A Review Paper on Comparison between Energy Efficiency Measures Employed in Indian Energy Intensive Industries with Rest of the World

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Abstract: ***Energy is the most fundamental and essential requirement for the survival and growth of all living things on earth. Energy has been recognized as one of the key inputs for the economic growth and social development of a country. However, for both social and economic purposes the energy usage needs to be optimized. In industries, energy consumption is measured as specific energy consumption (SEC) (energy/product). In order to reduce the SEC, it is necessary to have awareness about the modern technologies used in industries. In recent times India has become one of the biggest producers of textiles, cement, chemicals, etc. and other industrial outputs. In this paper, a comparison of specific energy consumption in various energy intensive industries of India with what is prevalent internationally. Moreover, various the energy saving measures for industries falling under PAT scheme IV are described, which can reduce the overall specific energy consumption for that industry. At last, the reasons why SEC for Indian industries are higher than rest of the world are provided. After analyzing all the data, it is concluded that except cement sector, in all the energy intensive sectors under PAT scheme IV, Indian industries still have to work on reduction of its' SEC by applying various energy efficiency measures and adopting latest technologies.***

Keywords: Specific Energy Consumption, Energy Efficiency, Energy Intensive Sectors

1. Introduction

Energy is the most fundamental and essential requirement for the survival and growth of all living things on earth. Energy has been recognized as one of the key inputs for the economic growth and social development of a country. Nowadays, energy requirement has been increasing day by day due to rapid industrialization, rising urbanization, technology progress and socio - economic development.

Energy intensity is defined as the energy consumed per unit output in the context of the industrial energy practice, which is called specific energy consumption (SEC). Also, it is the key determinant of the projection of the energy requirement in future. Energy efficiency is inversely related to the energy intensity. Energy intensity is the amount of energy used to produce given level of output. So, it is important to find intensity to show the energy consumption in industries and its conversion to the product or the economy of the country. The aim of the paper is to review SEC for various sectors and compare SEC for these sectors within India and worldwide average. This paper compares the energy consumption structure of Indian energy intensive industries to foreign industries at global level and also depicts the global energy demands trends.

Thereare10 industries, which are top energy intensive industries in India in terms of energy consumption [2].

- Aluminum,
- Cement
- Chlor alkali
- Fertilizer
- Iron and Steel
- Pulp and Paper
- Textiles
- Thermal power stations
- Commercial buildings (hotels)
- Petroleum Refinery

In this paper, SEC of these industries in India and world is compared and energy efficiency measures employed in these industries in India are also described.

1.1 Global energy demand

Global energy consumption in 2020 increased at nearly twice the average rate of growth since 2010, driven by a robust global economy and higher heating and cooling needs in some parts of the world. Fuel demand of the world has been increased from all the types of sources. Even renewable sources such as solar and wind registered two - digit growth. Demand of higher electricity was responsible for over 50% growth in energy requirement. From **Figure 1**: Average annual global primary energy demand growth by fuel, 2010 - 20 [3], it can be seen that gas and renewable sources were the major energy sources in the world which accounted for a supply of nearly 125 Mtoe (ton of oil equivalent) and 75 Mtoe of energy respectively.

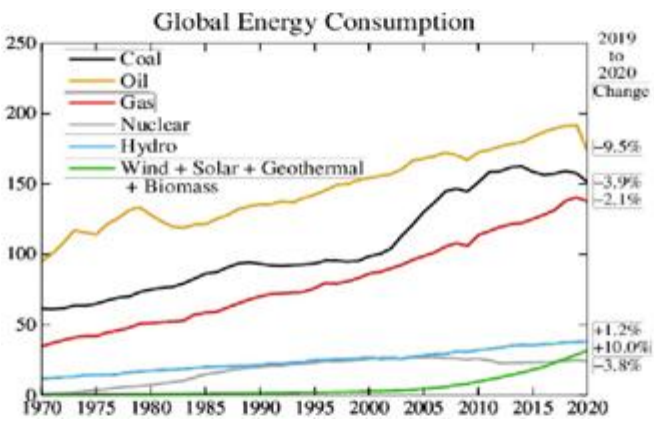

Figure 1: Average annual global primary energy demand growth by fuel, 2010 - 20 [3]

Over the 25 years, worldwide industrial energy consumption is projected to grow from 51, 275 ZW in 2006 to 71, 961 ZW in 2030 by an average of 1.4% per year which can be seen in the **Figure *2***: World industrial energy consumption comparison by fuel in 2006 and 2030 (ZW) [1] [1].

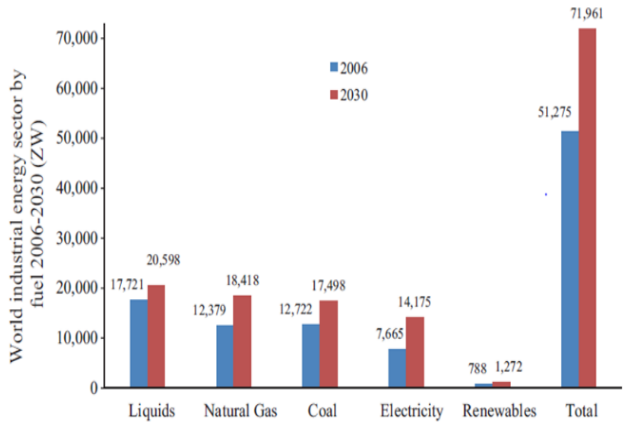

Figure 2: World industrial energy consumption comparison by fuel in 2006 and 2030 (ZW) [1]

1.2 Energy demand in India

In India, as per central statistics office of India, the industries in India meets their energy requirement mainly using coal, crude petroleum, electricity, natural gas and lignite where coal accounts for 43% and crude and electricity account for 35% and 13% respectively. Annual energy consumption? Moreover, in economic year of 2016 - 17, energy consumption is increased by 3.32% [2].

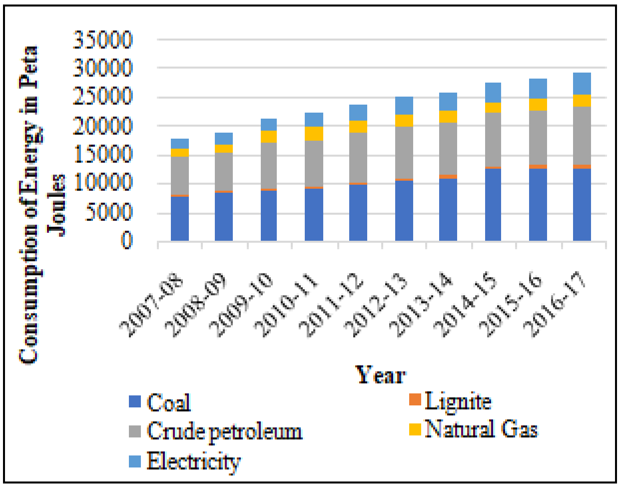

Figure 3: Trends in comparison of energy sources in India

2. Comparison of SEC of industries between India & World

The SEC of 8 major energy intensive industries which are covered under the PAT scheme by Bureau of Energy efficiency (BEE) in India is compared to the rest of the world. This comparison is vital for understanding of trend in various countries and also for further improvement in energy consumption.

2.1 Cement Industry

The SEC in cement industry is measured in electrical energy consumption and thermal energy consumption. World average for both the SECs are 100 - 110 kWh/ton of cement and 850 - 860 kcal/ton of clinker respectively. On the other hand, as per status paper on alternative fuels and raw materials (AFR) usage Indian cement industry by Confederation of Indian Industry [4], in India the average of both the SECs are 76 kWh/ton of cement and 740 kcal/ton of clinker respectively. The best practices in India shows these values as 77 kWh/ton of cement and 680 kcal/ton of clinker [4].

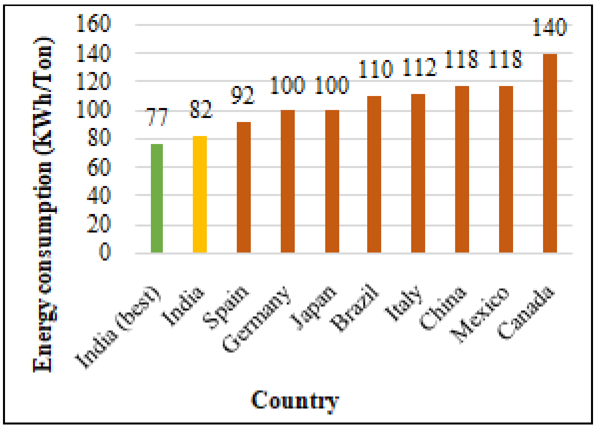

Figure 4: Electrical energy consumption in cement industry (kWh/ton of cement) [4]

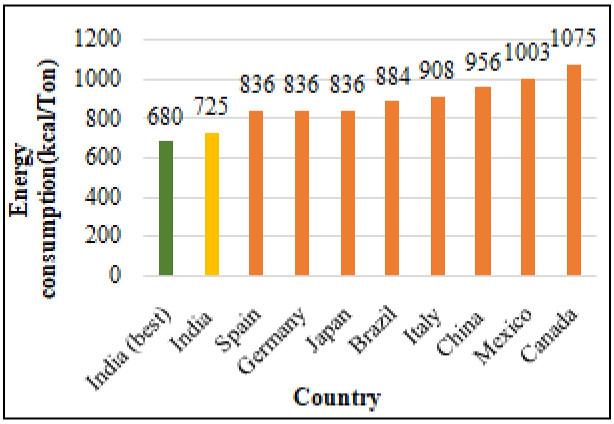

Figure 5: Thermal energy consumption in cement industry (kWh/ton of clinker) [4]

