is necessary to outline the energy flow within an industrial facility along with the classification of energy usage and its relationship to processes and production outputs.

Imported energy in the form of electricity, gas or solid fuels, for example, coal or peat, along with onsite renewable energy systems provide the primary energy source for a facility. Solid fuels, oil or natural gas are mainly utilised by energy transformation/generation systems such as boilers to generate heat for process and space heating. Electricity (both imported and generated) is used by energy transformation/generation systems mainly to run electric drives to generate mechanical energy. Typical applications include pumps, fans, air conditioning (chill generation, ventilation), and compressors. The energy carriers are the means by which energy moves through the facility, which include compressed air, hot/chilled water, electricity and steam. Energy utilisation systems are the end users of both the electrical and thermal energy. For example, equipment drives and motors use electricity and clean-lines use hot water. The energy drivers are the variables such as weather changes expressed in degree days and variation in production volumes/type which affect energy consumption[40]. The generalised model is shown in fig 1 below.

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[38] Rita Werle, R., Conrad U. Brunner, C., & Cooremans, C., Financial incentive program for efficient motors in Switzerland: lessons learned, Proceedings of the ECEEE 2014 Summer Study on Energy Efficiency in Industry. Arnhem, 3-5 June 2014

[39] Schmid, "Energieeffizienz in Unternehmen - Eine wissensbasierte Analyse von Einflussfaktoren und Instrumenten. ETH Zürich: vdf Hochschulverlag AG.," 2008

[40] E. Giacone and S. Mancò, "Energy efficiency measurement in industrial processes," Energy, vol. 38, pp. 331-345, 2012.

As an example of this energy flow and transformation, for a technical service such as compressed air, electricity (imported and/or generated from Solar/Wind Turbine) is used by a compressor (energy transformation) to generate compressed air (an energy carrier). The compressed air is used for a product cleaning operation and the main energy driver is production volume, as the use of compressed air will increase as the volume of production increases.

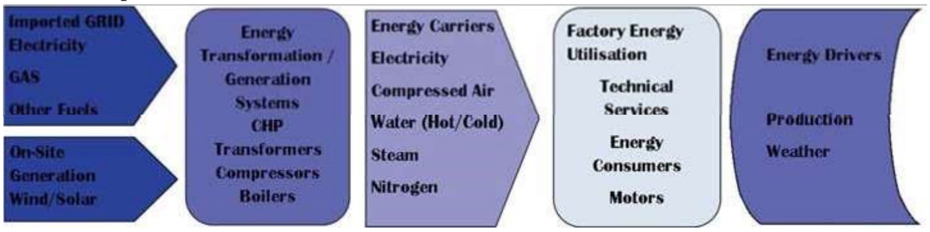

Fig. 1. Energy flows in an Industrial Facility

Previous research on manufacturing energy consumption has focused on developing more energy efficient machines/processes[41]. In one case study[42] the effective energy used to directly make the product in a metal processing factory was analysed as 48% of the total energy consumption and is referred to as an efficient production process. In another study[43] the energy requirement for the active removal of material was shown to be quite small compared to the background functions needed for the operation of manufacturing equipment. Drake et al. showed[44] that there are significant amounts of energy associated with machine start-up and machine idling. As a result, in a mass production environment, more than 85% of the energy may be utilised for functions that are not directly related to the production of parts.

This suggests that energy saving efforts, which focus solely on updating individual machines or processes may be missing a significant and perhaps a bigger opportunity. Hence a more holistic mapping of the relationship between production and energy consumption should be applied as research[45] also suggests that a lack of understating between production operations and energy usage prevents energy efficient decision making in real-time. With knowledge of the direct and indirect energy flows and their

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[41] NAM, "Efficiency and Innovation In U.S. Manufacturing Energy Use," National Association of Manufacturers, NAM2006

[42] S. Rahimifard, Y. Seow, and T. Childs, "Minimising Embodied Product Energy to support energy efficient manufacturing," CIRP Annals - Manufacturing Technology, vol. 59, pp. 2528, 2010

[43] J. B. Dahmus and T. C. Gutowsky, "An Environmental Analysis of Machining," in ASME international Mechanical Engineering Congress and RD&D Expo, Anaheim, California, USA, 2004

