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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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Renewable Energy in Manufacturing

A technology roadmap for REmap 2030

JUNE 2014

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1. Introduction to REmap 2030

The International Renewable Energy Agency (IRENA) is developing a global renewable energy roadmap to double the share of renewables in the global energy mix by 2030. The aspirational target for this roadmap – called REmap 2030 – is derived from the Sustainable Energy for All (SE4ALL) initiative, which is currently chaired by the United Nations Secretary-General and the World Bank President. REmap 2030 is the result of a collaborative process between IRENA, national REmap experts within the individual countries and other stakeholders.

IRENA's approach in REmap 2030 uses two parallel tracks:

- A country-based analysis to identify actions on technology deployment, investment and policies in collaboration with IRENA Members and other key entities; and
- A series of technology roadmaps to identify cross-country insights on actions needed to achieve the target of doubling the share of renewables in the global energy mix.

REmap 2030 suggests that existing and future renewable energy expansion, as currently planned, will result in a 21% share of renewables in the global energy mix (IRENA, 2014). This leaves a 9 percentage-point gap to achieve a 30% renewable energy target in 2030, or a 15 percentage-point gap to achieve the 36% target, as indicated in the SE4ALL Global Tracking Report (Bannerjee, *et al.*, 2013). Furthermore, the initial results of the country-based analysis suggest that there are very few countries that have explicit policies to support renewables deployment in the manufacturing sector.

To complement the country-based analysis and to help bridge the gap towards doubling renewables globally, IRENA has developed a technology roadmap for the global manufacturing sector. The roadmap is based on a quantitative study and two stakeholder workshops (“Renewables for a New Product Mix”, convened in Brussels, Belgium on 19 April, 2012 (IRENA, 2012a) and “Renewables for Small and Medium Enterprises in South Asia”, held in New Delhi, India on 21-22 November, 2012 (IRENA, 2012b)), as well as feedback from industry stakeholders at meetings held at the International Energy Agency (IEA) and World Business Council for Sustainable Development (WBCSD).

The data presented in this paper is based on in-depth studies that assesses the techno-economic potential in

the manufacturing sector at regional level up to 2030¹. The roadmap presents the aggregated high-level results, and the detailed results will be presented more extensively in an IRENA working paper currently under preparation. This first-of-its-kind analysis includes detailed data on energy demand projections in the energy-intensive sectors (e.g., iron, steel and non-metallic minerals), as well as a number of less energy-intensive sectors (e.g., food, tobacco and textiles). The analysis also differentiates between renewable energy deployment in existing and new-build plants. Feedstock use for material production is analysed as a separate category and included as an option to increase the share of renewable energy in this sector. Energy efficiency improvements, production capacity growth estimates, local availability of resources, local fossil fuel prices and the role of policies to promote renewable energy deployment have been considered as part of the analysis, this included the option to relocate industries to resource-rich areas. Individual technology options (e.g., bio-ethylene and bio-methanol production from biomass, heat pumps, solar thermal applications and biomass co-generation) are analysed in detail based on IRENA's technology briefs (IRENA, 2013).

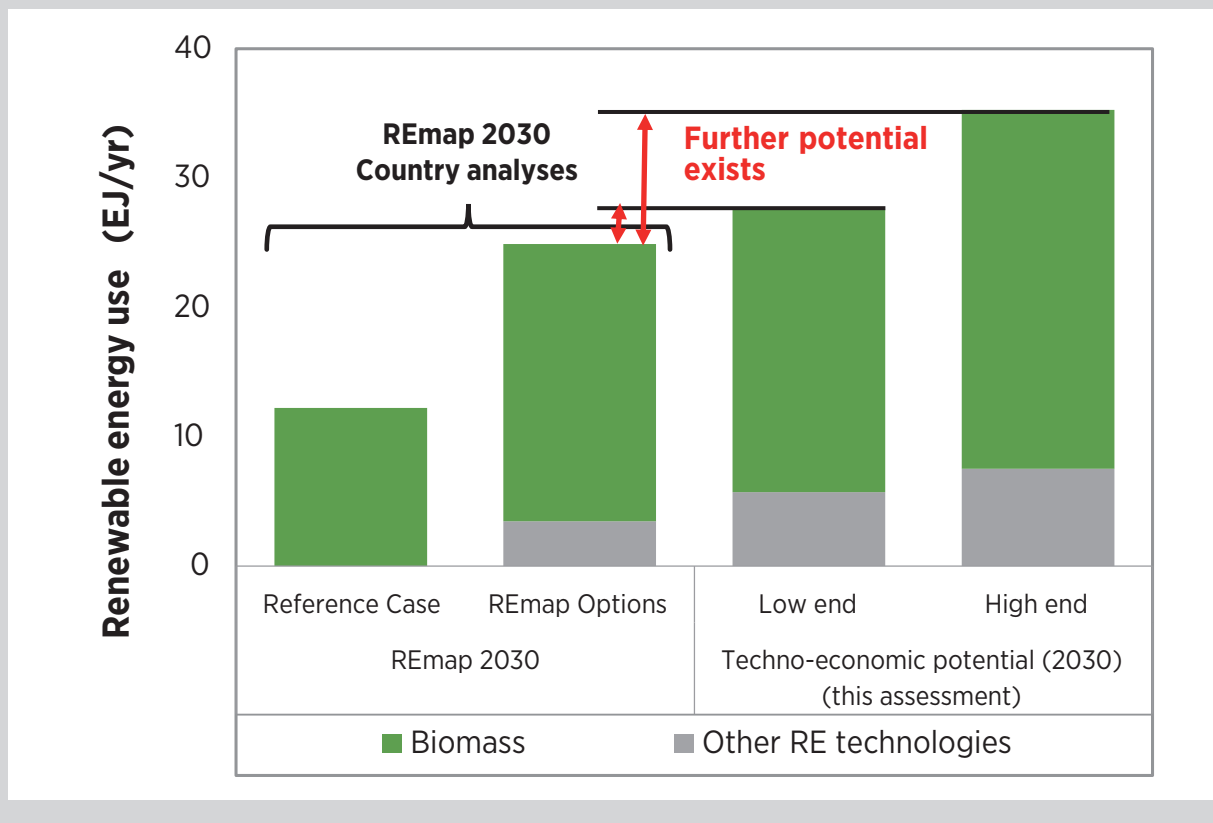
Comparing REmap 2030 results with the manufacturing roadmap

REmap 2030 is based on a country-by-country analysis of renewable energy options between 2010 and 2030. In total 26 countries were analysed, thereby covering around 75% of global energy consumption. The roadmap consists of two parts. A Reference Case that reflects renewable energy deployment in existing national energy plans. On top of that, IRENA has worked with national experts to identify additional REmap Options. In total, around 400 “realisable” REmap Options were identified for the 26 countries; 74 of these REmap Options were identified in the manufacturing sector.

The results indicate that in the Reference Case the share of renewable energy in the manufacturing sector will

¹ The working paper “Renewable Technology Options for the Manufacturing Industry: Assessment of the Global and Regional potential to 2030” is currently under preparation, and will be published as a separate paper on IRENA's website.

Figure 1: Renewable energy use in the manufacturing sector, 2030



increase from 8% in 2010 to 9% in 2030.² This is comparable to the predicted 12% in 2030 from the New Policies Scenario (NPS) developed by the IEA (2013). If the renewables-based electricity consumption is included, the renewable energy share in the Reference Case would increase from 11% in 2010 to 15% in 2030 (IRENA, 2014). If the countries were to implement the 74 REmap Options in the manufacturing sector, the renewable energy share would increase to about 19% of heat demand, or 26% if both heat and renewable-based electricity is considered (IRENA, 2014). Scaled up to the global situation, this would be equivalent to a total renewable energy demand of 25 exajoules (EJ).³

The analysis for this roadmap suggests, however, that the renewable energy share can be increased even further. The analysis complements the REmap 2030

results, as it takes a regional perspective instead of country-by-country analysis and specifically focusses on the techno-economic potential. Assuming the availability of low-cost biomass sources and reduced capital costs for emerging technologies (e.g., solar thermal), the renewable energy share could be increased from 19% following the implementation of the REmap Options to 27% if the techno-economic potential is fulfilled. If a carbon dioxide (CO₂) price (or a similar policy raising fossil fuel prices for industry) were to be introduced, the economic realisable potential would increase further to around 34%, with a total renewable energy demand of 38 EJ in 2030. In other words, an additional techno-economic potential for renewable energy deployment of around 13 EJ has been identified in this study (see Figure 1). The priority areas in this roadmap show how this gap between the REmap Options identified by the country-by-country analysis and the global techno-economic potential could be bridged.

Additional analysis can be found in the upcoming working paper, where a total of four scenarios have been developed to assess the techno-economic potential of renewables in the manufacturing industry. The four scenarios take the industry sector's renewable energy share between 15% and 34%. The results presented in this roadmap refer to a scenario that favours renewable energy technologies, in terms of technical, economic and political aspects. Without any technological pro-

² Unless specifically indicated in the text, the renewable energy shares refer to the use of energy carriers to generate process heat only. It is estimated by the total renewable combustible and non-combustible energy use from all energy carriers (e.g., biomass, solar thermal) to generate process heat divided by the total final industrial energy use (excluding electricity and feedstock use). Electricity use of heat pumps to produce process heat is assumed to originate from 100% electricity, and therefore the related electricity consumption is accounted for as a renewable energy carrier in the estimation of the sector's renewable energy share unlike the rest of the industrial electricity consumption.

³ 1 EJ is 10¹⁹ joules, and is equivalent to the total energy consumption of a mid-size country.

gress and supportive policies, the potential could be lower than these estimates and closer to the developments according to the Reference Case in REmap 2030 (IRENA, 2014).

On the other hand, a study by Taibi, *et al.* (2012) regarding the renewables potential for the manufacturing sector in 2050 suggests that there is still the potential to grow renewables deployment beyond 2030. Compared to the 38 EJ identified in this study, they estimate a total renewables deployment potential of almost 48 EJ. Around 6 EJ would be supplied by solar thermal, 5 EJ by heat pumps, and the additional 37 EJ by biomass.

The real question is of course how this potential can be realised. This roadmap aims to initiate discussions for developing new policies to increase the share of renewable energy in the manufacturing industry. As such, it highlights in more detail six priority areas for technologies, application areas and regions where there are large opportunities for renewable energy deployment, and where dedicated policies could transform the landscape for renewable energy in the industrial sector. The roadmap also identifies the key stakeholders and the activities that they should undertake. It further determines indicators that can be used to monitor the progress of deploying renewable energy technologies.

2. Summary of key findings

The current situation and projections for 2030

The manufacturing industry turns raw materials into products, and is an important backbone of many economies around the world. The process of converting raw materials like oil, iron ore, trees or crops into products like plastics, metals, paper and food requires energy, mostly in the form of process heat. Process heating systems always include at least one of the following: devices to generate or supply heat; devices to transfer heat away from the source; devices to contain the heat, e.g. kiln, ovens, etc.; and devices to recover heat energy (US Department of Energy and Office of Industrial Technologies (DoE), 2001). In total, the manufacturing industry used 127 EJ of final energy in 2010, which is approximately a third of global energy demand (including feedstock use) (IEA, 2012b). The total use also includes electricity, feedstock for petrochemicals production, blast furnaces and coke ovens. Electricity accounts for around 20% of final energy use in manufacturing, and is used for the production of aluminium, equipment, and lighting and cooling in factories.