2.2 Iron and Steel Industry

The specific energy consumption in Iron and Steel industry in India and other developed countries are illustrated in

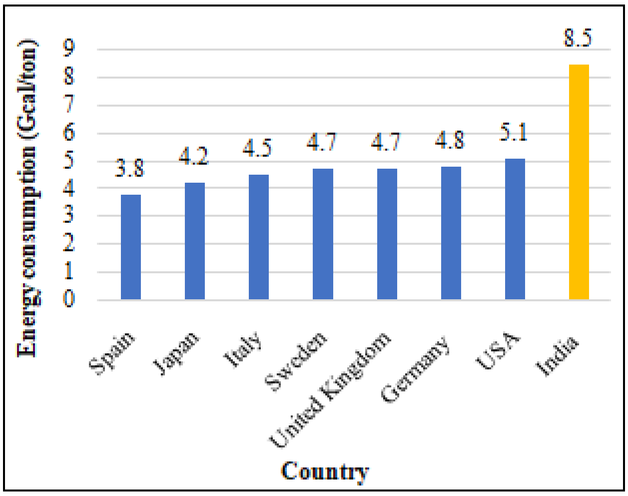

Figure 6: Specific energy consumption in iron & steel industry (GCal/ton) [5]Average SEC for iron & steel industries in India is 8.5 Gcal/ton, which is significantly higher than the developed countries. As shown in

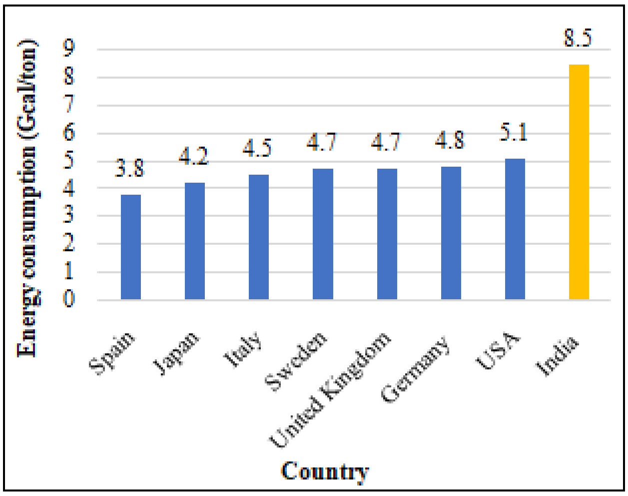

Figure 6: Specific energy consumption in iron & steel industry (GCal/ton) [5], Spain has the best SEC in iron & steel industries (3.8 Gcal/ton), which is lower than the half of the average SEC of Indian iron & steel industries [5].

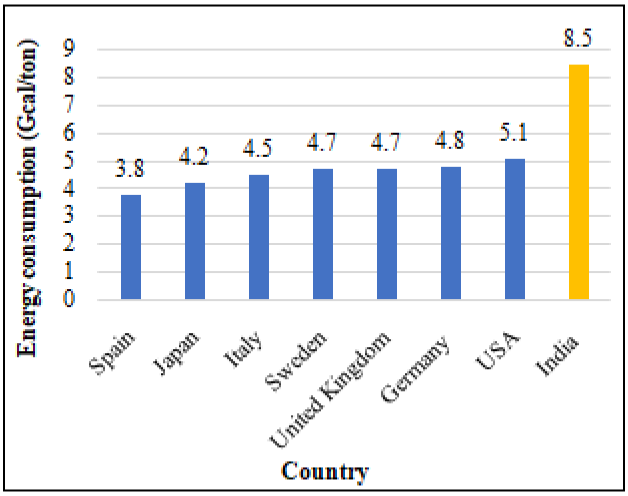

Figure 6: Specific energy consumption in iron & steel industry (GCal/ton) [5]

2.3 Aluminum Industry

As per International Efficiency Agency, global energy intensity of aluminum smelting process is 14, 154 kWh/Ton while for alumina refining process is 11, 564 MJ/Ton. Furthermore, world average SEC for entire manufacturing process of aluminum is 1.4932 Toe/ton. As per PAT scheme cycle 1, Indian average SEC for entire aluminum manufacturing process is 1.972 Toe/ton. Aluminum manufacturing process contains two major steps which are Alumina refining and smelting process. Comparison of SECs of both the processes in India and world is given in

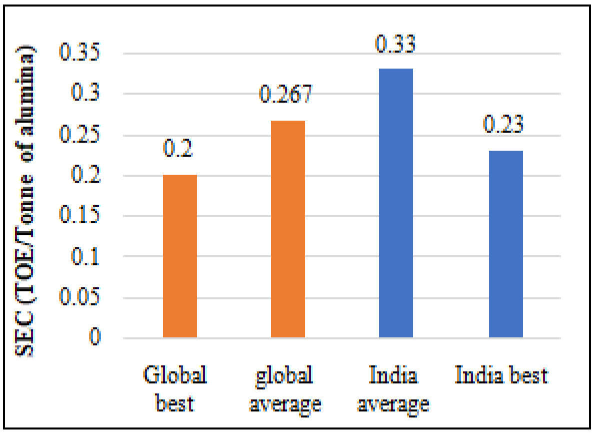

Figure 7: Specific energy consumption of alumina refining process (Toe/ton) [7].

Average SEC of Indian aluminum industries is 0.33 Toe/ton of alumina which higher than the world average which is 0.267 Toe/ton of aluminum. The best SEC achieved by the particular Indian aluminum industry is also higher than the best in the world but lower than the world average [7].

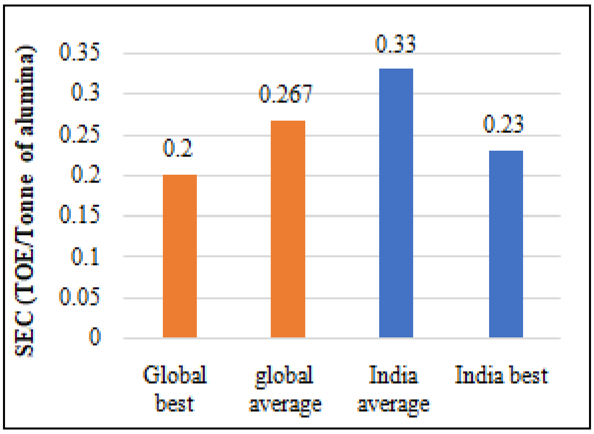

Figure 7: Specific energy consumption of alumina refining process (Toe/ton) [7]

2.4 Paper and pulp Industry

The average specific energy consumption of Indian pulp & paper industries is 52 GJ per ton of paper produced from which electrical energy consumption is 5 GJ per ton of paper [6]. Based on raw material, mainly 4 types of paper mills are producing papers such as wood based, agro based, recycled fiber based producing unbleached grades and recycled fiber based producing bleached grades. Maximum and minimum SECs for paper production using various raw materialsof India and world is compared in

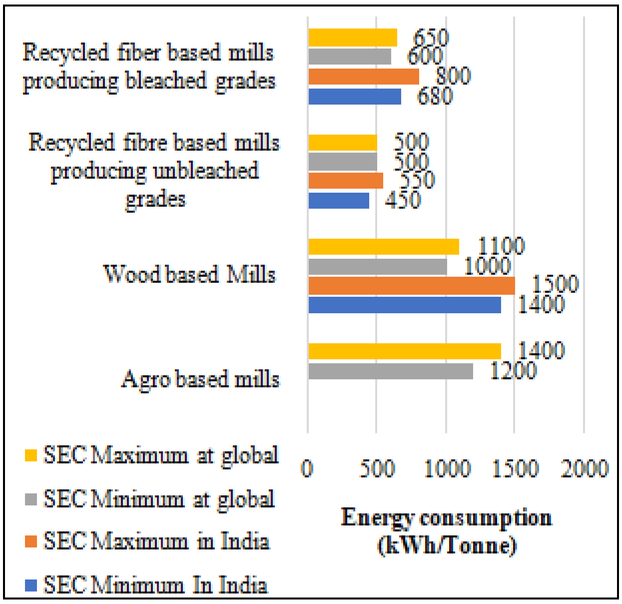

Figure *8: Specific energy consumption of paper production (kWh/ton)* [7]. From

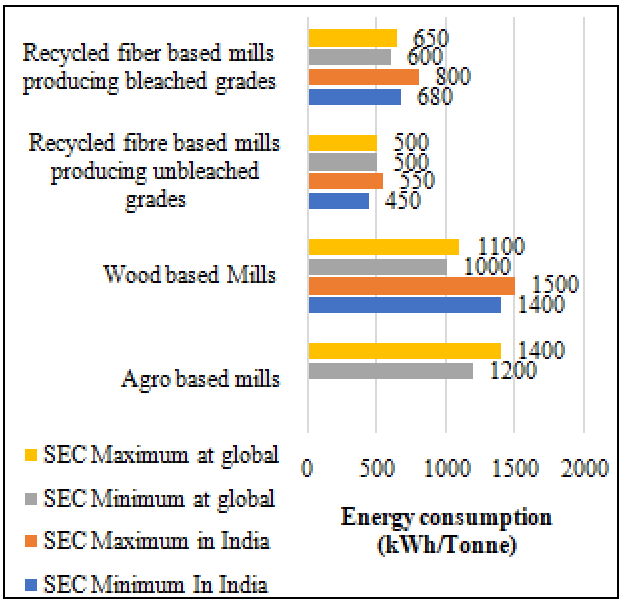

Figure *8: Specific energy consumption of paper production (kWh/ton)* [7]it can be seen that wood based and agro based paper industries are consuming higher amount of energy compared to the recycled fiber - based industries as SEC for recycled fiber - based industries is less than half of the SECs of the wood and agro based industries [7].