[44] R. Drake, M. B. Yildirim, J. Twomey, L. Whitman, J. Ahmad, and P. Lodhia, "Data collection framework on energy consumption in Manufacturing," in IEEE Annual Conference and Expo, Orlando, Florida, USA, 2006

[45] Y. Seow and S. Rahimifard, "Improving Product Design based on Energy Considerations, Glocalized Solutions for Sustainability in Manufacturing," in 18th CIRP International Conference on Life Cycle Engineering, Braunschweig, Germany, 2011, pp. 154-159

relationship to production activities it is possible to identify[46] the auxiliary (non-value added) energy within production where there may be significant potential for energy reduction. Developing a clear link between the temporal profile and/or efficiency of the energy consumption by the specific value stream can provide full transparency in the impacts (costs, emissions) of energy consumption and can provide positive feedback and cost reduction to reward improved performance by the value stream.

Currently, the skills and effort needed to identify and to describe the most important machines in a factory and to estimate their energy savings potential is described[57] as considerable – up to 10% of the energy budget before any saving is made. Top level analysis of energy usage, in some cases done purely at the utility bill or at a busbar level only identifies the amount of energy used. A time based energy profile of process level usage is required to support knowledgeable assessments of where improvements can be made throughout an organization while supporting the requirements of the business operations. The ability to identify and determine the impact of Significant Energy Users (SEU's) within an organization with detailed measurement of energy usage in real time can provide an awareness of the profiles and patterns of energy usage throughout a manufacturing or industrial process. Decision support systems and organization management are aided by the knowledge gained when evaluating the energy usage of process structures and components in a manufacturing environment whilst avoiding impact on production. The ability to link Production and Energy models is a vital link in the future application of demand side management to industry.

3.1 Monitoring and Targeting

Energy Efficiency begins with measuring energy consumption and continually revisiting those measurements. It is important to know the status of the current consumption profiles before taking improvement actions. However, in order to optimise the energy consumption, besides measuring energy consumption itself, it is important to observe process and activities leading to (higher than necessary) energy consumption. Therefore, it important to identify the most suitable approach to effectively monitor various manufacturing processes and correlate these measurements with the measured energy consumption data to identify what improvements in the processes could lead to reduced energy consumption.

Acquiring and using such context related knowledge is currently very time and cost intensive, for both users and vendors of industrial plants (machines/equipment), especially taking into account the recent trends in industry are demanding more flexibility (re-configurability) from manufacturing systems, leading to more dynamics in the manufacturing operation and consequently more difficulties in monitoring energy use patterns.

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[46] G. Mustafaraj, J. Cosgrove, M. Rivas, "A Methodology for Determining Auxiliary and Value-Added Electricity in Manufacturing Machines", International Journal of Production Research (Int J Prod Res), International Foundation for Production Research, Taylor & Francis, Sept 2015. (In Press).

57 Rita Werle, R., Conrad U. Brunner, C., & Cooremans, C., Financial incentive program for efficient motors in Switzerland: lessons learned, Proceedings of the ECEEE 2014 Summer Study on Energy Efficiency in Industry. Arnhem, 3-5 June 2014

This is especially a problem in flexible discrete manufacturing industry where interaction between the processes/production equipment and human operators leading to energy consumption variations is much more difficult to monitor compared to continuous process industry. The gathering of more detailed energy usage data requires a greater deployment of both standard sensing solutions (temperature, current, flow, etc) and additional sensing solutions such air-line pressures, compressor rpm, vibration, acoustics, etc.

A good Monitoring and Targeting (M&T) approach requires a structured definition of the energy sources mapped to the specific production line or plant. This may be done by process-flowcharting of the manufacturing process and integration of the sensing information on the flowcharts. The integration of the energy and work flow data in real-time gives a clear view of all of the energy paths through the process and gives a high visibility to the relevant energy sources that critically need to be metered. Thus, only the minimum necessary metering, allied with the use of temporary metering and datalogging, can be designed to have the least possible impact on production. In fact, a non-invasive approach to metering through clamp-on and external meters is vital in high volume production processes as any downtime required to fit meters is very expensive and generally not acceptable.