Two-thirds of the total final industrial energy use worldwide was from developing countries and economies in transition, represented by the non-OECD⁴ region in this study (87 EJ) (IEA, 2012b). China accounts for almost 30% of global energy demand in manufacturing. According to IRENA's projections, total global industrial energy use is projected to grow by 45% to 185 EJ in 2030, in the absence of energy efficiency improvements (including feedstock use).⁵ As earlier analyses by the IEA (2009) and the United Nations Industrial Development Organization (UNIDO, 2010) show improving industrial energy efficiency by implementing best practice and new technologies is a prerequisite to achieving the SE4ALL objectives. Implementing best practice tech-

nologies and retrofitting existing capacity can limit this increase to 150 EJ (see Figure 2).

More than 80% of the total final consumption (about 125 EJ) in the manufacturing industry is estimated to be used as process energy by 2030. The most energy-consuming sectors are the basic metals industry (iron and steel), the chemical and petrochemical industry, and non-metallic minerals (mainly, cement). Another area of growing energy demand is feedstock for chemical and plastics production, which is projected to increase to around 27 EJ by 2030 (excluding process energy use).

The projected energy use for 2030 translates to annual growth in industrial fuel use of 0.5% per year for process heat generation and 2.6% per year as feedstock for chemical and polymers production over a twenty year period. The growth of feedstock demand is nearly five-fold compared to the growth of fuels for process heat generation as demand of fuels as feedstock cannot be reduced through efficiency improvements. This highlights the importance of using other measures rather than energy efficiency to reduce fossil fuel use as feedstock in the chemical and petrochemical industry.

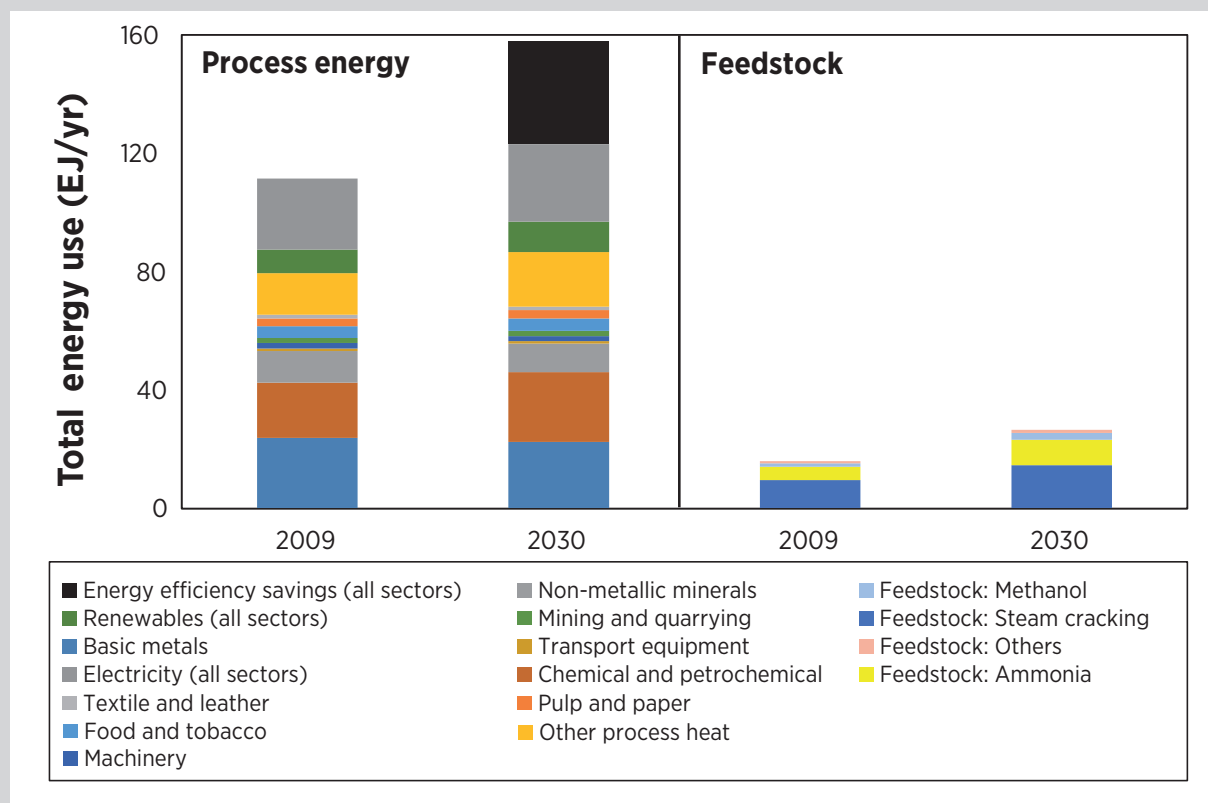
The energy efficiency improvement potential alone are not sufficient to reduce the increasing demand of fossil fuels and their associated environmental impact. Another approach to limit the industrial impact on CO₂ emissions is the development and deployment of suitable carbon capture and storage (CCS) technologies (UNIDO and IEA, 2011). CCS may contribute to the reduction of industrial CO₂ emissions, but it will increase energy use and is still expensive. Given the need for the development of a portfolio of technologies, in the past few years some industry sectors have prepared roadmaps to identify regional and technology pathways for a low carbon industry and to develop indicators for energy efficiency and greenhouse gas (GHG) emission reductions. While these encouraging efforts focus on a wide range of breakthrough technologies, more efforts are required to examine the role of renewable energy in improving sustainability of the manufacturing industry sector.

Achieving higher penetration levels for renewable energy in industry is key to realising substantial reductions in the sector's fossil fuel demand and related CO₂ emissions. Today, mainly the pulp and paper industry, and the food processing industry use renewable energy resources, accounting for approximately 45% and 25% of their energy demand, respectively. In total, renewable sources account for only 8 EJ, which is about 10% of the

⁴ Organisation for Economic Co-operation and Development.

⁵ This is equivalent to a growth in aggregated industrial production of approximately 1.7% per year in the entire period, the estimate is based on the bulk material demand projections from the IEA's Energy Technology Perspectives (ETP) 2012 (IEA, 2012c). While this could be representative of bulk materials production, such as iron, chemicals or cement from the energy-intensive sectors (covering 60% of the manufacturing industry sector's current total final energy demand, excluding feedstock use), it could be on the low side for less energy-intensive sectors such as food, textile, etc. (covering the remainder 40%). This, together with the effects of industrial energy efficiency improvements, explains the rather conservative demand growth in global industrial energy use estimates according to this study.

Figure 2: Estimated Global Industrial Energy Use, 2009-2030



sector's total global energy demand (excluding feedstock and electricity use). To date, renewable energy use in manufacturing has received little attention. Yet, renewable energy technologies can provide practical and cost-effective alternatives for process heat generation, and as a carbon source for the production of chemical and plastics. These potentials need to be exploited in order to achieve a doubling of the renewable energy share in the global energy mix by 2030.

Approach

The roadmap is based on a combination of quantitative techno-economic analysis, stakeholder workshops to identify and prioritise activities for the different stakeholders within each of these action areas, and an assessment of their role to turn actions into reality.

The techno-economic analysis explores the economic viability of renewable energy technologies, which depends on assumptions for future biomass feedstock prices (distinguishing between low-cost and expensive sources of biomass) and fossil fuel prices, as well as economic policies promoting the role of renewable energy.

The results displayed in this document are based on a policy scenario favourable to the deployment of re-

newables in the manufacturing sector. It is assumed that all technical options to substitute fossil fuels with renewable energy technologies for process heat generation and for chemical and polymer production will be exploited. This scenario also assumes that technological learning takes place for the various renewable energy technologies used in this sector. Furthermore, it is assumed that CO₂ emissions have a price, which stimulates fuel switching from emission-intensive fossil fuels to less emission-intensive fuels, or carbon neutral renewable energy technologies. Based on the IEA World Energy Outlook (WEO) (2011), CO₂ prices of more than USD 85 per tonne CO₂ are assumed for the OECD region, while in some non-OECD regions the prices could be up to USD 65 per tonne. For consistency, a relatively low rise in fossil fuel prices is assumed due to decreasing demand. All options which have a CO₂ emission abatement cost below 0 are assumed to be implemented (in USD/t CO₂).⁶ Once these options are identified, the second most important factor to increase the share of renewables is the availability of resources, notably biomass. A separate analysis – based on a country-by-country assessment of various biomass resources – has been used to estimate the biomass availability for the

⁶ Represents the difference between the annualised costs (in USD per year) of a renewable energy technology and a conventional technology used to produce the same amount of energy divided by the total emissions abated (in tonnes of CO₂ emission per year).

manufacturing sector⁷. It is assumed that the economic potential of low cost biomass sources will be exploited first. All potential estimates in this roadmap are *additional* to the total renewable energy use in the REmap Reference Case and refer to fuel use for process heat generation only, thereby excluding industrial electricity use and the related renewable potential in the power sector.

The stakeholder workshops asked participants to identify relevant renewable energy options, and the associated opportunities and barriers in their respective industries. Subsequently, the stakeholders were asked in a participatory process to rank and prioritise areas for action. The results of the workshops are incorporated into this roadmap and determine to a large extent the priority areas and the action items that have been identified.

Finally, for each action item we assessed and discussed the significance of the different stakeholder groups. The higher the scores, the more important is the role of the stakeholder in turning these actions into reality (see Annex 1 for a description of the assessment method).

Global potential of renewable energy in 2030

The results suggest that – assuming an availability of low-cost biomass sources and reduced capital costs for emerging technologies – the renewable energy share can be increased from 9% in the REmap Reference Case to nearly 27% in 2030.

If a CO₂ price on industrial emissions were to be introduced (or a similar policy raising fossil fuel prices) equal to the projections from the IEA World Energy Outlook (WEO) (IEA, 2011), the potential increases further to 34% by 2030. Based on these assumptions, IRENA analysis shows that the economic realisable potential of different renewable energy resources to generate industrial process heat could be as high as 25 EJ by 2030. The potential of biomass as feedstock adds another approximately 2 EJ. The potential of relocating new primary aluminium smelters next to renewable power supply and solar cooling are estimated to add another 1 EJ (see Figure 2). Total additional renewable energy potential in the industry sector is estimated to be 28 EJ by 2030. Together with the Reference Case projection of 10 EJ combustible biomass and waste use, the total renewable energy use in the global industry sector could reach 38 EJ by 2030.

⁷ The working paper “Global bioenergy supply and demand projections for the year 2030” will be published as a separate document on IRENA’s website.

Figure 3 shows that biomass could play a key role for high-temperature heat applications in the energy-intensive sectors where other technologies are not able to provide alternatives. In both the existing and new capacity, additional biomass demand could reach approximately 7 EJ by 2030. For other industrial applications where biomass can be used as a fuel, total additional biomass demand is estimated at around 13 EJ. Nearly 2 EJ additional biomass can be used as feedstock for the production of chemicals and polymers. Total biomass use (22 EJ) accounts for about three-quarters of the estimated total additional renewable energy potential in the global industry (28 EJ). Low-cost biomass provides the basis for renewable heat generation processes (14 EJ). Solar thermal and geothermal technologies offer potential in generating low- and medium-temperature process heat as a new capacity, estimated to be approximately 2.5 EJ and 1.1 EJ, respectively. The largest potential are found in the chemical, petrochemical, food and tobacco sectors of the OECD countries, China, other non-OECD European countries and India. In addition to this new capacity, heat pumps are also estimated to offer potential to be integrated into existing capacity, with a total potential of approximately 1.5 EJ worldwide.