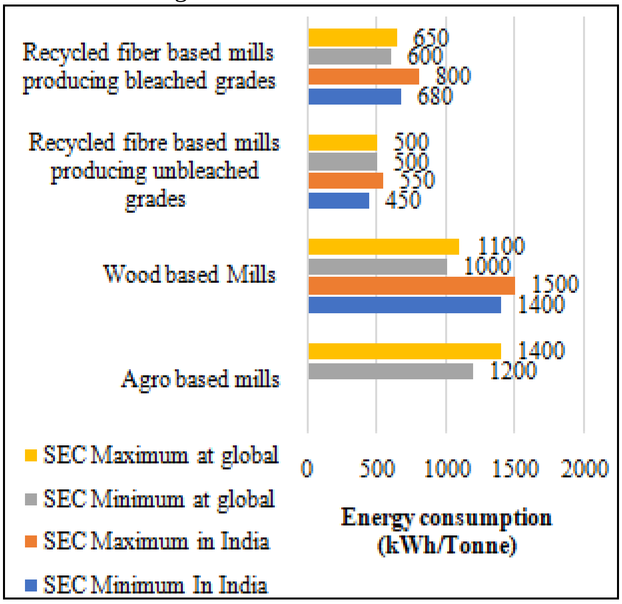

Figure 8: Specific energy consumption of paper production (kWh/ton) [7]

2.5 Fertilizer Industry

Urea and ammonia are the major products of fertilizer industry and comparison of the SECs for the production of urea and ammonia in India and world is shown in

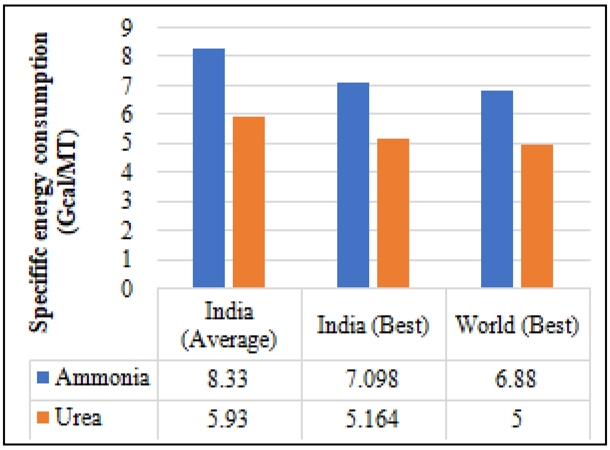

Figure *9: Specific energy consumption of fertilizer industry (Gcal/ton)* [8].

As per figure, average SECs of ammonia and urea production in India are 8.33 and 5.93 Gcal/ton respectively. Plant running at best efficiency in India has SECs of 7.098 and 5.164 Gcal/ton for ammonia and urea respectively which is higher than the SEC of plant running at best efficiency in the world.

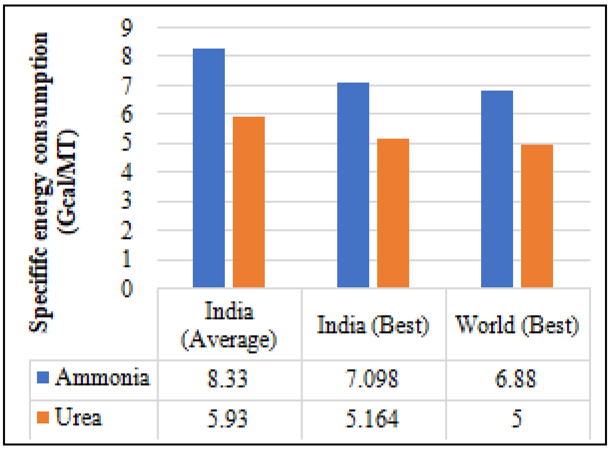

Figure 9: Specific energy consumption of fertilizer industry (Gcal/ton) [8]

2.6 Chlor - Alkali Industry

Soda ash and caustic soda are the major products of fertilizer industry and comparison of the average SECs for the production of soda ash and caustic soda in India and world is shown in

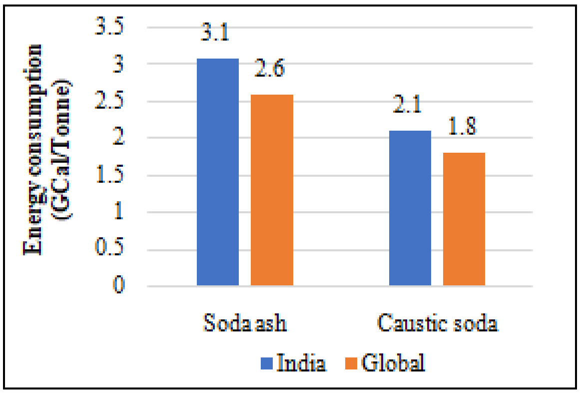

Figure 10: Average specific energy consumption of chlor - alkali industry (Gcal/ton).

As per

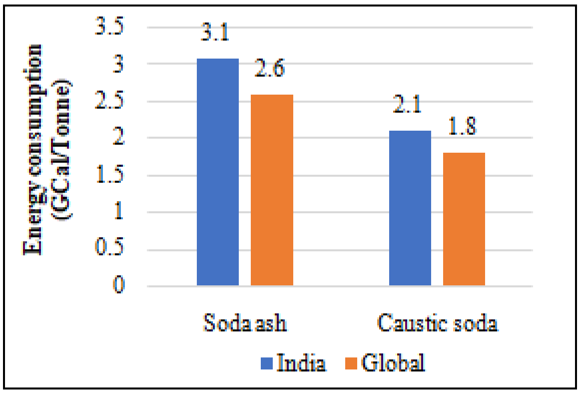

Figure 10: Average specific energy consumption of chlor - alkali industry (Gcal/ton), India is lagging behind the world in terms of SEC of the soda ash and caustic soda production. SEC values for soda ash and caustic soda production in India are 3.1 and 2.1Gcal/ton respectively whereas for world those values are 2.6 and 1.8Gcal/ton.

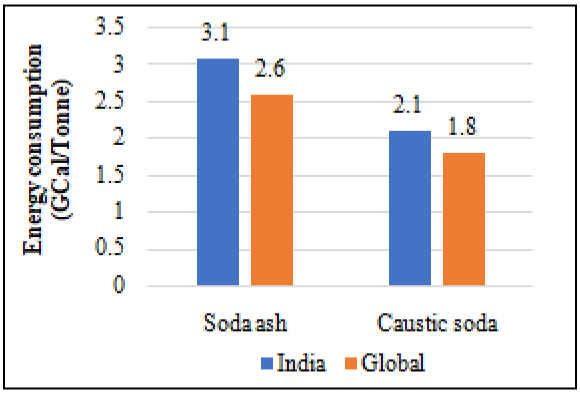

Figure 10: Average specific energy consumption of chlor - alkali industry (Gcal/ton)

2.7 Textile Industry

Total energy consumption of textile industry in India is 1.8616 million Toe. As per PAT the average energy consumption of all the plants for baseline period of PAT (year 2007 - 08 to 2008 - 09) is 1.2059 million Toe. According to Shakti Sustainable Energy Foundation the energy consumption benchmark for Indian textile industries is as below.

Table 1: Energy benchmark given by shakti foundation in FY - 2017 - 18for India in various division in textile industry

Section	Energy consumption
Spinning	3 – 3.5 kWh/kg of yarn
Weaving	2.9 – 3.1 kWh/m^3
Knitting	0.09 – 0.2 kWh/kg of fabric
Dyeing	Electrical: 0.04 to 0.15 kWh/ kg of fabric Thermal: 4 – 9 kg of steam/ kg of fabric

2.8 Thermal power plants

The total energy consumption of all the power plants which are included in PAT scheme is 30000 Toe. In India, SECs for thermal power stations are varies from 1774 kcal/kWh to 5134 kcal/kWh and plant efficiency varies from 16.7% to 48.5%. By improving average efficiency in India from 30% to 35%, 52 million tons of coal can be saved [9]. As per report of national productivity council, India, specific energy efficiencies in coal based thermal power plant is tabulated below [10].

Table 2: Heat rate in thermal power plant in India [10]

Category (MW)	India's average (kcal/kWh)	India (Best operation) (kcal/kWh) (2013 - 2014)
150 and below	2755	2528
150 - 240	2592	2314
250 - 500	2430	2216
500and above	2358	2358

2.9 Commercial buildings (Hotels)

Electricity is the primary energy source, which is used to power HVAC, lighting, vertical transportation, and almost all equipment. Gas is mainly used for cooking and boilers, but due to more availability of gas for commercial use for power generation as well.
In hotels where only electricity and gas is consumed, the average proportions of two fuels are 91% & 9% respectively which are included in PAT cycle - VI.