3.2 Energy Flows in Production Operations.

A review of methodologies[47,48] that categorise energy usage and energy efficiency in industry highlighted that industrial companies still lack appropriate methods to effectively address energy efficiency in a comprehensive and practical manner. This is primarily due to:

- The complexity of production sites that due to business needs, operate more than one production process.
- Production sites may produce various types of products, each with different energy intensity factors.
- Specific energy consumption depends on the production rate and Significant Energy Users (SEUs) are typically viewed in isolation from production operations rather than in conjunction with it (i.e. cycle time and energy usage analysed together to determine process SEUs).
- Comparing different installations (i.e. process equipment, technical services upgrades) using energy efficiency indicators can lead to misleading conclusions, when attempting to take all variables associated with energy efficiency into account.

47 K. Bunse, M. Vodicka, P. Schönsleben, M. Brülhart, and F. O. Ernst, "Integrating energy efficiency performance in production management – gap analysis between industrial needs and scientific literature," Journal of Cleaner Production, vol. 19, pp. 667-679, 2011/5// 2011

48 E. Giacone and S. Mancò, "Energy efficiency measurement in industrial processes," Energy, vol. 38, pp. 331-345, 2012

- The analysis of thermal energy is considerable more complicated in practice than the analysis of electrical usage.

3.3 Methodologies

Hermann et al proposed work that focused on the optimization of the process chain with the objective of securing the best electric energy efficiency. The study proposed a five step approach using a simulation model. These steps include; (1) Analysis of production process chain; (2) Energy analysis of production and its equipment; (3) Energy analysis of technical building services; (4) Load profile and energy cost/energy supply contract analysis; (5) Integrated simulation and evaluation of the production system. However, the work was not extended to an industrial facility or practical application.

Seow and Rahimifard[49] provide a product perspective of energy monitoring and attribute the energy consumed by the product to both the process and the plant. They describes the 'product' viewpoint and the methodology for using energy consumption data at 'plant' and 'process' levels to provide a breakdown of energy used during production. The approach of using a 'product' viewpoint is very much in line with the now standard approach of 'Lean' manufacturing. This approach postulates that Energy consumption in manufacturing can be categorized into Direct Energy (DE) and Indirect Energy (IE), which constitute the embodied energy of a product. DE is the energy required to manufacture a product in a specific process and can be subdivided further into theoretical energy (TE), the energy necessary for actual value creation and auxiliary energy (AE), the energy required by supporting activities for the individual machine/process. Indirect Energy (IE) is defined as the energy necessary to maintain the production environment (lighting, heating /ventilation). This approach has been extended further in table 4 below to outline the Energy Management Opportunities (EMOs) that exist at each level.

The proposed energy breakdown also draws particular attention to the auxiliary energy usage, and the potential areas in the factory where energy efficiency measures can be introduced. This allows decisions makers a more holistic view of energy usage in an industrial facility, with more focus on the potential for reduction. For mature factories where the low-hanging fruit of Tariff Structures, Lighting and VSDs have been addressed the most obvious 'sweet spot' for cost reduction is to address auxiliary energy consumption through change in operations and behaviours.

Table 4. Industrial Energy breakdown

Primary Energy		Energy Breakdown	Focus Areas	EMOs	Potential for Savings

[49] Y. Seow and S. Rahimifard, "A Framework for Modelling Energy Consumption Within Manufacturing Systems," CIRP Journal of Manufacturing Science and Technology, vol. 4, pp. 258-264, 2011

Industry Primary Energy	Direct Energy (DE)	Value-Added Energy (VAE)	Mechanical Processes. Thermal Processes.	New Equipment Re-using waste heat	5-10% Reduction, Capital Investment required
		Auxiliary Energy (AE)	Operations Idle Equipment Air/Water Human Factors	Operational & Behavioural Changes	20% Reduction Low/No Cost Initiatives
	Indirect Energy (IE)		HVAC Lighting Grid	New Facility Design / Retrofit. Demand Side Management (DSM)	5-10% Reduction, Capital Investment required

Information from an industry study[50] in Ireland established that the relative percentage of direct versus indirect energy usage on a large manufacturing sits was 57% (DE) to 43% (AE) respectively. In other words 57% of the energy consumption went towards making the products and 43% of the total energy consumption went towards supporting the production environment. The direct energy usage was then analysed into either the value added energy or the auxiliary energy. In this case study, the value added energy accounts for 31% of overall energy usage and the auxiliary energy accounts for 26% of overall energy usage. The flow of energy in the SEUs and the approximate direct, (value added and auxiliary) and indirect energy usage is diagrammatically represented using a Sankey diagram in figure 2 below.