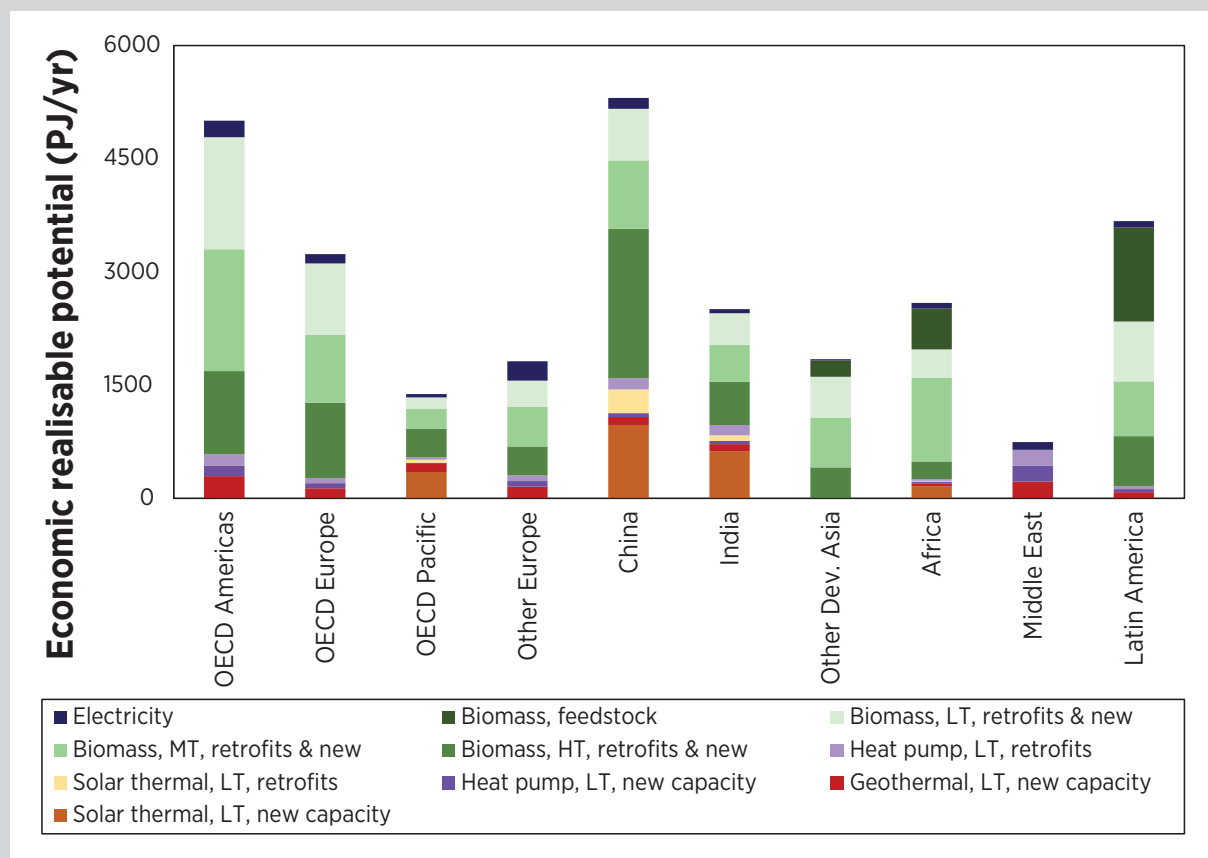
Locating new primary aluminium smelters next to renewable energy power plants (1 EJ) and substituting electricity-intensive cooling equipment in the food and tobacco sector with solar cooling (0.1 EJ) could contribute in total up to 1.1 EJ. Increasing the share of renewable energy in the power sector is already cost-effective in some regions. This could contribute further by increasing the share of renewable energy in industry through electricity.

Region and sector findings

The largest renewable energy potential are in Asian countries (9.7 EJ). OECD Americas also have a high potential for various renewable energy technologies due to the capital stock turnover that will take place in the next two decades as well as high CO₂ prices (5 EJ); and despite having the highest resource availability, the estimated potential in Africa are low due to the limited production capacity in place estimated for 2030 (2.6 EJ). The Middle East is constrained by biomass resources, as well as low cost-effectiveness of technologies because of the cheap fossil fuels, and thus it has the least potential worldwide (0.7 EJ). Advancements in high-temperature solar thermal technologies could change the outlook for renewables in this region.

The largest potential worldwide are estimates for the chemical and petrochemical sector (6.9 EJ: 4.9 EJ for process heat and 2.0 EJ bio-based feedstocks). This is followed by the other energy-intensive sectors, namely iron and steel, and non-metallic minerals sectors

Figure 3: The Economic Realisable Potential of Renewable Energy Technologies in the Manufacturing Industry, with a Breakdown by Regions, 2030.



LT: low-temperature; MT: medium-temperature; HT: high-temperature

(6.4 EJ). Among the less energy-intensive sectors, the largest potential are in food and tobacco (2.6 EJ) offered by a wide range of renewable technologies.

Costs of renewable energy technologies

An estimated additional potential of 25 EJ for process heat generation can raise the renewable energy share in the industrial fuel mix from 10% to as high as 34% worldwide. These are optimistic findings and Figure 4 shows the cost-supply curve which represents these findings (blue curve), as well as the results if there are no CO₂ prices (orange curve) and in addition to that if access to biomass residue supply is limited (grey curve).

The y-axis of the curve represents the average incremental cost of substituting 1 gigajoule (GJ) of fossil fuel with renewable energy options. Figure 4 shows that in the most optimistic scenario more than 80% of the total potential worldwide are viable with an average substitution cost below USD 0 per GJ of fossil fuel substituted (blue curve in Figure 4). These potentials are

offered by geothermal, heat pumps and low- and high-temperature biomass applications. The most expensive option is solar thermal (USD 2 per GJ). In the case of no price on CO₂, the incremental substitution costs would increase by USD 4-6 per GJ and reduce the economic viability of most technologies, thereby decreasing the total renewable energy share to around 27% (orange curve). Limited biomass availability for industrial use would reduce the total renewable energy share to around 15% (grey curve).

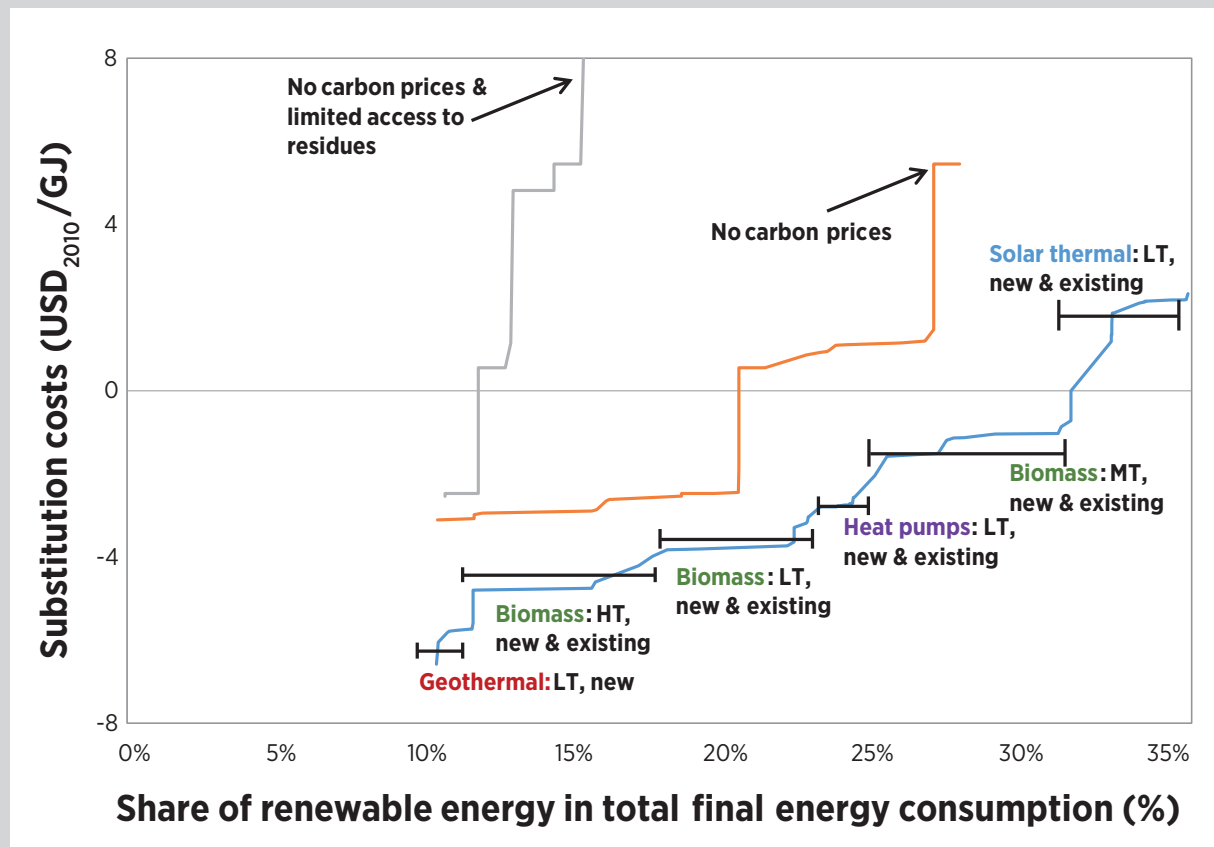
Priority areas for action

Based on the findings of the techno-economic analysis and the feedback from our stakeholder workshops, IRENA identified six priority areas that warrant action from both policy makers and industrial stakeholders.

These are:

- 1. Energy-intensive sectors:** With 75% of the total industrial energy demand and long lifetimes for these types of plants, the energy-intensive

Figure 4: Average Cost of Substituting Renewable Energy Technologies into the Global Manufacturing Industry, 2030



The world can double its share of renewable energy in TFE by 2030.

Note: Data for process heating systems only.

Note: In this study only the potential of technologies with a negative mitigation cost are considered to have economic realisable potential (or a negative substitution cost, in USD per GJ of fossil fuel substituted). The curves shown in the figure, however, have average substitution costs above 0 as well. This is because the costs plotted refer to the average of that technology for each of the 10 regions, and not limited to the regions where the technologies have economic realisable potential only.

LT: low-temperature; MT: medium-temperature; HT: high-temperature

sectors need to consider renewable energy options not only as an integral part of their new build capacity, but also as part of their existing capacity.

2. **Small- and medium-sized enterprises (SMEs):** Accounting for more than 90% of all manufacturing businesses, SMEs play a crucial role in increasing the deployment rate of renewable energy technologies, providing local manufacturing opportunities and stimulating cost reductions through learning by doing.
3. **Biomass:** Among the renewable technology options, biomass has the largest substitution potential in the manufacturing industry, but immediate and internationally coordinated action is required to alleviate the serious supply constraint of sustainable sourced and low-cost biomass

resources, and to deploy the most resource efficient biomass use applications.

4. **Solar thermal systems:** Solar thermal heat systems have a large technical and economic realisable potential in small scale plants and less energy-intensive industries like the textile and food sectors, but the vicious circle of high initial capital costs and low deployment rates needs to be broken.
5. **Electrification:** With increased electrification in the industry sector, renewable energy deployment can only be achieved through technology development in both the industry and power sectors.
6. **Regional aspects:** Regional potential depends on production growth, ratio of existing and new capacity, and renewable resource availability. En-

ergy pricing and climate policies can ensure a level playing field and biomass resource constraints may be elevated by trade, but equally important will be specific policies to support the different industries in deploying renewable energy.