2.10 Petroleum Refinery

The Indian refinery sector is next only to the US and China in global volumes with a massive capacity 247.57 MMTPA. There are around 23 petroleum refineries plant in India. Out of this PAT has covered 20 plants (till PAT cycle V).

3. Best energy efficiency measures taken in energy intensive industries in India

3.1 Cement Industry

In cement industry, raw materials, coal and clinkers are being grinded in grinding mills. Grinding mills alone use the 75% of the plant electricity consumption [11].

1) Installation of vertical grinding mill (VRM)

Vertical roller mill has number of advantages over other mills such as ball mill such as,

a) It has a strong drying ability as hot blast stove provides hot air at 450 °C.
b) The vertical roller mill has a big feed size which simplifies the crushing system and saves the secondary crushing.
c) The fineness adjustment of the product is flexible and convenient.

Vertical grinding mills use 30 - 35% less energy than ball mill. ***Table 3**: Comparison of SECs of VRM and Ball* mill shows the potential of VRM over ball mill. It shows the difference in SEC between ball mill and VRM.

Table 3: Comparison of SECs of VRM and Ball mill

Blaine (cm^2/g)	Portland cement		Slag*	
	4000		4000	
	VR mill	Ball mill	VR mill	Ball mill
SEC (mill)	21.3	44.9	25.7	51.8
SEC (Fan etc.)	8.3	4.9	9.4	7.6
Total	29.6	49.8	35.1	59.4
*Slag with 8% moisture				

2) Installation of cross bar cooler

Cement manufacturing process is an exothermic process and thus it continuously releases the heat. Temperature must be kept maintained using cooler for exothermic processes to avoid unwanted heating. If efficiency of cooler reduces due to high loading on cooler, it cannot be able to maintain temperature which can reduces overall efficiency of the process. This type of cross bar cooler has been introduced in one of the cement industries of the capacity of 3550 TPD in place of 3200 TPD. ***Table 4**: Results achieved by installing cross bar* coolershows the SEC, thermal energy consumption and potential to save coal, before and after the cooler upgradation.

Table 4: Results achieved by installing cross bar cooler

Parameter	Before installation	After installation
Specific energy consumption (kWh/t clinker)	7.65	6.30
Thermal energy consumption (kcal/t clinker)	200	140
Coal saving (MT/year)	8520	

3) Installation of raw mill energy efficient classifier with vortex rectifier

In one of the cement plants, raw mill was designed for feed having moisture of 5% normal and 10% maxima. Over the period of time normal feed moisture increased to more than 10% and it reduced the raw mill output because hot gas generator had to be operated for drying and it consumed coal. Since, more heat was required for drying, the gas volume to be increased in mill thereby causing higher product residue [11]. To overcome this problem raw mill classifier was replaced with energy efficient classifier with vortex rectifier and results of modification are shown in table 5. SEC was reduced significantly after modification [11].

Table 5: Results achieved after modification of classifier [11]

Parameter	**Raw mill 1**	
	Before modification	After modification
SEC (mill) (kWh/t)	5.56	4.55
SEC (fan) (kWh/t)	6.33	6.28
Total	11.89	10.83

3.2 Iron and Steel Industry

1) Installation of top pressure recovery turbines (TRT)

In modern blast furnaces pressure of 3.6 psig to 36psig generates and thus top flue gases from blast furnace can be used to generate electric power. However, pressure difference over generator is low, the large gas volumes can make the recovery economically feasible. After the blast furnace gas is used in top pressure recovery turbines, it can be used as a fuel in iron and steel manufacturing processes. This method is classified in two types, dry and wet where dust is removed using venturi scrubber and dust - collector respectively. Dry method is more effective as temperature low drop is relatively low [12].

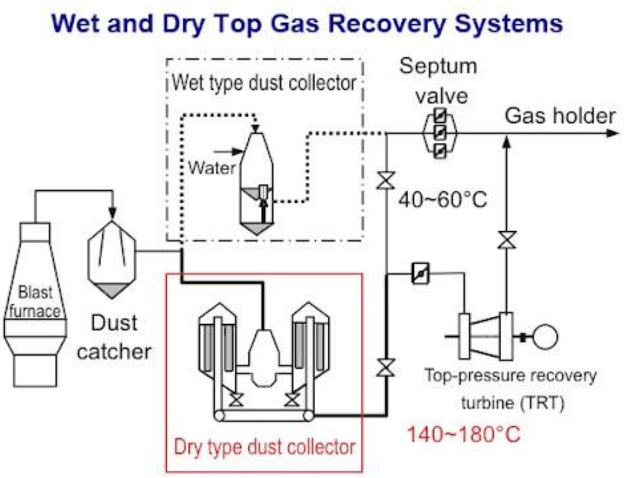

Figure 11: Top gas recovery system

A plant producing 1.1Mton/year iron and having blast furnace of capacity of 1500 Nm^3, the estimated gas generation is 212, 500 Nm^3/year [12].

2) Implementation of coke dry quenching (CDQ)

Coke dry quenching method is used in cooling of the red - hot coke in cooking process of coal in Iron and steel industries. In convectional method of cooking process, water is used to cool down the coke. In CDQ method, inert gases are used to cool down the coke and also it recovers the 80% of sensible heat of red - hot coke as this energy can be used to generate steam for electricity generation. It does not only recover and utilize the thermal energy of red - hot coke but also results in improvement of coke quality (M10 index can be improved by 1 point). This process offers distinct advantages of sensible heat recovery, conservation of water and zero air and water pollution [13].

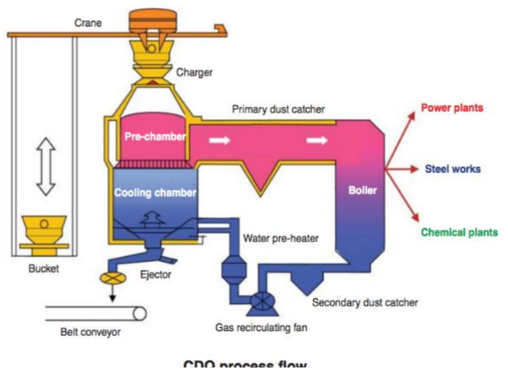

Figure 12: Coke dry quenching (CDQ) flow diagram

3) Hot charging and directrolling mill

Fuel consumption at heating can be reduced by charging high temperature semi - finished materials just after continuous casting (CC) into the heating furnace with temperature maintained as high as possible. Further, by improving the measures for preventing the temperature drop of the semi - finished materials (billets, blooms, slabs) after CC, thesematerials are directly sent to the rolling mill without going through the heating furnace, eliminating the heating process and substantially reducing the fuel consumption [13].

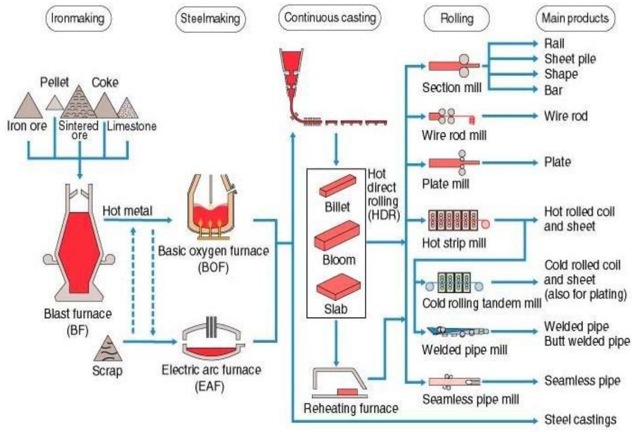

Figure 13: Iron & Steel making process [26]

3.3 Aluminum Industry

a) Implementation of slotted anode in pots

Modern technology has reduced the sizes of slotted anodes from large to midsize which are used in smelting process in aluminum industry. Nowadays, these improved slotted anodes are being used that help to reduce the risk of cracking and also help gas bubbles to escape from the anode bottom surface. Smelter using slotted anodes report saving between 0.11 to 0.17 kWh /kg of aluminum produced which can improve the aluminum production by 11% to 17% [14].