[50] Harrington, J., Cosgrove, J., & Ryan P., A Strategic Review of Energy Management Systems in Significant Industrial Sites in Ireland", Conference on Energy Efficiency in Industry, European Council for an Energy Efficient Economy (ECEEE). Arnheim, NL. 3-5 June 2014

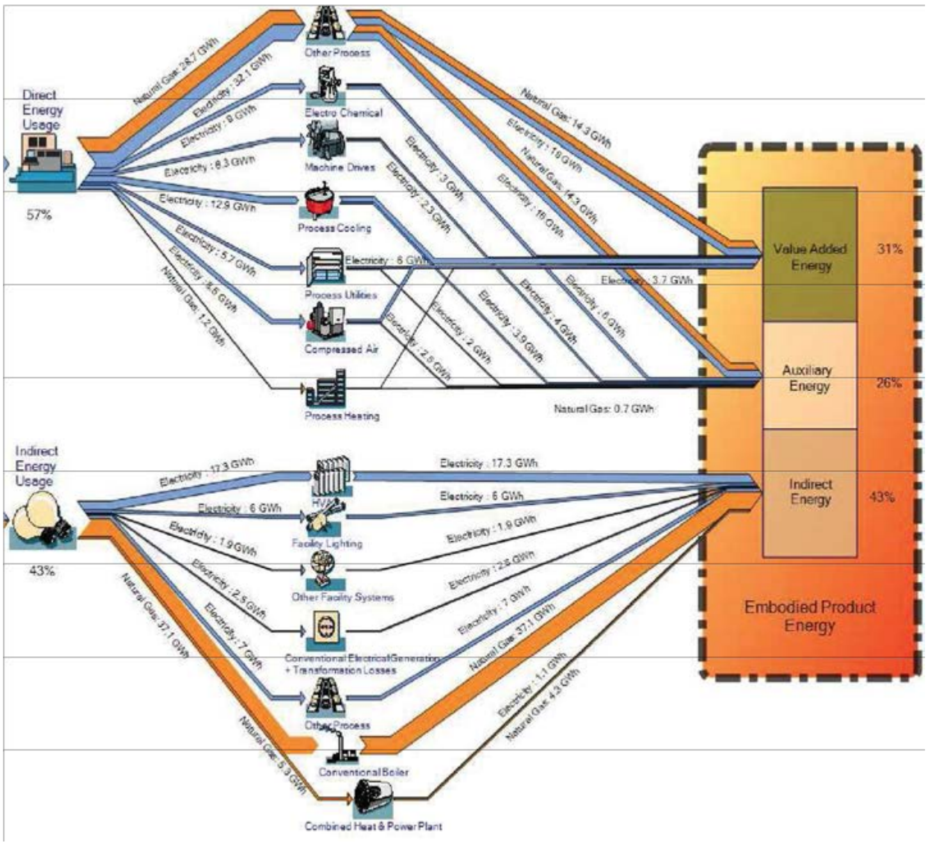

Fig. 2. Sankey Diagram showing the Flow of Energy per SEU and Categorised into Value Added, Auxiliary and Indirect Energy.

4 Value Stream Mapping

4.1 Lean Energy Management

The earlier review of methodologies that categorise energy usage in industry highlighted that companies still lack appropriate methods to effectively address energy efficiency in a comprehensive manner. The approach proposed here introduces a practical process mapping methodology that combines energy management with value stream mapping that can clearly link the provision of technical building services (Air/Water/Steam) to the production requirements. The methodology is non-complex, applies lean manufacturing principles and upon application to a medical device discrete manufacturing facility was successful in identifying the relationship between the energy usage and production activities for a particular value stream.

Energy Management focuses on the systematic use of management and technology to improve energy performance in a selected site. It requires that energy procurement, energy efficiency and renewable energy be integrated, proactive and incorporated in order for it to be fully effective[51]. Value Stream Mapping (VSM), a widely used tool of Lean Manufacturing, is a type of symbolic model that graphically enables the end user to observe the material and information flow as product or service travels through a value chain[52]. The model represents the flow of resource such as materials, information and personnel along with their interactions through a production chain. It specifies activities and cycle times and also identifies value-added and non-value added activities in the process. It allows the visualisation of all the manufacturing system, rather than just the equipment.