Large structural and regional changes in production activity could increase the potential quantified in this roadmap even further. A large share of bulk material demand worldwide can be supplied by regions with

abundant renewable energy sources, like Latin America or Africa. Furthermore, many industries are relying on subsidised energy prices, thus different pricing mechanisms could substantially increase the economic viability of the renewable energy technologies. Finally, there is an important social dimension to the deployment of technologies in the manufacturing sector. Customers are demanding products that are produced in a clean and sustainable way, and renewable energy could help provide the solution.

3. Opportunities in energy-intensive sectors

The energy-intensive sectors, namely iron and steel, chemical and petrochemical, non-ferrous metals, non-metallic minerals, and pulp and paper, are estimated to continue to use more than 75% of industrial energy use (including feedstock). However, they account for less than 5% of all global manufacturing plants (30 000–60 000 plants globally). Biomass offers the largest potential to provide high-temperature process heat for these sectors and to replace the fossil fuels that are currently used for chemical and polymer production.

Key findings

The substitution potential of fossil fuel-based energy use with renewable energy technologies is estimated to range from 8% (iron and steel sector) to as high 30% (non-metallic minerals sector) for the different energy-intensive sectors.

Total potential of renewable energy technologies are estimated at around 14 EJ with about 85% for process heat generation and the remainder for chemical and polymer production. Biomass use for various applications offers the main renewable energy opportunity. Biomass can be used to produce process heat (via steam and direct heat) at varying temperatures, including high-temperature applications above 400 degree Celsius (°C), and it is the only renewable option to replace fossil fuel based feedstocks. Furthermore, biomass can also be easily integrated into existing plants for cement or brick production, and into the production processes of iron and steel making.

Action areas for the energy-intensive industries

Renewable energy integration into new capacity and maximise the potential in existing capacity: The long life of plants (up to 60 years and even more) limits the turnover of stock. By 2030, more than half of the total energy use of the energy-intensive sectors will be from the existing capacity. The other main challenge for renewable energy deployment is the large energy demand

per plant in the energy-intensive sectors. This requires continuous access to energy supplies (e.g., biomass) and in most cases on-site land for storage of biomass or construction of solar thermal plants. Another barrier is that most production processes in energy-intensive plants (e.g., chemical plants) are optimised with highly integrated material and energy flows. This is particularly the case for the chemical and petrochemical industry, whereas existing plants in the iron and steel, and non-metallic minerals sector can in most cases employ biomass use without major process modifications. When designing new plants renewable energy technologies need to be exploited. Existing plants where renewable energy technologies can be integrated without major process modifications, need to be identified.

Renewable energy technologies for high-temperature heat demand: High-temperature heat applications account for more than two-thirds of the total process heat demand. Currently, biomass offers the only renewable energy option to provide high-temperature heat. To an extent, solar thermal heat systems could also provide high-temperature heat, but more research, development and demonstration (RD&D) is required to commercialise those technologies available.

Bio-based feedstocks: Compared to the total energy demand of the energy-intensive sectors, feedstock use represents one-third of this demand, thereby highlighting the increasing importance of global polymers consumption for various applications (e.g., transport, construction and packaging). Production of materials always requires a source of carbon, as it is the building block of organic chemicals. For this reason, fossil fuels can only be substituted with biomass. Given the increasing importance of fossil fuels used as feedstock, specific action items are dealt with in more detail in Section 5.

Sustainable biomass logistics: Most production facilities are large-scale centralised plants operating at economies of scale, which will require large energy flows to be brought from within and across national borders. The key factors defining the economic viability of biomass are: its energy density; production costs; the distance it needs to be transported; and the type of transport mode. Cost-competitiveness of biomass can be maintained through an effective logistics infrastructure as consumption increases.

Table 1: Stakeholder Priorities within the Action Area: Energy-Intensive Sectors

Stakeholders / Activities	Renewable energy integration	High temperature heat demand	Bio-based feedstocks	Sustainable biomass logistics
Governments / policy makers	2.5	2.5	2.5	4.0
Industry / associations	3.25	3.25	3.5	3.5
Technology / equipment suppliers	2.8	2.8	2.5	2.5
Funding organisations	1.8	1.8	2.3	2.5
Research	2.3	2.3	2.8	1.0
Non-government organisations / statistics offices	2.0	2.0	2.0	2.8

Where:

High scores (above 3.25) indicate a crucial role for the stakeholder (colour-coded red); medium scores (greater than 2.5 up to 3.25) indicate an important role for the stakeholder (colour-coded orange); and scores 2.5 or lower are left blank indicating a lesser stakeholder importance. See Annex 1 for further explanation.

Policy needs and stakeholder interactions

Table 1 shows the priorities for stakeholders related to an increase in renewable energy use in the energy-intensive sectors. According to the stakeholder workshops, both governments and other organisations collecting data have a critical role to play in ensuring that biomass residues are available in a sustainable way (values greater than 3.25; Table 1). Industry has a critical role in the development of new technologies for all the identified priority areas. Other focus areas to accelerate the uptake of renewables in the energy-intensive industry are dedicated renewable energy policies targeting the integration of renewables into new plant designs (Table 1). Policies also need to support existing plant owners to explore the technical possibilities to substitute ageing process heat equipment with renewable energy alternatives, without making major modifications to the plant.

Biomass currently offers the only real renewable technology alternative to fossil fuel-based high-tem-

perature process heat generation for chemical and polymer production. There are a few other limited renewable sources that can also provide the high-temperature process heat (advanced concentrated solar thermal is thought to provide the greatest opportunity). Consequently, policies should promote the cascading use of biomass resources ensuring that they are used effectively and efficiently. Industry, research organisations and technology suppliers need to focus on the development of economically viable solar thermal technologies, which can provide higher temperatures of process heat.

Along with the increasing global demand and trade of biomass, sustainability concerns (Table 1) need to be taken into account to avoid issues such as deforestation, loss of biodiversity, increased greenhouse gas emissions from land use change and other potential conflicts that could lead to an increase in food prices. Again, policy makers and industry need to collaborate to ensure that the issues around sustainable and cost-competitive biomass logistics are addressed.

4. Opportunities in Small- and Medium-sized Enterprises

More than 90% of all manufacturing plants globally are SMEs and the cost of energy can be a substantial part of their total production costs. Biomass, solar thermal systems, geothermal energy and heat pumps can provide reliable and affordable energy, especially for SMEs that require low- to medium-temperature heat for their operations.

Key findings

SMEs account for over 90% of the number of businesses in the world, and provide jobs for more than half of the working population. They also play an important role in the economies of both industrialised and developing countries by accounting for up to 50% of their gross domestic product. Most SMEs are part of the less energy-intensive sectors such as food, textile or machinery, while others are located in the energy-intensive sectors (e.g., brick making, small ammonia plants and cement kilns). Today, in both the food and non-metallic mineral sectors, biomass and waste are already used to provide process heat. Still a large share of the SMEs' process heat demand is met by fossil fuels. SMEs are estimated to account for 15%-30% of the current total final industrial energy use (excluding feedstocks) (Banerjee, *et al.*, 2012). The temperature levels of process heat demand vary given the wide range of products produced, with about two-thirds requiring high-temperature applications; this is because proportionally the energy-intensive sectors account for most of the SMEs energy use worldwide.

Although the absolute potential in SMEs are less than in the rest of the industry, the substitution potential per plant is higher. For several industrial applications, more than 50% of energy consumption can be provided through a portfolio of renewable energy technologies including biomass, solar thermal systems, geothermal and heat pumps. Renewable energy can provide a low-cost, reliable resource for many SMEs and small-scale industry clusters, especially if they have high energy expenditures (e.g., brick kilns, small paper mills, textile factories, foundries, and food processing plants) relative to their total production costs. Furthermore, the availability of different technologies can provide flexibility to SMEs to reduce their dependency on fossil fuels. In the near term, it will be necessary to replace inefficient and aging machinery (and reduce the need for back-up

equipment such as diesel generators) with new production technology, integrated to renewable process heat generation technologies.

Furthermore, three-quarters of the SMEs are located in developing countries where large renewable energy resources exist. Given these unique potential, SMEs can play a crucial role in the development of local industries using renewable energy technologies. Moreover, due to the sheer number of SME businesses, the deployment of renewable energy technologies could lead to the development of renewable energy equipment along the supply chain, and encourage learning by doing. Securing access to reliable and affordable energy is crucial for SMEs, but they often do not have the resources to negotiate preferential energy prices and usually various barriers exist to the deployment of the latest energy technologies. These barriers need to be overcome first to exploit these large potential.

Action areas for SMEs

Overcoming barriers to new technology uptake: Energy costs often form a substantial part of the overall production costs, yet few SMEs know how they can reduce their dependence on expensive fossil fuels. Additionally, most production capacity is based on ageing and inefficient equipment, thereby increasing the energy demand of process heat generation. Replacing inefficient equipment with new capacity and integrating new capacity with renewable energy technologies are two key areas that can benefit SMEs. To realise the many opportunities which exist for the SMEs, barriers will need to be eliminated by developing effective strategies (see Box 1).

SME clusters: Many SMEs operate in clusters organised around a specific set of industrial operations (see Box 1). The proximity of multiple SMEs with similar operations and energy demand structures makes SME clusters a target to promote renewable energy deployment.

Mix of renewable energy technologies: The low absolute energy demand per plant in most SMEs, as well as the varying temperature levels of process heat use, offer the opportunity to take advantage of the range of renewable energy technologies available. Biomass, solar, geothermal, heat pumps can all be deployed in SMEs.

Box 1. Renewable energy in SMEs in South Asia

IRENA (2012b) organised a workshop in New Delhi, India on 21–22 November in partnership with the Federation of Indian Chambers of Commerce and Industry (FICCI) and the Independent Power Producers Association of India (IPPAI) as part of a global series on manufacturing in the sector. The workshop objective was to prioritise activities to accelerate the deployment of renewables in the manufacturing sector.

Table 2: Sector-specific Opportunities and Barriers in the Dairy, Tea, Foundry, and Textile Sectors in India

Sector	Opportunities	Barriers	Solutions/Strategies
Dairy	<ul style="list-style-type: none"> Production in areas with high solar radiation 6% reaches market place Hot water for hygiene 	<ul style="list-style-type: none"> 75% of farmers are small/poor Highly diverse players within supply chain Quality first No measurements 	<ul style="list-style-type: none"> Renewable energy technologies can support changes in supply chain structures
Tea	<ul style="list-style-type: none"> Energy= 40% of costs 49% energy from wood Mandated fuel switch Add-on solutions Improvement of product quality 	<ul style="list-style-type: none"> Conservative Shortage in cash flow Land leases Labour shortage Monthly variations 24-hour operations 	<ul style="list-style-type: none"> Research and development (R&D) for reduction in labour processes Interstate wheeling and banking of wind energy
Foundry	<ul style="list-style-type: none"> Short payback times 95% in SME clusters 	<ul style="list-style-type: none"> Small percentage of costs Highly competitive Education levels are low 	<ul style="list-style-type: none"> Technology transfer between clusters
Textile	<ul style="list-style-type: none"> Large energy replacement potential in spinning, weaving and finishing Low productivity, low quality Heat/Power ratio ideal 	<ul style="list-style-type: none"> Delivery total demand Improvement of product quality is only concern Unorganised sector 	<ul style="list-style-type: none"> Data sharing can become part of Memorandum of Understandings to support renewable energy applications
General	<ul style="list-style-type: none"> Low- medium-temperature Replacement of petroleum fuels High solar radiation Lack of reliable and affordable electricity 	<ul style="list-style-type: none"> Lack of awareness Supply side limitations Long and complex decision making process Limited reference projects High initial costs Limited space Non-solar hours Technical integration Short payback expectations 	<ul style="list-style-type: none"> Seminars/meetings/networking Demonstration projects Replicating successes Competitiveness instead of costs Post audit performance studies Make data sharing mandatory Provide packages Support entrepreneurship Quality Assurance/Quality Control mechanisms Standard financing evaluations

Based on the experiences from the different sectors, the workshop participants suggested the following four key actions:

1. Develop a broad national vision focused on fuel substitution. This vision can be translated into a national target.
2. Develop a sector-based approach for replication of successful renewable energy applications. Each sector is different and will require specific examples to de-risk investments.
3. Use existing regional infrastructures to target “entrepreneurial” SMEs. An associated SME innovation fund needs to be established to support these first movers.
4. Develop business models for specific SME clusters supported by knowledge-management centres collecting and providing data on renewable energy applications.