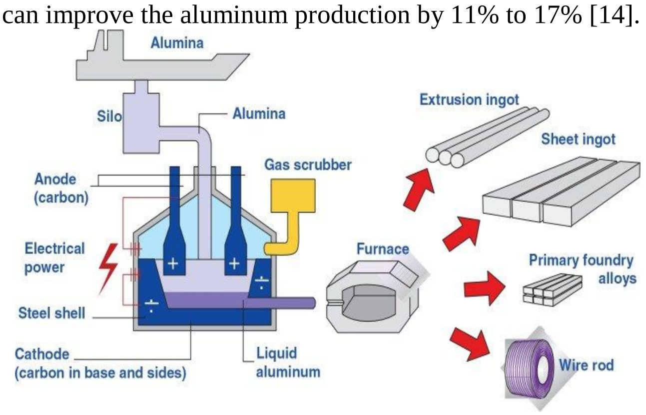

Figure 14: Smelting process

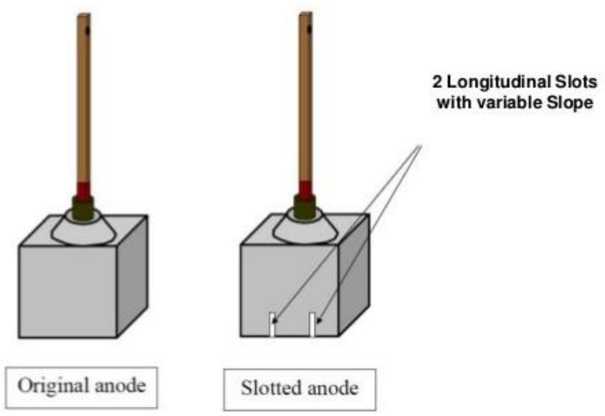

Figure 15: Difference between original anode and slotted anode

b) Eco - contact to reduce voltage drop at conductor joint

Energy lost at electrical joint constitute a huge portion of losses in electrical system. Eco - contact sheet, which can be used to increase conductivity of electrical connection, thereby minimizing losses by 90%. Also, it can be more efficient at high temperature. Use of this sheet can reduce damage of electrical contacts and increase in life span of electrical connections. This was tested at few places at Hindalco and it is found that it was able to reduce loss by more than 90% at some place.

Figure 16: Eco contactor provided on aluminum to copper joints of DC isolator

c) Installation of 100% graphite cathodes

To decrease electrical resistance in cathodes, graphite cathodes can be used. To make graphite cathodes, carbon cathodes are heated to 3000° C. This increases the order in the carbon planes and removes the hetero - atom, leading to a better electrical conductivity.

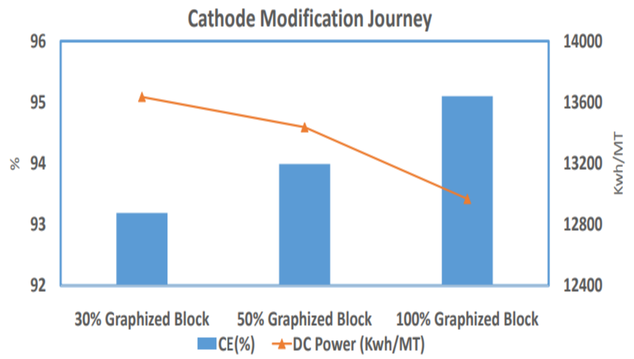

Figure 17: Results of cathode modification

In Vedanta Limited (Jharsuguda), 30% graphitic cathodes have been replaced by 100% graphic cathodes which reduced the cathode resistance from 25 µΩ. m to15 µΩ. m. Moreover, DC power consumption has been reduced from 13, 635 kWh/MT to 12, 958 kWh/MT.

3.4 Chlor - alkali Industry

a) Upgrading to the 6th generation zero gap cell

This technology is highly energy efficient as it has increased utilizable area of membrane in combination with zero gap design across the entire active membrane area. In addition, it has more equalized current distribution to the membrane and improved release of gas bubbles which reduces the possible stagnation of the gas transport inside the single cell. The entire anode compartment is made by titanium and cathode compartment by nickel and in between both the compartments membrane is placed with zero gap. Which allows whole membrane area to be active [15].

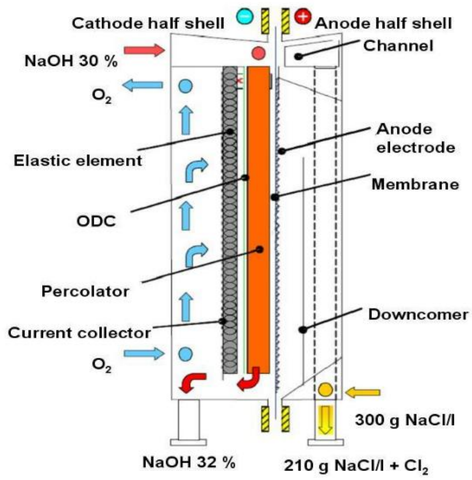

Figure 18: 6th generation zero gap cell

b) Pre - heating of feed brine using chlorine in recuperator

Usually, steam is used to heat brine from 60°C to 90°C and for this 397 kg of steam/T of caustic is consumed. Plant having capacity of 250TPD consumes 36300 MT of steam in a year. Brine can be preheated from 60°C to 80°C using hot chlorine gas coming out from electrolyzes at 80°C and thus steam consumption can be reduced significantly. (Steam consumption to increase brine temperature from 68°C to 90°C is 145 kg/T) [11].

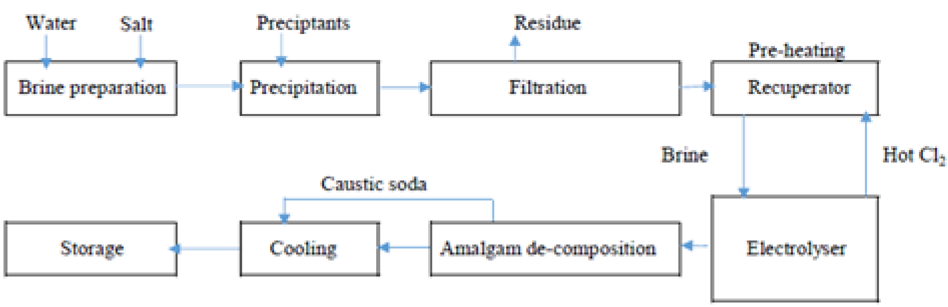

Figure 19: Caustic soda production

Figure 20: Pre - heating of feed brine using chlorine in recuperator [11]

c) Replacing reciprocating compressor with screw compressor for chlorine liquefication

Rotary screw compressor uses rotors to compress large volumes of gaseous refrigerant to a high pressure and temperature. Screw compressor has simple structure, less component and larger capacity. Also, it makes less vibration and less surging as it displaces gas continuously via sweeping motion of the rotors [16]. As per case study, the power reduction for conversion of reciprocating compressor with freon screw compressor was 12 kWh/ T of chlorine [11].

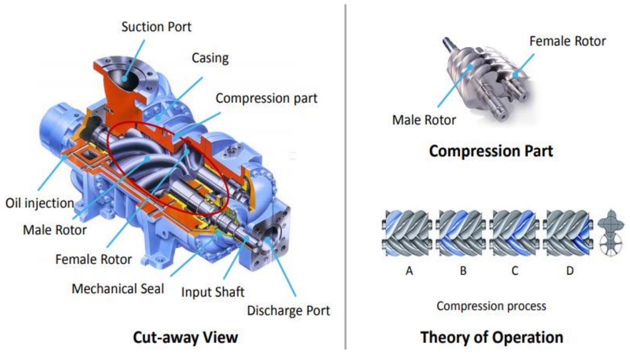

Figure 21: Screw compressor layout

3.5 Paper and Pulp Industry

a) Installation of extended de - lignification system for cooking wood

In pulp mills, lignin content is represented by Kappa number and it is removed in de - lignification step. By introduction of extended de - lignification system Kappa number can be decreased compared to the conventional system. This technology reduces chemical consumption in bleaching system by 30 - 50% compared to the conventional Kraft cooking method.

Table 6: Comparison of conventional cooking and extended de - lignification

Parameter	Conventional cooking	Extended de- lignification
Steamconsumption (ton/ton of pulp)	1.42	0.7
Kappa number	21 - 22	12 - 13
Yield (%)	45.3	46
Washing Loss (kg/t of pulp)	16	10
Black liquor conc. (%)	14.2	16

b) Installation of belt conveyor in place of pneumatic conveyor

In paper and pulp industry, chips are transported using pneumatic conveyor which is more energy intensive compared to the mechanical conveying system as it uses pressurized air. For same conveying distance and material transfer rate pneumatic conveyor consumes 10 times more power than mechanical conveyor. In a mill processing 1000 tons of pulp in a day and blower capacity of 300 m^3/hr. For pneumatic conveyor, motor size and power consumption would be 1000 HP and 18.2 kWh/t while for mechanical conveying system, motor size and power consumption would be 50 HP and 1 kWh/t respectively.

c) Installation of down flow Lo - solid cooking system

The cooking involves chips preheating, impregnation and digestion. During cooking, the fibers are separated by dissolving lignin using white liquor. Conventionally, Batch digester is used for cooking wood chips to separate and dissolve the lignin from the cellulosic raw material and considerable quantity of the steam and electricity is consumed. In one of the plants this conventional system was replaced by continuous down flow Lo - solid cooking system and its' benefits include reduction of 60% steam consumption per ton of pulp produced, uniform pulp quality and improved digester yield [17].