Wormak and Jones[53] suggest that five principles of the Lean thinking philosophy are required for value stream mapping. Firstly, value must be defined; providing the customer with the right product or service, at the right time and price, as determined in each case by the customer. Secondly, the value stream must be determined; specifying particular activities needed to design order and distribute a specific product from concept to launch. Thirdly, tasks must be designed so that through progressive achievement, stoppages, scrap and backflow are eliminated. Fourthly, the "pull system"; a system designed to where nothing is produced by the upstream supplier until the downstream customer requires it, must be implemented. Finally, the target of complete elimination of waste should be constantly reviewed with the aim that all activities across a value stream must only create value.

The use of VSM and energy management is present in literature and has been trialed in certain industries in the US[63]. An example of this is the work carried out by the US Environment Protection Agency in the development of the "Lean, Energy and Climate Toolkit"[54]. This provides strategies and techniques to improve energy and environmental performance in tandem with achieving leans goals such as quality, reduced waste and improved customer responsiveness. Despite the fact that it provides detailed information in relation to lean principles, energy monitoring and targeting, and green-house emissions management, the output tool is still quite complicated and prior knowledge of VSM is required to understand and use it.

Based on the principle that VSMs serve as a magnifying glass to view the whole manufacturing system, Fraizer et al[55] has proposed the use of the "concept of value" and the VSM tool as a means of determining energy consumption in a current state. In particular, the work focuses on determining energy characteristics of the process.

Paju et al suggest the concept of Sustainable Manufacturing Mapping (SMM). This is based on the combination of VSM, Life Cycle Assessment (LCA) and Discrete Event Simulation (DES) to provide a highly visual model that allows for the assessment of sustainability indicators in manufacturing. The main outcomes are goal definition, identification for sustainability indicators, and modelling of current and future state process maps. Despite the robustness of SMM work, the main challenges observed are

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[51] Carbon Trust, "Energy Management- A comprehensive guide to controlling energy use,", 2011. http://www.gbc.ee/710eng.pdf Accessed 15/03/2015.

[52] C. Keskin and G. Kayakutlu, "Value Stream Maps for Industrial Energy Efficiency," in PICMET'12: Technology Management of Emerging Technologies, Vancouver, Canada, 2012, pp. 2834-2831

[53] J. P. Wormack and D. T. Jones, Lean Thinking. New York, NY: Simon & Schuster, 1996.

[54] EPA, "Lean, Energy, and Climate Toolkit," U. S. E. P. Agency, Ed., ed, 2011.

[55] R. C. Fraizer, "Bandwith analysis, lean methods, and decision science to select energy management projects in manufacturing," Energy Engineering, vol. 105, 2008.

the idea that a goal-oriented approach can be quite complicated, as the assessment does not use the same indicators every time to carry out an evaluation. In larger multinational companies, where each VS or SBU operate as "small factories" it could be difficult to compare performance against one another, or even set targets for the company as a whole if the indicators are not shared across the board.

Due to the complexity and prior knowledge of particular techniques for the application and implementation of the above methodologies, the process mapping methodology proposed in this chapter follows the basic principles of Value Stream Mapping and encompasses the concept that production is multidimensional and that system dynamics are critical to the evaluation of a production area. It also includes both direct and indirect factors that affect energy efficiency in production operations.

4.2 Mapping Methodology

The primary aim of the proposed process mapping methodology is to effectively acquire production and energy data from a production environment that could be modelled to provide both steady-state and dynamic energy consumption and potentially provide a multi-dimensional hierarchical view of this energy consumption and cost directly related to production equipment.

The proposed methodology to acquire such data was designed around the following principles:

- The methodology is not related or restricted to a specific case but generic in nature and applicable to diverse manufacturing types (i.e. continuous and discrete).
- The methodology pursues a holistic perspective of the relationship between manufacturing processes and energy consumption, including all relevant process and energy flows as well as their interdependencies.
- The methodology is flexible so that it can be applicable to small and medium sized enterprises typically facing obstacles towards energy efficiency measures and usage of simulation.
- The methodology provides multi-dimensional evaluation of improvement measures in all relevant fields of actions.
- The methodology can adapt to an ever changing production environment such as equipment relocation or process improvement.