Table 3: Stakeholder Priorities within the Areas of Action: SMEs

Stakeholders / Activities	Overcoming barriers	SME clusters	Integration of RE technologies
Governments / policy makers	3.25	2.5	2.3
Industry / associations	3.5	3.8	3.25
Technology / equipment suppliers	2.3	2.5	3.8
Funding organisations	3.25	2.0	2.0
Research	2.3	2.3	3.0
Non-government organisations / statistics offices	3.0	2.0	2.0

Where:

High scores (above 3.25) indicate a crucial role for the stakeholder (colour-coded red); medium scores (greater than 2.5 up to 3.25) indicate an important role for the stakeholder (colour-coded orange); and scores 2.5 or lower are left blank indicating a lesser stakeholder importance. See Annex 1 for further explanation.

Policy needs and stakeholder interactions

Table 3 shows the priorities for stakeholders related to an increase in renewable energy use in SMEs. Industrial associations will play a key role to work together with policy makers and funding organisations to develop clear and effective strategies to remove barriers and deploy a mix of renewable energy technologies. Access

to capital, as well as awareness and knowledge of new technologies and their benefits are essential. Dissemination of information is another key area where statistics offices and progress indicators can play a role (Table 3). Industrial associations also play a crucial role in supporting SME clusters and in developing new technologies. Technology lock-in to biomass use needs and should be possible to avoid in SMEs, since solar thermal, geothermal and heat pump alternatives already exist.

5. Biomass

As discussed, biomass, due to its versatility has the highest potential among the different renewable energy options in the manufacturing industry. Biomass can be used as a feedstock to replace fossil fuels, it can be used to produce low-, medium-, and high-temperature heat, and it can be used as a fuel for localised electricity production. Its potential exists in all sectors.

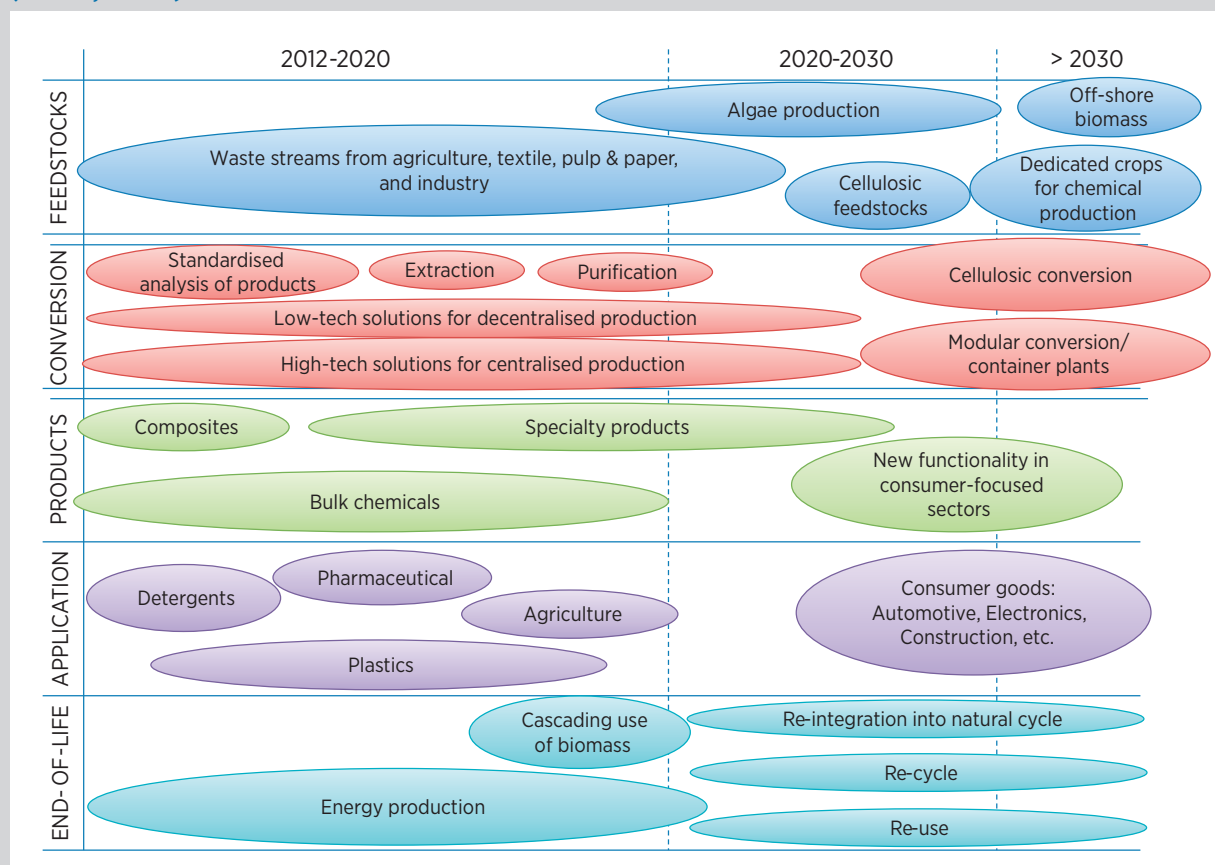
Key findings

All current renewable energy use in industry is predominantly in the form of biomass (8 EJ) (IEA, 2012b). This is mainly due to by-products and waste use, such as bagasse and rice husk in sugar production, and other traditional industries; biogas from sewage and farms for food processing; and black liquor in the pulp and paper sector. Furthermore, cement producers reported

around 3% biomass use in their kilns (Cement Sustainability Initiative (CSI), 2013). Yet, the future potential is even larger, especially given the requirements of the energy-intensive sectors. IRENA analysis suggests that approximately three-quarters of the total renewable energy technology potential could come from biomass (22 EJ). This approximates to nearly tripling its current use (8 EJ) by 2030. About 10% of future biomass potential are used as feedstock and the remainder is shared between high-temperature applications (30%) and other uses as fuel (60%). Biomass use comes with a number of advantages, it can be stored and provide heat upon demand. Moreover biomass fired process heat technologies can be integrated into the existing plants of most sectors.

Realising cost-effective and sustainable biomass potential, however, depends on a number of factors; its local availability, as well as access of plants to the biomass sources. With the exception of Latin America and Af-

Figure 5: Opportunities for Bio-based Feedstocks in the Production of Chemicals and Polymers (IRENA, 2012a)



rica, domestic biomass residues can only realise 30% or less of its full economic potential in the various regions analysed, because of the resource constraints. Some of these resource constraints may be alleviated by biomass trade, but this requires investments to transform biomass into forms that have a higher energy density (e.g., wood pellets, biofuels) and these will also incur additional transportation costs.

The versatility of biomass also results in competitive uses within and between the industry sector, and other sectors of the economy, namely buildings (for heating and cooking), transportation (as biofuels), and power. Increased biomass consumption for biofuels production and/or to provide heating demand in buildings creates additional pressure over the limited resources, thereby reducing availability to the industry sector. The demand for biomass in all sectors of the economy can be reduced by deploying other renewable energy and low carbon technologies, such as electrification of the transport sector, passive houses and the use of solar thermal systems or heat pumps for low- and medium-temperature heat. Furthermore technologies (and materials) developed need to make best use of these limited resources. Otherwise biomass availability may be limited to high-temperature process heat applications, as well as for chemical and polymer production, which always requires a carbon source (see Box 2).

Action areas for biomass

The sustainability of biomass resources: Biomass is at the heart of the nexus of energy, food, water and land scarcity, offering the highest potential for deployment in all three end-use sectors of transport, buildings, and industry. To reach these potential by creating the least additional burden on water and land sources, biomass needs to be sourced in a sustainable manner (see Box 2). One sustainable source of biomass is biogenic waste material. However, inconsistent waste regulation, cheap waste disposal options and the lack of an infrastructure to collect, transport and use waste flows, limits the use of waste as a resource. Residues can provide an important share of the potential demand, although their availability may not be sufficient. Energy crops could provide the remaining demand, but they need to be cultivated sustainably.

Relevance to agriculture and forestry sectors: In the long-term, renewable based products provide the opportunity to create new products with improved functionality and added value (see Box 2). Such products require certified high-quality feedstocks, and in some cases it may also be an advantage to have dedicated crops for renewable-based products. Essentially more effort in this area of agricultural R&D is crucial.

Trade barriers for biomass: Existing producer and consumer markets for manufacturing products are not necessarily found in biomass-rich regions. Consequently in some territories, trade barriers and import taxes are important obstructions to the deployment of renewable-based products. These should be regulated in a way that creates opportunities for the deployment of renewable energy technologies.

Cascading use of biomass: Cascading the use of biomass will allow its use as a feedstock to bio-based polymers first, after which the discarded products can be recycled for several life cycles, and subsequently incinerated with heat and electricity co-production at the end of their life (IRENA, 2012a). Compared to immediate burning of biomass for heat or power generation, cascading offers the possibility to use same resource for multiple purposes. However, less than 10% of post-consumer plastic waste is recycled today, only a quarter is incinerated, and the rest is sent to landfills (IEA, 2009). Making best use of limited biomass resources requires (i) recycling rates to be increased by reducing the quantities of plastic ending up in landfills, (ii) maximise recycling trips of plastics to the extent that the material properties allow, and (iii) incinerate post-consumer waste with efficient energy recovery. This would reduce the competition for biomass resources, create added economic value, and allow for multiple uses of the same resource.

Niche markets for bio-based feedstocks: Chemical plants in Brazil and India have already demonstrated that bio-ethylene can be produced at competitive prices as long as biomass is sourced at a low-cost (IRENA, 2013). The next step is the accelerated expansion of bio-based chemicals to substitute petrochemical-based polymers, starting with the high value-added counterparts, where the unique properties of the bio-based chemicals warrant comparable material characteristics. These high value-added products can be found in polymer markets with their high volumes, or niche markets where consumers seek specific properties that can be provided by plastics produced from biomass.

Policy needs and stakeholder interactions

Table 5 shows stakeholder priorities that relate to an increased biomass use in the industry sector. Increasing the share of renewable energy use in the industry sector needs to be achieved in a sustainable manner, and most stakeholders would play a crucial role to achieve this. Collection of biomass residues should not exceed safe removal rates required to maintain soil organic matter. Energy crops specific for biofuels and bio-based materials are alternatives, but they need to be cultivated

Box 2. Bio-based chemicals

IRENA organised a workshop in Brussels, Belgium on 19 April 2012 (IRENA, 2012a). The workshop brought together 11 stakeholders from industry and academia from different regions to identify common areas of concern and importance for accelerating the deployment of biomass use in the manufacturing industry. An overview of the opportunities for biomass use in the whole life cycle of chemicals and polymers is provided in Figure 5.