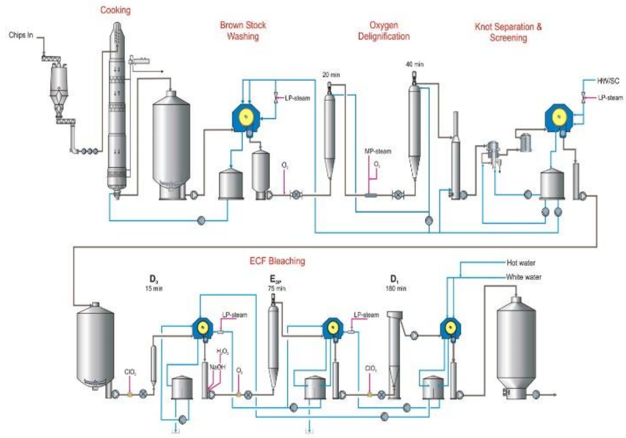

Figure 22: Pulp production

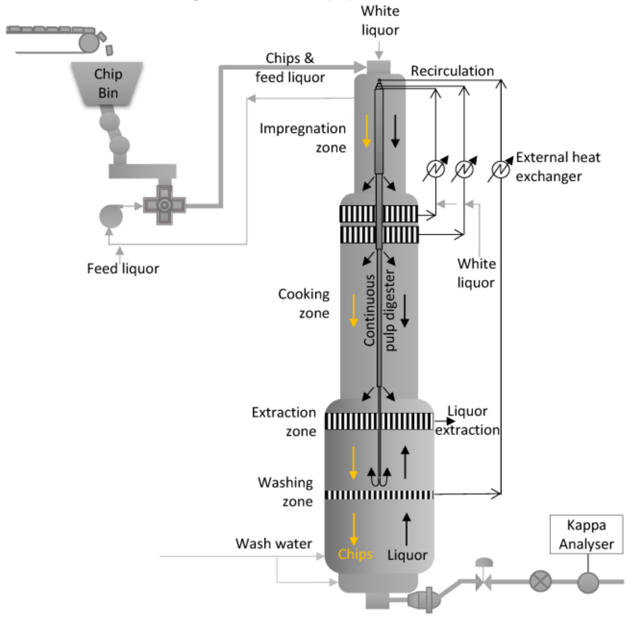

Figure 23: Down flow Lo solid cooking system

3.6 Fertilizer Industry

a) Installation of vortex mixer

In urea production carbon dioxide, ammonia and ammonium carbamate are used as reactants. They are injected in high pressurized reactor in co - current manner. Vortex mixture can be used to mix these reactants efficiently. The plants which have problems of bottleneck and high energy consumption, vortex mixture can be installed in urea reactor itself. The energy consumption can be reduced by 0.04 to 0.07 Gcal/t of urea [18].

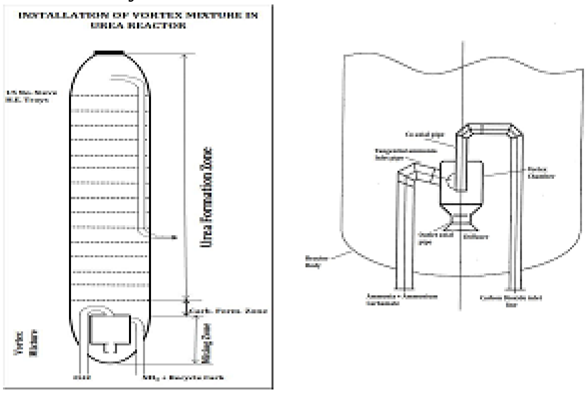

Figure 24: Schematic diagram of vortex mixer

b) Use of efficient catalyst

In ammonia synthesis process, nickel - based catalyst is used which is filled in the tubes in a reformer. By improving the shape of catalyst, geometric surface area per unit volume can be increased which improves the overall activity of catalyst. Moreover, increase in void age in catalyst will lower the pressure drop. By improving the shape and size of the catalyst, the tube side heat coefficient for a target pressure drop can be improved by 20–40 %. The energy savings are up to 0.2 MMBtu/t of ammonia [19].

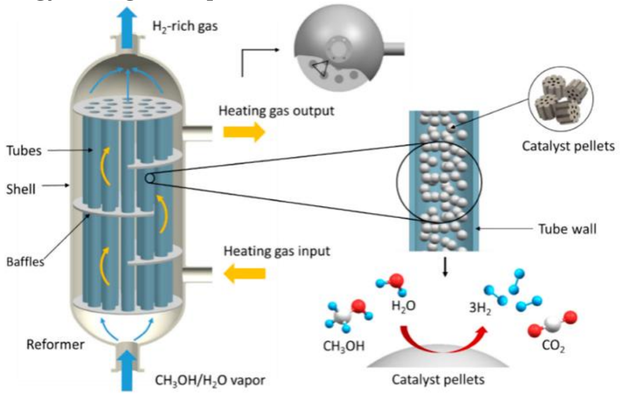

Figure 25: Catalyst filling in reformer in ammonia synthesis

Era:	1930s	1940s	1980s	2000s	2014
Cross section	Square	Ring	4-hole	QUADRALOBE™	CATACEL$_{JM}$ SSR™
Form	Cube	Cylindrical pellets	Cylindrical pellets	Cylindrical pellets	Cylindrical foil supported structure
Relative activity	1.00	1.32	1.64	2.00	3.00
Relative pressure drop	1.00	0.47	0.62	0.43	0.34

Figure 26: Comparison of catalyst shapes

c) Use of enhanced CO2 removal solvent

In the ammonia manufacturing process, CO_2 formed in the gasification and shift conversion process is generally removed by scrubbing with solvent. Usually, mono ethanol amine (MEA) is used as a solvent which has some significant drawbacks such as high energy requirement for regeneration. By replacing MEA with activated methyl di ethanol amine (aMDEA) energy consumption can be reduced as, being an activated, aMDEA has large surface area compared to MEA and thus it can absorb high amount of CO_2 for the same volume. Overall energy consumption for the regeneration can be reduced from 2.4 - 3.4 GJ/t of CO_2 to 0.8 - 1.9 GJ/t of CO_2. This change was implemented in IFFCO (Kalol) and energy consumption was reduced from 3.4 GJ/t to 2.5 GJ/t. Moreover, reboiler duty was reduced by 22.15 GJ/hr. The overall energy saving was 1.2 GJ/t of NH_3 produced.

3.7 Textile Industry

a) Installation of heat recovery system in mercerize machine

Mercerizing is a very crucial stage of textile processing. In process, fabric is treated in a stretched condition with 270 grams/liter caustic soda solution. The caustic is washed off during the stretched stage. Residue caustic is washed with hot water using a counter current system. the counter current washing consists of a series of water baths heated with steam. The baths are inter - connected with each other. The fresh make - up water enters at one end while the spent water at about 90°C is drained off at another end. This spent water can be used to pre heat the fresh water from 30°C to up to 80°C. As per PAT scheme, a 15000 TPA composite mill in India has installed waste heat recovery system for mercerize and has achieved energy saving of 20–30 % in term of fuel consumption [20].

Figure 27*:* Heat recovery in mercerizing machine shows, heat recovery in caustic recovery process in textile industries by Korting CRP.

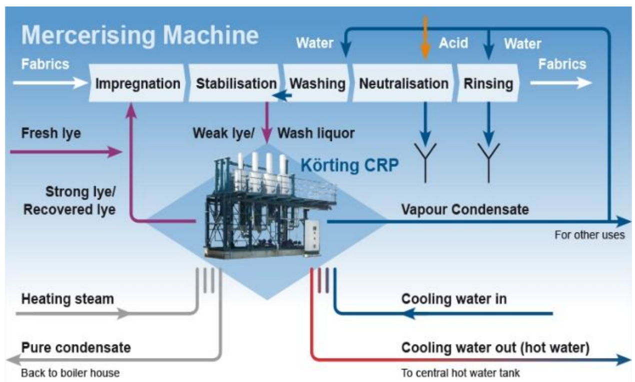

Figure 27: Heat recovery in mercerizing machine

b) Replacement of electric heating in polymerize to thermic fluid heating

Curing is significant to improve crease recovery properties of cotton fabric. In polymerize machine, the cloth is exposed to air at temperature of 160°C for curing. Centrifugal blower passes air through electrical heaters and hot air is blown on the fabric. Electric energy is high - grade energy, which is normally recommended for temperature above 300°C. the cost of electric heating is 3 to 4 times more than thermal heating. Here, thermic fluid can be very economical option as temperature requirement is only 160°C [20].

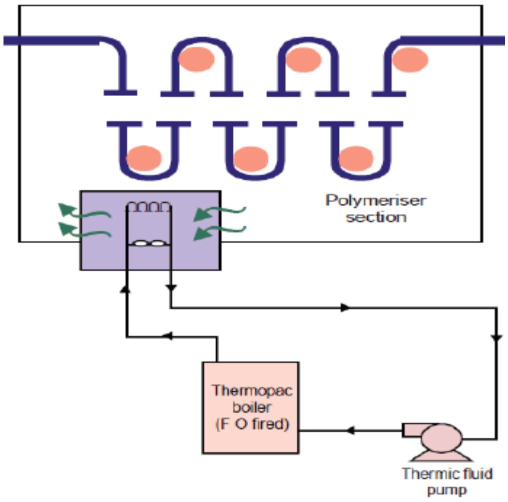

Figure 28: Thermic fluid heating in polymerizer

c) Installation of photocell detector for speed frame

Speed frames are provided with pneumatic suction arrangement near the front roller. Whenever any breakage of roving occurs, suction keeps drawing the rove till breakage is detected, frame stopped and the ends are connected again. This leads to roving losses in addition to the energy consumption for pneumatic blower. A photocell detector can be installed to detect front breakage. Whenever the photocell detects breakage, the machine is stopped. The operator will then connect the broken rove and restart the machine. This totally eliminates the requirement of the pneumatic blower and also roving losses. The benefits achieved are 100% energy saving by avoiding the pneumatic blowers and reduction in roving loss breakages. As per PAT scheme report, a 15000 TPA spinning mill in India has installed photocells for speed frames and has achieved specific energy consumption reduction of 0.05 kWh/kg [20].