The methodology consists of five main steps;

1. Process Step Identification,
2. Equipment Identification,
3. Determination of Significant Energy Users,
4. Technical Services Identification and
5. Data Collection Availability.

These steps are generally applied to one value stream or strategic business unit to create a process map but can be scaled up and/or aggregated to factory level, providing the overall production process and energy usage of a factory.

1. Process Step Identification

Each process step in the production chain is identified and labelled according to production specifications or internal factory documents. Both the throughput (i.e. batch size) and the cycle time for each process step for each unit of manufacturing (i.e. cycle time/batch) is identified. Differentiation between automated and manual steps is highlighted, as manual steps are not considered unless determined to have a significant impact.

2. Process Equipment Identification

The equipment used for each process is then identified along with the quantity of equipment per step. This is critical as there may be a one-to-many relationship between the process step and process equipment although generally each product will only take one path through the process. Process equipment energy consumption data is then collected. The electrical consumption provided by the manufacturer (typically referenced on the equipment plate or manuals) should be collected, as well as any thermal energy usage (i.e. gas to generate process heat).

3. Determination of Significant Energy Users

Based on the cycle time and the energy consumption data of each item of equipment, a list of process SEUs can be determined. It is critical to take into account the accurate cycle times, as the machine rating alone may not be suitable to assess the scale of the energy consumption involved from a product perspective.

4. Technical Services Identification

It is necessary to identify the technical services (compressed air, water, steam, nitrogen, dust extraction, etc.) used by each process step. These services require both electrical and thermal energy and should be accounted for as part as the energy usage of the process. As specific metering at the process step is not usually available, a method of allocating consumption of the technical services across the value stream must be developed.

5. Data Collection Availability

It is necessary to identify if there is sub-metering available at process level for both electrical and thermal energy. If energy meters are installed at this step then information can be gathered from the energy monitoring system. If meters are not in place, then it may be possible to use control information from variable speed drives (VSDs) or programmable logic controllers (PLCs) on the machines or to deploy sensors that can gather data on the behaviour of the process (cycle time, temperature, etc).

By applying the above five steps to a production environment, the relationship between production and the energy consumption in the technical services and process steps is highlighted. This can be used to understand how manufacturing activities function within an industrial facility and how energy and manufacturing are interrelated. It also identifies the true significant energy users for a particular process and can highlight both the value added and auxiliary energy, where energy optimisation and reduction techniques can be applied. A sample high level process map carried out on a value stream is outlined in figure 3.