Based on the production growth of basic chemicals (*i.e.*, steam cracking products, ammonia and methanol), it is estimated that the related feedstock use of the global industry sector will grow from 16 EJ in 2010 to 27 EJ in 2030. This is equivalent to an increase in feedstock energy demand of 2.6% per year. The share of feedstock use in the total fuel demand of the industry sector is estimated to grow from 15% in 2010 to 22% in 2030. This shows that the substitution of fossil fuels used as feedstock is equally important as their use for heat generation. Bio-based materials can be categorised as: (i) standard compounds made from renewable feedstocks, *e.g.*, bio-based ethylene; (ii) materials with similar functionality, *e.g.*, Polylactic Acid (PLA) versus Polyethylene Terephthalate (PET); and (iii) products with different functions, *e.g.*, biodegradable plastics. There are commercialised examples for each category. Feedstock prices determine the production costs and in most regions, the bio-based equivalents are more expensive than their fossil fuel counterparts (see Table 4) with the exception of regions with cheap sources such as Latin American countries and India.

Table 4: Overview of production costs for ethylene and methanol from bio- and fossil fuel-based feedstocks

	Bio-based ethylene (USD/t)	Fossil fuel-based ethylene (USD/t)	Bio-based methanol (EUR/t)	Fossil fuel-based methanol (EUR/t)
China	1 340–2 180	600–1 300	160–900	100–300
India	1 000–1 670			
Latin America	970–1 630			
OECD and rest of the world	1 700–3 380			

Source: IRENA (2013).

The workshop participants identified a number of action items that need to be addressed to overcome existing barriers, and to take advantage of current and future opportunities. These actions cover three broad areas:

- Improve the availability, both in terms of price and quantity, of organic waste resources and biomass;
- Support technology development and innovation along the whole value chain, and dedicate specific resources and policies to develop the bio-economy and ensure a level playing field;
- Create new markets for bio-based products by increasing awareness and a stable policy environment.

sustainably, especially if on degraded land. Improving the agricultural productivity of regions that lag behind others and utilising biomass with high yields and with high useful products are important strategies. These require governments, companies and R&D institutions to allocate more financial resources to agricultural R&D, while R&D funding organisations should increase the proportion of funding allocated to the agriculture and forestry sectors. Furthermore sustainable land use management should be an essential part of the agricultural and forestry policies.

Regions with limited biomass resource availability will depend on the imports of biomass and its associated products. Governments should work together with industry to aim to utilise domestic resources for local economic growth. Subsequently, all stakeholders (Table 5) should work together to minimise trade barriers (*e.g.*, import quotas) and meet the growing demand from imports in a cost-effective way.

There are to date no targets on the extent that biomass should contribute to the production of materials. By

Table 5: Stakeholder Priorities for the Areas of Action: Biomass

Stakeholders / Activities	Sustainability of biomass resources	Agriculture and forestry sectors	Trade barriers for biomass	Cascading use of biomass	Niche markets for bio-based feedstocks
Governments / policy makers	3.5	2.5	4.0	2.5	2.0
Industry / associations	3.5	2.0	3.5	3.25	3.25
Technology / equipment suppliers	1.8	1.5	1.8	3.0	3.0
Funding organisations	3.5	2.0	2.5	2.0	2.0
Research	3.0	2.5	2.5	2.5	3.25
Non-government organisations / statistics offices	3.5	3.0	3.0	2.0	1.5

Where:

High scores (above 3.25) indicate a crucial role for the stakeholder (colour-coded red); medium scores (greater than 2.5 up to 3.25) indicate an important role for the stakeholder (colour-coded orange); and scores 2.5 or lower are left blank indicating a lesser stakeholder importance. See Annex 1 for further explanation.

considering the sustainability limits on biomass use, targets should be developed to increase the share of renewable energy in feedstock use. Given the varying bio-based chemical and polymer markets, policies should target the deployment in both the large volume markets and the niche applications. This requires sustainability criteria (e.g., emissions, land use) to be clearly defined. Statistics offices will play an important

role here (Table 5). Also, industry should be steered to develop and use resource-efficient technologies and tailored bio-based materials, which allow for multiple use, such as the cascading uses of biomass (e.g., feedstock and process heating combinations). Similar targets and efforts are also required for using biomass to generate process heat in a sustainable way.

6. Solar thermal process heat

With low- and medium-temperature heat accounting for 45% of total industrial process heat use, solar thermal systems have a large potential. Currently, there is a total installed thermal capacity of 42 MW_{th}, and yet less than 100 solar thermal plants exist for industrial process heating worldwide (<1% of total global industrial process heating). High initial capital costs, low operation hours and land requirements at site form the main barriers, but cost reductions can be achieved with an increase in solar thermal deployment.

Key findings

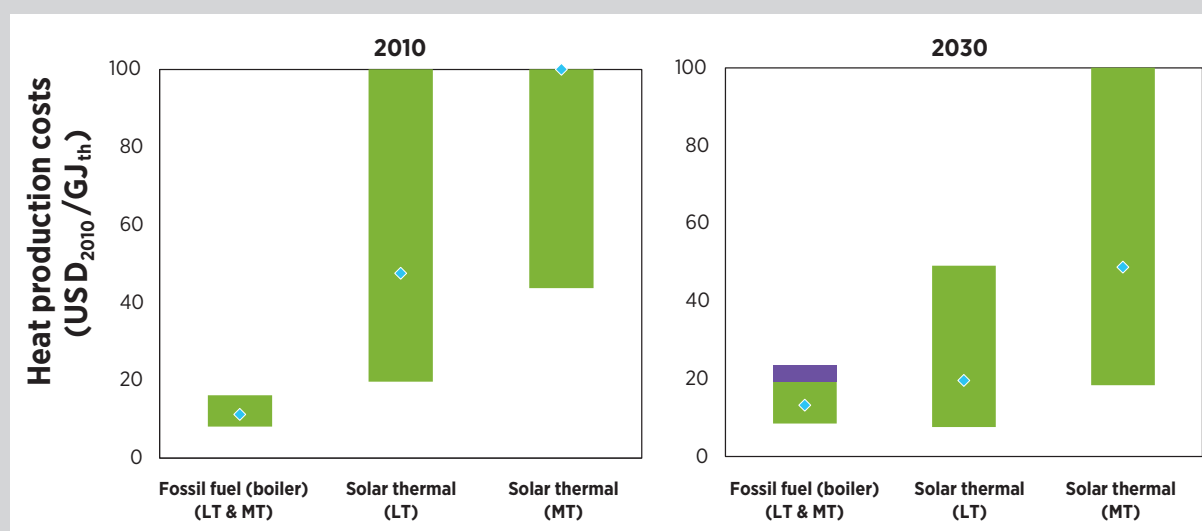
Despite their tremendous potential, solar thermal systems have only been harnessed in a limited number of plants. There are around 100 systems currently in place, with the highest number of solar thermal systems installed in the food processing industry and textiles. Austria, Greece and Spain have the highest number of systems installed. Solar thermal systems mostly provide low-temperature heat applications, but new designs make it possible to provide steam temperatures of up to 400 °C, with examples found in some sectors of India and enhanced oil recovery fields in the Middle

East. The largest solar thermal installation in the world (50 gigawatt-hours (GWh)) was opened in October 2013 in a copper mine in Chile.

Due to complex integration, space constraints and high temperature requirements of process flows in the energy-intensive sectors, the deployment of solar thermal systems has so far been limited. IRENA analysis suggests that by 2030, 1.3 EJ of economic realisable potential will exist worldwide (2% total process heating demand). A slightly lower potential of 1.2 EJ is estimated for less energy-intensive sectors. Furthermore, the sheer number of SMEs in less energy intensive sectors creates a larger potential market for deployment.

High capital costs currently restrict the deployment of solar thermal systems in industrial applications; however, technological learning could reduce these costs substantially (see Figure 6). Heat generation costs between now and 2030 are projected to decrease by at least 40%, and could even further reduce to 60% if deployment rises further. The capital costs could differ substantially among both countries and regions, as the technology is fairly simple and could be manufactured locally. A number of countries like India, could benefit from cheaper capital costs compared to the equipment costs in developed regions such as Europe.

Figure 6: Heat Production Cost Projections for Fossil Fuel-based and Solar Thermal Technologies.



Where: The green bars show that range of costs across the different regions, and the purple bar show the additional costs from a price on CO₂. The solid blue dot shows the weighted average of the world. LT: low-temperature; MT: medium-temperature.

Action areas for solar thermal process heating

Expansion of deployment: Solar thermal systems have been successfully distributed within the building sectors of China, Turkey, and Greece, and are beginning to expand in South Africa. This has resulted in greater local manufacturing capacities and reduced costs. Similar deployment strategies should be used throughout industry, starting with targeting low- and medium-temperature heat applications. Additionally the deployment of advanced vacuum tube collectors with compound parabolic concentrator or the recently developed high vacuum flat-plate collectors for high-temperature applications should be promoted.

Focus on SMEs: SMEs are an interesting market for solar thermal systems for three reasons. First, SMEs often rely on volatile and expensive fossil fuels for heat production, and solar thermal systems reduce their dependency on fossil fuels and contribute to the reduction of operating costs of the SMEs. Second, the heat demands per plant are relatively small compared to the energy-intensive industry, which makes the integration of solar heating systems easier. Third, the sheer number of SMEs present could result in rapidly declining costs due to learning by doing and more effective operations by installers. This could create a virtuous circle in which with declining costs and more experience, the deployment of solar heating systems is accelerated in this market segment.

Local manufacturing: The current costs of industrial solar thermal systems are determined by a relatively small number of suppliers of these highly sophisticated

technologies. Although these technologies have a high performance, they are generally too costly for a global market. More equipment being manufactured locally will reduce capital costs, create added value and local business opportunities along the supply chain.

Policy needs and stakeholder interactions

Table 6 shows stakeholder priorities that relate to increased solar thermal use in the sector. Solar thermal technologies are relatively mature, so industry, technology providers and funding organisations, all play a critical role in expanding its deployment in the manufacturing sector. Measuring progress and the dissemination of information is critical, so policy makers should engage in the development of clear targets for process heat generation.

Only with higher rates of deployment, and subsequent learning, will the technology become cost-competitive. Industry associations and other organisations collecting and disseminating information about deployment opportunities are key for this action area (Table 6). Another important strategy is to increase capacity in SMEs. Funding organisations together with industry can play a key role to support SMEs when investing in new process heat generation equipment. Technology providers themselves are a critical stakeholder in the development and use of locally manufactured equipment, and governments, funding organisations, and research organisations are important stakeholders to support the development of local manufacturing.

Table 6: Stakeholder Priorities within Areas of Action: Solar Thermal Process Heating

Stakeholders / Activities	Expansion of deployment	Focus on SMEs	Local manufacturing
Governments / policy makers	2.5	2.0	2.5
Industry / associations	3.8	3.25	2.3
Technology / equipment suppliers	3.0	2.5	3.5
Funding organisations	3.0	3.0	2.5
Research	2.5	2.5	2.5
Non-government organisations / statistics offices	3.5	2.0	2.0

Where:

High scores (above 3.25) indicate a crucial role for the stakeholder (colour-coded red); medium scores (greater than 2.5 up to 3.25) indicate an important role for the stakeholder (colour-coded orange); and scores 2.5 or lower are left blank indicating a lesser stakeholder importance. See Annex 1 for further explanation.