3.8 Thermal power plants

a) Intelligent soot blowing system

In boiler of thermal power plant, soot is produced in the boiler and stack when SO_2 from flue gas react with alkali ash, it produces alkali sulphate which acts as a glue and bind fly ash particles together. Soot is excellent insulator and reduce heat transfer in boiler, thereby stack flue gas temperature increases which is wastage of energy. Steam soot blower are traditional soot blower which have various disadvantages such as high operating and initial cost. Sonic horn can be used in place of steam soot blowing system. Sonic horn has many advantages such as it does not create corrosion, erosion or mechanical damage to boiler tubes and does not produce any effluent. It creates sound on the same principle of Sankha. There is no moving part in sonic horn hence it has very low maintenance cost.

Figure 29: Sonic soot blower

As shown in figure 27, because of having no moving part proper cleaning of all tubes surface is possible in sonic horn. One steam blower if operated 6 times in a day consume 3 tone of steam which is equivalent to 500 kWh of energy, where as one sonic horn consumes 2 kWh equivalent of power in a day [21].

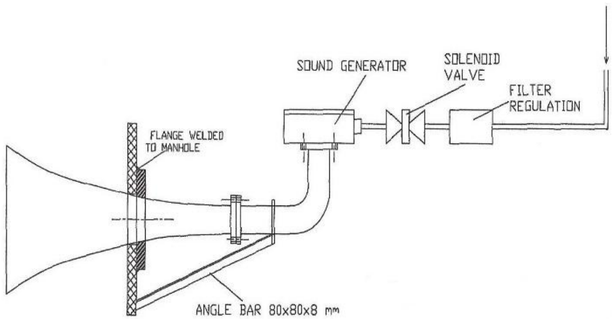

Figure 30: Schematic diagram of sonic horn

b) Improvement in condenser pressure

Condenser vacuum plays an important role in the performance of a turbine and in ensuring maximum output. The desirable vacuum in condenser of a thermal power plant is 0.08 kg/cm^2 abs. There are several factors which impact condenser vacuum such as air ingress due to leakages, fouling condenser tubes, ejector performance, higher cooling water temperature, inadequate cooling water flow etc. As per Good practices manual by Indian productivity council, an improvement in condenser vacuum by 0.01 kg/cm^2 is estimated to reduce fuel consumption by 1% for same power output [10].

c) Reduction in excess air ratio

Oxygen is required for combustion of any fuel, which is supplied by air. Every fuel has their own theoretical air requirement for complete combustion. But in practice, the theoretical air alone is not sufficient to ensure proper and complete combustion. Therefore, there is a need to supply some excess air. Excess air should be optimum. The optimum excess air level can be found for the best boiler efficiency by calculating losses due to incomplete combustion. and loss due to heat in flue gas is minimized.

As per case study in Shree textile industries, their boiler was operating at 187% excess air level and 13.7% oxygen in the flue gas which is very high. As the boiler has ID and FD fan whereas the ID fans is larger than FD fan, the velocity of the flue gas was observed to be very high and resulting in excessive loss of the heat in the dry flue gas with stack temperature of 445 °C. The overall boiler efficiency was found 35% which is very low [27].

For general operations of thermal power plant boiler, the accepted excess air percentage is around 20% but it can still be further reduced to 14 - 15% to reduce dry flue gas losses. For every 1% reduction in excess air, there is approximately 0.6% rise in boiler efficiency. The corresponding reduction in GHG emission will be 4.5 tCO_2/Million Units [10].

4. Comparison of energy saving measures employed in India and Globe

4.1 Cement Industry

An average SEC (3.3228 GJ/t of cement) of manufacturing of cement of India is significantly lower than the world average SEC (3.5 GJ/t of cement) for cement manufacturing. The main reason behind this is most of the plants are using modern technology. Still number of cement plants in India are using ancient technology but they are actively trying to improve their energy efficiency under PAT scheme by adopting various energy efficiency measures which are mentioned in PAT scheme report. According to Industrial Efficiency Technology database, if all the plants in world adopt modern technologies than average SEC of the world can be reduced by 1.1 GJ/t of cement.

4.2 Iron and Steel Industry

The iron and steel manufacturing industry are the largest manufacturing sector in the world. As per IETD, India is 4th largest steel producer in the world. The major energy consumption process in steel making is coke oven, sintering and blast furnace. They consume about 61.3% of the total energy consumed. The slabbing mill and hot strip along with others consume about 36.5% of the energy.

Many best energy saving practices have been implementing in plants. CDQ is one the best practices to reduce energy consumption in iron and steel plants. As per IETD, CDQ is widely used in Japan and Korea. According to a report from IEA in 2007, less than 30% of plants in China have this technology. In India CDQ technology is not widely applied. In China, energy use for coking has decreased from 5.6 GJ/t of coke to 4.2 GJ/t of coke between 2000 - 2004.

4.3 Aluminum Industry

Hall - Heroult system is widely used for the production of aluminum. Efficiency of this system can be improved by adopting advance cell technologies like wetted drained cathode and Hall - Heroult inert anode. As per report of U. S Department of Energy, Decreasing the anode - cathode distance (ACD) results in a proportional decrease in the voltage drop associated with the electrolytic bath. Energy is saved when the ACD reduction is matched with the ability to maintain current efficiency and heat balance.

The comparison of voltage drop using modern Hall - Heroult cell and conceptually keeping various ACD (shown in figure 31) was done and results are illustrated in table 7.

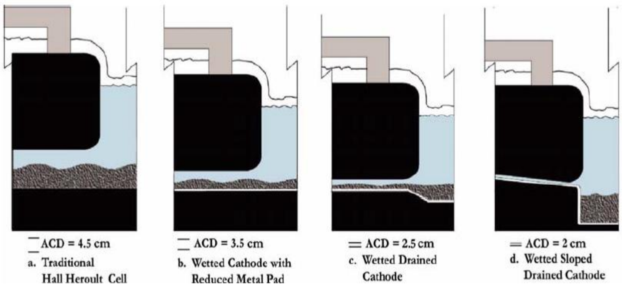

Figure 31: Conceptual wetted cathode cells [22]

Table 7: Comparison of results obtained by various ACD [22]

ACD (cm)	Voltage - drop for bath	Overall voltage - drop	% Reduction in energy usage
4.5	1.75	4.60	
3.5	1.36	4.21	8
2.5	0.97	3.82	16
2	0.78	3.63	20

This technology is widely used in USA since 2007 but it is not implemented in India currently.

4.4 Paper and Pulp Industry

Indian industries are lagging compared to the world's average energy consumption per ton of product as Indian paper mills are consuming 23 - 37 GJ of energy to produce 1 ton of paper while other countries are consuming 18 - 22 GJ of energy for the same. Between 1990 and 2008, average specific energy consumption of all the major paper and pulp producing countries was decreased.

One of the main reasons of having higher SEC in India includes use of combined heat and power (CHP) system. Spain, UK, Finland, Germany and Italy meet more than 25% of the total electricity demand of their pulp and paper industry using CHP. Additionally, Spain and the United Kingdom have the highest percentage of CHP use in the pulp and paper industry in Europe, with estimated CHP usage rates of 61% and 40% respectively [25]. With increased recycling and the greater diffusion of CHP, the IEA estimates potential savings of more than 20% at the current level of energy consumption for the Indian pulp and paper industry [23].

4.5 Fertilizer Industry

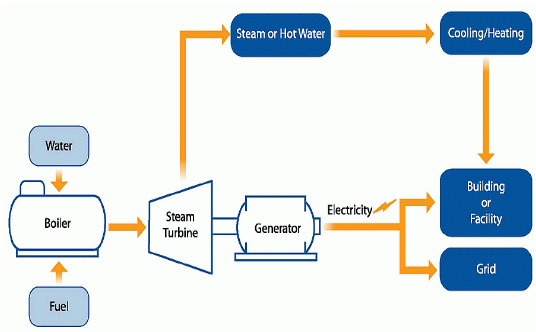

Figure 32: Basic combined heat and power (CHP) system

India is lagging behind the world in terms of average SEC in fertilizer industry. The share of nitrogenous fertilizers in overall fertilizer production in India is more than 85% and nitrogenous fertilizers are the most energy intensive fertilizers. Another reason is number of fertilizer plants in India are running on less than 80% of capacity utilization. Mainly 3 types of feedstocks are used in fertilizer industry from which natural gas is best feedstocks but in India only 50% of plants are running on this technology while in world 80% [24].

Table 8: SEC by feedstock type [24]

	Natural gas based	Naphtha based	Fuel oil based
SEC (GJ/T) (Urea)	26.5	29.1	40.5
SEC (GJ/T) (ammonia)	36.5	39.9	58.4

4.6 Chlor - alkali Industry

In India, soda ash and caustic soda are the major products of chlor - alkali industries and India is lagging behind world average in terms of SEC in both the products. The major reasons behind higher SEC of India are as below

- Nearly 25% of total caustic soda plants are running on mercury process which more energy intensive [24].
- Most of the soda ash manufacturers in India are using Solvay process.20% of overall energy can be saved by replacing Solvay process by modified process [24].