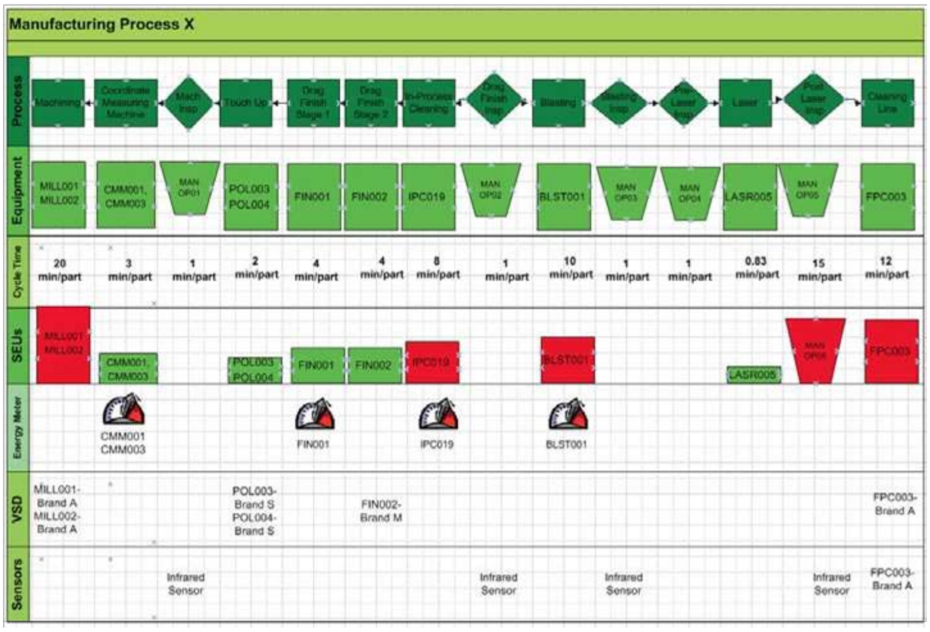

Fig. 3. Process Mapping Methodology Output- Visual Representation

As is clear in row 4, the items in red represent Process SEUs and their respective size reflects the scale of the energy consumption. Row 5 show the existing meters available and it is clear that not all the SEUs are appropriately monitored. Additional rows can then be added to reflect the different cross-cutting or technical services that apply at each significant production step.

The method is one that can be updated easily to reflect changes in the production environment and to provide a holistic view of the energy and technical services in the context of the varying production activity.

5 Conclusion

The chapter describes the background to energy usage in production operations and sets out some principles, process steps and methods to provide a more holistic view of the Significant Energy Users (SEUs) and the related consumption of energy and technical services (Air, Water, etc).

Sustainable Manufacturing (SM) is the new paradigm for manufacturing companies and involves the integration of all relevant dimensions that affect or have effects on third parties while conducting manufacturing operations, including energy, environmental impact and life-cycle analysis. Roadmapping exercises with European Industries have described the smart sustainable factory of the future will be one where there is full integration between the production activity and the associated energy used and where the operation of the factory can be optimised around its energy and ecological impact.

Potential reductions in energy consumption of 20% and in GHG emissions of 30% have been identified on industrial sites where there is an in-depth understanding of energy flows in the manufacturing process and a clear analysis of energy usage. However multiple studies have found that actual savings of 10-12% are more likely due to identified barriers such as; lack of time, lack of resources, lack of knowledge and a primary focus on production. Some changes in industrial practice is required to achieve the full potential savings that are available, including the analysis of NonEnergy Benefit (NEBs) which can be worth up to 2.5 times the energy efficiency improvements alone.

A model based on direct and indirect energy analysis from a 'product' viewpoint has been extended to identify waste or auxiliary energy in line with 'Lean' principles in manufacturing. The methodology outlines the process flow, energy metering requirements, the technical utilities servicing the process and an identification of the significant energy users. In large industrial facilities it has been shown that up to 60% of energy consumption is directly consumed in production activities, although of this, it has been shown that anywhere from 52–85% of the energy may be used for functions that are not directly related to the production of parts. In one application on an industrial site in Ireland, auxiliary energy of 26% was identified. This auxiliary energy identified represents the best opportunity to gain energy savings through operational and behavioral changes at the lowest possible cost.

The key energy consumers (SEUs) that need close attention on industrial sites normally includes the following;

- Heating Systems for facility and provision of hot water/steam for production processes
- Compressed Air systems
- CHP and waste heat recovery
- Provision of chilled water and di-ionised water
- Facility internal and external lighting
- Electrical tariffs, structures and conversion/distribution
- Production machines and conveyors
- Operating Procedures / Employee Behaviour
- Air Conditioning / Vacuum Extraction

In addition, due to the significance (over 70%) of electricity consumption in motive power and potential savings of 20-30%, industry should have a clear strategy on the use of energy efficiency motors, on the correct sizing of motors, on the use of variable speed drives (VSDs) and on the use of advanced control systems to optimise performance.

Developing a clear link between the temporal profile and/or efficiency of the energy consumption by the specific value stream can provide full transparency in the impacts (costs, emissions) of energy consumption and can provide positive feedback and cost reduction to reward improved performance by the value stream. The ability to link Production and Energy models is also a vital link in the future application of demand side management to industry.

The proposed process mapping methodology (Value Stream Mapping (VSM)) effectively acquires production and energy data that could be modelled to provide both steady-state and dynamic energy consumption and potentially provide a multidimensional hierarchical view of this energy consumption and cost directly related to production equipment. The approach of using a ‘product’ viewpoint is very much in line with the now standard approach of ‘Lean’ manufacturing and the method is one that can be updated easily to reflect changes in the production environment and to provide a holistic view of the energy and technical services in the context of the varying production activity.

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