7. Electrification of the industry sector

Electricity demand is expected to continue to grow in the manufacturing industry, partly due to an electrification of production processes, as well as due to the production growth in electricity-intensive industries, such as the non-ferrous metals sector. Relocation of such industries next to renewable energy power plants is one option that would increase the renewable energy share in the electricity sector, but even more important is the decarbonisation of the power sector in general.

Key findings

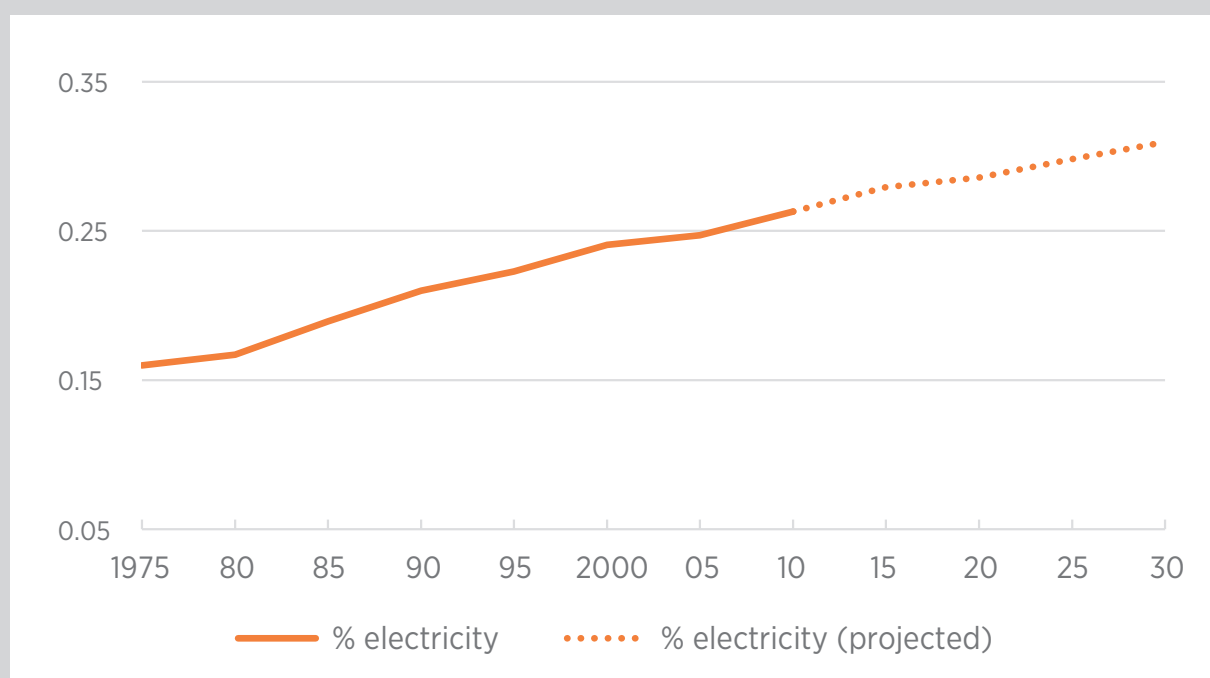
The share of electricity use in the industrial sector could increase from about 10%-15% in 1980s, to 25%-30% by 2030 (see Figure 7). Past increases are due to a number of reasons, such as: improvements in fuel use efficiency as opposed to growing electricity demand; decreases in the relative price of electricity compared to fossil fuels increased electricity demand in the food sector (hygiene

and health policies requiring increased refrigeration and cooling); production growth in electricity-intensive non-ferrous metal sector (e.g., increased demand for aluminium and copper in the automotive sector); and higher rates of recycling. By 2030, industrial electricity demand is projected to grow to at least 26 EJ from its current levels of 24 EJ.

Already some primary aluminium smelters use renewable energy power generation to provide the required electricity. For example, a considerable share of the electricity demand of the aluminium smelters in Africa and Iceland are already met with large-scale hydro-power plants.

Despite the relatively long life of plants in the aluminium sector (~60 years), it is projected that about a quarter of the sector's energy demand in 2030 will come from new capacity built between today and 2030. These plants can benefit from re-location to sites where hydro power plants exist, providing up to 1 EJ realisable potential for renewable electricity in the non-ferrous metals sector.

Figure 7: Historical and Projected Share of Electricity in Global Industrial Energy Demand



Source: IRENA analysis based on IEA (2012a,b; 2013).

Electrification of industrial processes that currently run based on process heating creates further opportunities. One of the building blocks for the chemical and petrochemical sector is hydrogen, which is commonly produced via steam reforming or gasification of hydrocarbon feedstocks. Electrolysis today offers an important alternative for hydrogen production, but the process requires significant amounts of electricity. Thus electrolysis is viable only if it uses renewable electricity and if the process efficiency is improved in the near future.

On-site renewable energy electricity generation: Several large manufacturing companies are integrating renewable energy power generation into their existing manufacturing plants either through solar PV panels on the production facilities, wind turbines on site, or other sources of renewable energy.

Technology development: Process technology R&D should also focus on electricity-based alternatives, ensuring that the electricity sector is decarbonised.

Action areas for electrification

Decarbonisation of the power sector: Increased electricity consumption from the industrial sector should, wherever possible, be provided by the development of new renewable power generation capacity. Renewable power generation costs have fallen for wind, solar photovoltaic (PV), concentrated solar power (CSP) and some biomass technologies, although hydropower and geothermal produced at good sites remains the cheapest way to generate electricity.

Relocation: New capacity investments in electricity-intensive industry sectors should, wherever possible, be located near renewable energy power generation sites. This will reduce the transmission and distribution losses associated with electricity transmission, and simultaneously provide a reliable and affordable energy source for these plants.

Policy needs and stakeholder interactions

Table 7 shows the priorities for stakeholders related to electrification in the industry sector. In many countries, there are policies aimed at increasing the share of renewables in the power sector. These policies should also encompass the development of electricity-based technologies in end-use sectors, notably for the industrial sector where most production processes operate on fossil fuel-based heat. As can be seen in Table 7, concerted efforts from governments, industry, and technology providers are required to develop policies that support the decarbonisation of industry.

Starting with the electricity-intensive sectors, policies should also steer industry to integrate investments with renewable electricity, either by re-locating production next to renewable power plants or by investing in on-

Table 7: Stakeholder Priorities within the Areas of Action: Electrification

Stakeholders / Activities	Decarbonisation of the power sector	Relocation	On-site power generation	Technology development
Governments / policy makers	3.5	2.0	2.0	3.0
Industry / associations	3.5	3.0	3.0	3.0
Technology / equipment suppliers	3.5	1.8	3.25	4.0
Funding organisations	3.0	1.5	2.0	1.5
Research	2.5	1.5	2.5	3.5
Non-government organisations / statistics offices	3.0	1.5	2.5	1.5

Where:

High scores (above 3.25) indicate a crucial role for the stakeholder (colour-coded red); medium scores (greater than 2.5 up to 3.25) indicate an important role for the stakeholder (colour-coded orange); and scores 2.5 or lower are left blank indicating a lesser stakeholder importance. See Annex 1 for further explanation.

site power generation capacity to meet their demand. Overall, it is the industry itself that will be the most important stakeholder for these developments (Table 7).

Electrification will require substantial R&D efforts to commercialise new technologies. There are several process technologies that are being developed and that can

radically change the way in which the manufacturing industry operates, but much more research and funding is needed to scale up these processes. Technology suppliers play a crucial role, and should work closely together with governments, the manufacturing sector, and research institutions to make this happen.

8. Regional aspects

Regional potential of renewable energy technologies depend on a number of factors. These are the share of existing and new capacity, local renewable energy resource availability, energy pricing and climate policies.

China is the global manufacturing powerhouse and could therefore play a key role in the increase of renewable energy in the global manufacturing industry. However, due to low fossil fuel prices and slowing industrial growth projections, additional efforts will be required to deploy the potential in the existing capacity and create a level playing field for all technologies.

Africa and Latin America have the largest untapped renewable energy resources in the world, although comparably their manufacturing industries remain the smallest worldwide. Renewable energy has the potential to transform the industrial sectors of Africa and Latin America, reinvigorate their growth through the provision of reliable and affordable energy, and particularly in Africa transforming the economic competitiveness of SME clusters.

Key findings

Chinese manufacturing, which accounted for only 5% of global manufacturing value added in 1995, reached 20% by 2010, rivalling the world's largest manufacturing economy United States. In terms of production volumes, China is a major player in almost all industry subsectors (Table 8). Industrial energy consumption is estimated to

grow accordingly. Despite these growth figures, renewable energy deployment in China is negligible. This is mainly due to the low price and abundance of coal, and a greater share of high-temperature process heating in bulk materials production.

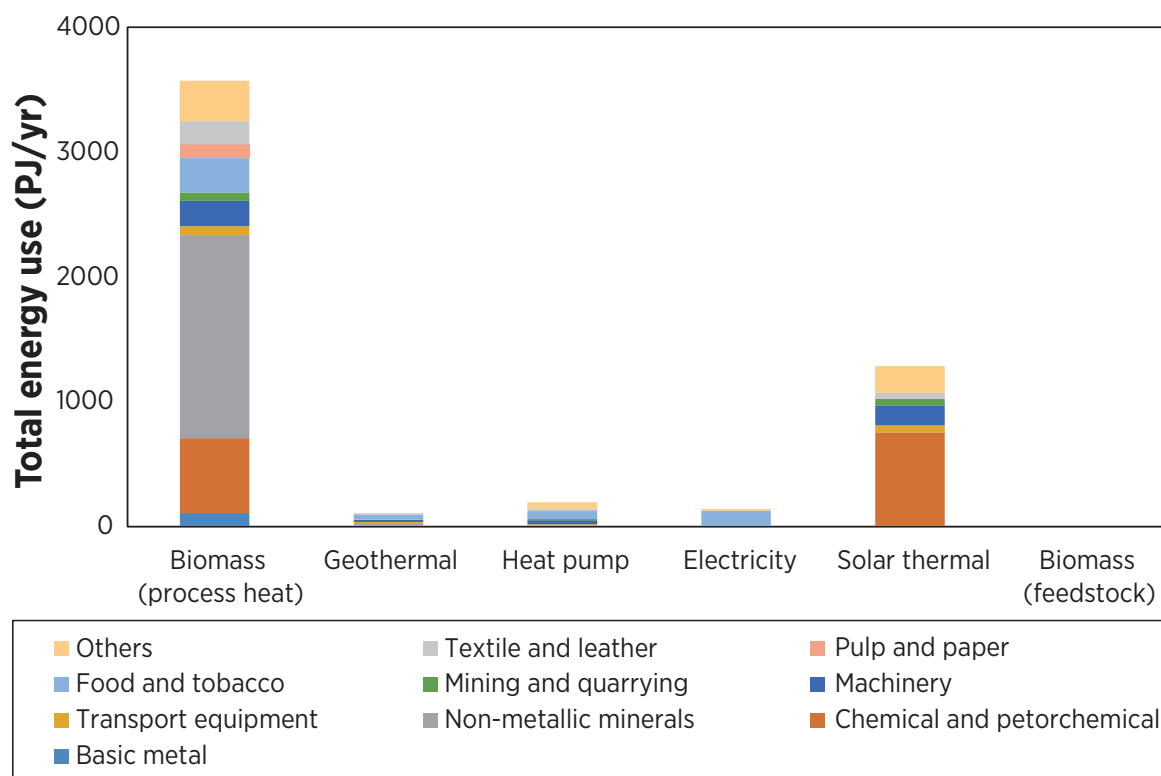
Chinese industry – with its enormous variety of industrial subsectors – has one of the largest realisable potential to increase its share of renewable energy in the world (Figure 8). Biomass dominates the total renewable energy potential in China. More than 3 EJ of biomass could be deployed in the manufacturing sector, of which the basic metals and non-metallic sector alone require 1.7 EJ. Despite this high potential, the total share of renewable energy in the manufacturing sector is projected to be just above 15% by 2030. With the growth rates for industrial production expansion projected to slow down in the years ahead (partly explained by the decreasing demand for materials), China has an opportunity to examine how it can maximise these potential in its manufacturing industry. In addition to the potential in high-temperature applications in heavy industry, integrated pulp and paper mills can be an option, as well as its experience in solar thermal systems that could be applied to many of the SMEs in China. The main barrier to renewable energy deployment will be low coal prices, as is the case today.