4.7 Textile Industry

14% of the total national output of the industries in India come from the textile industry. Moreover, textile industry contributes 25% of the total export earnings of India. It gives direct employment to about 30 million people. In textile industries energy consumption has been boosted with implementation of technology. However technological development also offers better productivity and quality that can overcome the efficiency measure.

Measures for improvement in energy efficiency have been adopted by some large - scale mills. However, Small and Medium Industries (SMI), which are backbone of Indian economy, continue to use older technologies. In addition, the greatest number of manufacturers in textile industries in India are SMIs. Moreover, the awareness level of energy conservation remains poor among the SMIs. Thus, Indian textile industries are still behind in terms of efficient energy consumption. Asian Regional Research Program in Energy, Environment and Climate (ARRPEEC) estimated that SMIs have a potential to save 15 to 20% of their energy consumption [24].

4.8 Thermal power plants

The performance of coal power plants can be expressed in terms of overall efficiency of the plant. The efficiency may be based on either higher heating value or lower heating value. In India, mainly efficiency is calculated based on higher heating value. The best efficiency of sub critical thermal power plant in India is 37%. There are quite number of thermal stations in India which are more than three decades old and are running at very low efficiency such as 20%. Efforts are made to improve efficiency of thermal power plants. Super - critical thermal stations having higher efficiency are getting installed in country which have efficiency of 40%. Modern super critical technology is largely available in Japan and Europe. Some of the countries have even adopted highly efficient Ultra - super critical technology [9].

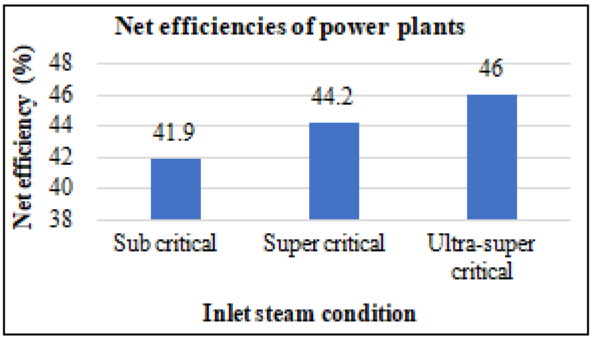

Figure 33: Net efficiencies of thermal power plants - varying inlet steam conditions

5. Conclusion

Table 9: SEC comparison of world average to India's average consumption in various sectors

Sector	Average SEC (India) to Average SEC (world)
Cement	Lower
Iron & Steel	Higher
Aluminum	Higher
Paper & Pulp	Higher
Fertilizer	Higher
Chlor - alkali	Higher
Textile	-
Thermal Power Plant	-

Table 10: SEC comparison of Indian energy intensive industries to the world average SEC

Sector	Measurement taken to reduce SEC	Reduction in SEC after measurement
Cement	Vertical Grinding Mill (VRM)	30 - 35%
	Cross bar cooler	Around 20%
	Raw mill energy efficient classifier with vortex rectifier	Around 10%
Iron & Steel	Top pressure recovery turbines	Generate extra energy up to 7MW for 1.1Mton/y plant capacity
	Implementation of coke dry quenching (CDQ)	Recover 80% sensible heat and Improve coke index (M10)
	Hot charging and direct rolling mill	Around 6%
Aluminum	Implementation of slotted anode in pot	Increase production by 11 - 17%.
	Eco - contact to reduce voltage drop at conductor joint	Upto 90% reduction in losses
	Use of 100% graphite cathodes	Around 5 - 6%

Paper & Pulp	Extended de - lignification system for cooking wood	Steam consumption reduce up to 50% and Kappa number improves
	Belt conveyor in place of pneumatic conveyor	For equal conveying distance, it reduces 90% energy consumption
	Down flow Lo - solid cooking system	Steam consumption reduce up to 60%.
Fertilizer	Use of vortex mixer	It reduces energy 0.04 - 0.07 Gcal/t of urea.
	Use of efficient catalyst	In ammonia, 0.2MMBtu/t energy can save
	Use of enhanced CO2 removal solvent	It reduces 30 - 35% energy consumption
Chlor - alkali	Upgrading to the 6th generation zero gap cell	
	Pre - heating of feed brine using chlorine in recuperator	Steam consumption reduce up to 64%.
	screw compressor for chlorine liquefication	Power reduction of 12kWh/t of chlorine
Textile	Heat recovery system in mercerize machine	It saves 20 - 30% energy
	Replacement of electric heating in polymerizer to thermic fluid heating	Thermic heating duty will be 3 - 4 times lesser than electric heating
	Use of photocell detector for speed frame	It saves 0.05kWh/kg energy
Thermal Power Plant	Intelligent soot blowing system	It saves around 500kWh per day
	Improvement in condenser pressure	Reduce fuel consumption by 1% for same power output
	Reduction in excess air ratio	By every 1% reduction, it increases boiler efficiency by 0.6%.

Energy is the key driver of economic growth and development and thus Ministry of power has taken significant steps for conserving energy resource through its various flagship programs such as Perform, Achieve and Trade (PAT), standards and labelling (S&L). Bureau of Energy efficiency (BEE), India has introduced a PAT scheme in which threshold limit of energy consumption for each sector of industries have been specified.

To conclude the discussion, looking into the specific energy consumption in all energy intensive industries, in India, cement industry is the most energy efficient industry compared to the average SEC of world. All other major industries in India have higher average SEC than the world average.

Table 11: SEC comparison of Indian energy intensive industries to the world average SEC

Sector	Average SEC (India)	Average SEC (world) (GJ/T)
Cement	3.3 (GJ/T)	3.5
Iron & Steel	31 (GJ/T)	17
Aluminum	80 (GJ/T)	61
Paper & Pulp	30 (GJ/T)	20
Fertilizer	25 (GJ/T)	24
Chlor - alkali	10 (GJ/T)	9
Textile	12.6 (GJ/T)	
Thermal Power Plant	0.01 (GJ/kwh)	

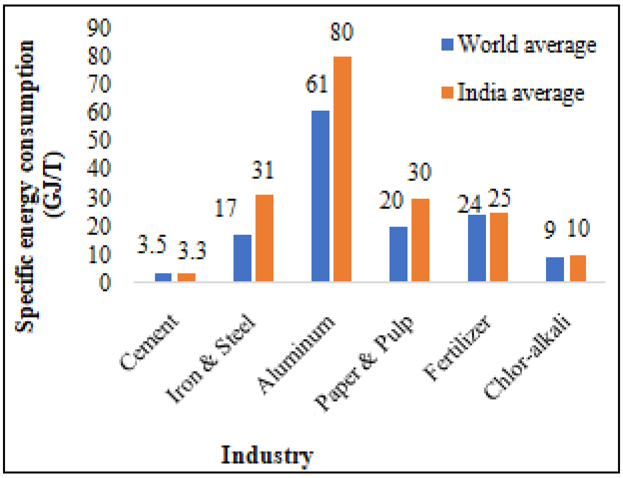

Figure 34: SEC comparison of various industries of India and world

Table 12: Why India is ahead/behind the world

Sector	Why India is ahead/behind the world
Cement	Compared to India relatively large number of plants in world are using older technologies.
Iron & Steel	Wide implementation of coke dry quenching method in countries like Japan and Korea
Aluminum	Unlike developed countries, lack of adoption of technologies like wetted drained cathode, Hall - Heroultinert anode and decreased anode - cathode distance (ACD)
Paper & Pulp	Wide Adoption of energy efficient combined heat and power (CHP) system in European countries.
Fertilizer	Relatively high production of nitrogenous fertilizers in India compared to world. Number of plants running on lower capacity utilization. Only 50% plants are using natural gas as feedstock.
Chlor - alkali	25% plants of caustic soda in India are using mercury process. Lack of adoption of modified process instead of Solvay process for soda ash production.
Textile	Poor implementation of energy efficiency measures in India as having more than 70% of manufacturers are in form of SMIs.
Thermal power plants	Adoption of sub - critical, super critical and ultra - super critical power plants in many developed countries.

Conflict of Interest
The authors declare they have no Conflicts of Interest.

Nomenclature
Abbreviations and Description

- ACD Anode Cathode Distance
- AFR Alternate fuels & Raw materials
- ARRPEEC Asian Regional Research Program in Energy Environment and Climate
- BEE Bureau of Energy Efficiency
- CC Continuous Casting
- CDQ Coke Dry Quenching
- CHP Combined Heat and power

- CO Carbon Monoxide
- CRP Caustic Recovery Process
- DC Direct Current
- FD Forced draft
- GC Gas Chromatography
- GHG Green House Gas
- GJ Giga Joule
- HP Horse Power
- ID Induced Draft
- IEA International Energy Agency
- IETD Industrial Efficiency Technology Database
- IFFCO Indian Farmers Fertilizer Cooperation Limited
- MDEA Methyl Di ethanol Amine
- MEA Mono Ethanol Amine
- MJ Mega Joule
- MMBTU Metric Million British Thermal Unit
- MT Mega Ton
- MTOE Mega Tons of Oil Equivalent
- MW Mega Watt
- PAT Perform Achieve and Trade
- SAIL Steel Authority of India
- SEC Specific Energy Consumption
- SME Small and Medium Industries
- SO, Sulphur Monoxide
- TPA Tons per Annum
- TPD Tons per Day
- TRT Top Recovery Turbines
- VRM Vertical Roll Mill

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