Africa has the lowest share of added value provided by manufacturing out of all the regions worldwide, at around 11% in 2008 and this is not expected to grow by much (UNIDO and United Nations Conference on Trade and Development (UNCTAD), 2011). The share of value added in Latin America is similar to the average

Table 8: Top Five Countries with Share of Production Capacity in Several Manufacturing Industries in 2010

Ethylene	Ammonia	Steel	Cement	Pulp and Paper	Cotton and synthetic yarn
US (20%)	China (33%)	China (46%)	China (54%)	US (22%)	China (50%)
China (9%)	India (9%)	Japan (7%)	India (7%)	China (20%)	India (8%)
Saudi Arabia (9%)	Russia (8%)	US (6%)	US (2%)	Japan (6%)	Pakistan (4%)
Japan (5%)	US (6%)	India (5%)	Turkey (2%)	Canada (5%)	Turkey (3%)
Germany (4%)	Trinidad & Tobago (4%)	Russia (5%)	Brazil (2%)	Germany (4%)	US (3%)

Figure 8: Potential of Renewable Energy Technologies in China, 2030



found for developing countries (~25%). However, both regions have the opportunity to use reliable and cheap renewable energy resources as a driver for their manufacturing sectors. An additional driver for reallocating new production capacities in Africa is that most raw materials for the manufacturing industry are mined in Africa. Simultaneously, the use of renewable energy for productive uses, *i.e.*, creating income generation and/or added value, provides an opportunity for economic development in Africa. The substitution potential for both regions could be greater than 60% of their total fuel mix given the abundant sources of reliable and affordable energy.

An important issue for Africa is the structure of its industry. The industrial sector predominantly produces chemicals, glass and cement (a few large plants), as well as processing food and beverages (by SMEs). The sector is dominated by a few large multinational corporations (MNC) supported by a large network of SMEs, often operating informally. Some SMEs operate in clusters around a MNC, while others agglomerate in clusters of enterprises belonging to the same sector. Several opportunities already exist. New capacity aluminium smelters could be relocated alongside untapped hydro potential, and up to 40% of fossil fuel use in the cement sector can be substituted with biomass. Large volumes of largely unutilised biomass are associated with saw

and wood mills, and are estimated to provide the majority of the economic potential from biomass. These processes can also be net generators of electricity and, depending on their locality, can either sell to the grid or support local communities. This is already standard practice in many installations across the continent.

Finally, food processing is one of the largest manufacturing sectors in both Africa and Latin America. Sugar, dairy, tea, coffee, and cocoa are some of the main products. In the African sugar industry, as in Latin America, optimising the bagasse by-product for co-generation facilities can meet all the required energy demand and provide electricity for export. In the dairy sector, larger facilities with feeding sheds may be able to meet all their fuel demand with biogas from manure. Solar thermal technologies for the production of steam (in the dairy sector), preheating of air (in the tea and coffee sector), and drying (in the coffee and cocoa sector) can provide between 35% and 70% of the total process heating demand required⁸.

In both regions, biomass as feedstock for the production of chemicals and polymers can be an important driver

⁸ The latter applications are analysed and discussed in more detail in IRENA's upcoming publication "Renewable Energy for Productive Uses in Africa".

for biomass use to produce high value-added products. Latin America is one of the first regions worldwide to commercially produce bio-ethylene and Africa can benefit from a similar experience in utilising its resources. While the percentage substitution potential are large in both regions, untapped resources would still remain, especially given the limited growth projections of industrial energy use between today and 2030. Consequently, their contribution to the global renewable energy potential are limited. Trading of biomass from these regions to others where demand is high and investing in more production capacity in Africa and Latin America are two strategies the global industry sector can benefit from to increase the overall renewable energy share.

Action areas at region level

Create a level playing field for renewable energy alternatives: Profitability and costs will remain the main drivers for both consumers and companies. The inclusion of externalities, such as CO₂ emissions (in particular given the emissions from the carbon-intensive coal used by many industries), in the price of products at a global level will make renewable based products more competitive. The introduction of a CO₂ price or other forms of pricing could be considered in order to support the deployment of renewable based products. In addition, low cost coal is a major potential barrier to the limited deployment of renewable energy. Removing fossil fuel subsidies and ensuring the availability of low cost renewable energy technology options can help support a transition to a less fossil fuel dependent manufacturing industry in China. As part of its overall energy policy, China is introducing carbon prices.

Biomass trade: China has a limited biomass resource relative to their energy consumption, while regions like Latin America and Africa have abundant biomass resources. Fortunately, neighbouring countries of China have rich sources of biomass (e.g., India and other developing Asian countries). Importing excess biomass from these regions would increase the supply in China and overcome the barriers related to the limited domestic production. Biomass trade networks could also be developed to export the unutilised biomass from Africa and Latin America to regions which need biomass for their industrial sectors.

Make abundant renewable energy resources available for industry: Reliable and affordable energy is an important factor for manufacturing industries when choosing their next production facility. Through the development of its abundant renewable energy resources, Africa has the ability to attract new industries and build a truly green economy.

Use existing resource flows: Many of Africa's industrial sites use biomass-based resources as input into their production processes. Examples are the food processing industry (tea, coffee, cocoa and dairy), the sugar industry, the textile and yarn industry, and the saw and wood processing industry. Industrial waste streams from these industries can be effectively used to meet the energy demand of the very same industries.

Accelerate technology development for modular production: In the mid- to long-term, there are opportunities to expand the renewable-based production in those regions that are resource rich, such as Asia and Africa. This will require technologies that are able to handle the local mix of renewables being available, as well as new technologies for the currently underexploited biomass resources. Widespread expansion into Asia and Africa would also require technologies that operate in a more modular approach, whereby production takes place on the basis of locally available resources.

Policy needs and stakeholder interactions

Table 9 shows stakeholders priorities that relate to regional aspects of the industry sector. The Table shows that governments play an important role in providing the policy framework for a level-playing field in China as well as biomass trade issues in Africa and Latin America. For China, energy pricing policies need to create a level playing field between the costs of fossil fuels and renewable options. This can be done by reducing the amount of fossil fuel subsidies for industry (a common case in most countries that are relying on the manufacturing sector). Fiscal instruments (e.g. CO₂ pricing) is another effective measure to ensure a leveling playing field between renewable and fossil fuels.

Access to energy is key for the industrial sector, and resource rich regions can benefit from attracting outside industry and gaining further from the growth of industrial activity (Table 9). Simultaneously, existing flows of renewable resources can be used more effectively. Most stakeholders play an important role in achieving access to resources. Industry associations and other forms of business partnerships can facilitate discussions for growth of the industry in such regions. Investment banks and governments can also provide support and various forms of incentives to encourage businesses to relocate to these regions, and statistics offices are key in providing data. Moreover, energy access also needs to be secured by developing international biomass trade. Governments, biomass producers and biomass product technology developers need to cooperate to develop a sustainable and effective worldwide biomass trade.

Innovation for the development of modular production facilities is also a key area to facilitate more effective usage of renewable resources (Table 9). The manufacturing industry, engineering companies, consultancy firms, R&D institutions, and R&D funding organisations will

therefore have to dedicate more resources and capital to the development of modular production facilities.

Table 9: Stakeholder Priorities within the Areas of Action: Regional Aspects

Stakeholders / Activities	Level playing field in China	Biomass trade in Africa & Latin America	Abundant resources for industry in Africa	Existing resource flows in Africa	Modular production in Asia, Latin America & Africa
Governments / policy makers	3.5	3.8	3.25	3.25	2.5
Industry / associations	3.0	3.25	3.25	3.25	3.0
Technology / equipment suppliers	1.3	1.8	2.8	2.8	3.5
Funding organisations	1.5	1.8	1.8	1.8	2.5
Research	2.0	2.8	2.8	2.8	3.5
Non-government organisations / statistics offices	3.0	2.8	2.8	3.25	2.0

Where:

High scores (above 3.25) indicate a crucial role for the stakeholder (colour-coded red); medium scores (greater than 2.5 up to 3.25) indicate an important role for the stakeholder (colour-coded orange); and scores 2.5 or lower are left blank indicating a lesser stakeholder importance. See Annex 1 for further explanation.

9. Tracking progress for policy makers

This roadmap has identified an additional 13 EJ of techno-economical potential for renewable energy deployment in the global manufacturing sector. This potential is on top of the deployment opportunities already identified within the REmap 2030 report. Based on these findings and the discussions in the stakeholder workshops, this section summarises five activities for policy makers that resonate across six different priority areas that have been identified:

1. Cost-competitiveness of renewable energy technologies depends on continued technology development and a level-playing field for renewables by removing energy subsidies for fossil fuels. Action is required at a global level to ensure that competitiveness across industries in different regions is not distorted. Pricing of CO₂ emissions has also shown to be an effective fiscal mechanism to increase the prices of fossil fuels. Regarding materials, prices of CO₂ need to be tailored to the life cycle of products as a large share of carbon is embedded in products, in addition to emissions from production processes in the chemical sector.
2. For the transport and buildings sector, biomass makes up the bulk of the renewables potential in the global industry sector, as both a fuel for process heat generation and as a feedstock for materials production. Considering the total global and regional demand compared to the limited sources of biomass supply, it is of paramount importance to source biomass sustainably. Policies need to promote the extraction, trade and use of waste material in the first instance, as these compete less with natural resources required for food production, namely water and land. This also requires policies to increase the trade of biomass residues, whilst addressing sustainability concerns. This approach could be ensured with policies that develop and promote technologies, which increase the energy density of products so that agricultural practices are sustainable, emissions from logistics are lower and conversion efficiency of biomass to final products are higher. Simultaneously, the development of policies to cultivate energy crops without interfering with deforestation, loss of biodiversity, and land use change emissions are required. To conclude, realising the potential identified in this study requires the development of energy policies, as well as policies addressing agriculture (food, feed, forestry) sectors and effective resource use. Policies need to be implemented at the sectoral

level through international collaboration for the engagement of both OECD and non-OECD countries. This will ensure the optimum distribution of biomass to the various applications within the different branches of the economy.

3. More technological developments are required to increase the number of renewable energy options for the industrial sector. Promoting the development of cheaper and more effective solar thermal, geothermal and heat pump technologies so they are cost-effective compared to both fossil fuels and biomass is an important area that governments can support through R&D grants, the creation of knowledge networks and information provision. Furthermore, demonstration projects and the sharing of experiences across different borders and regions can create new market opportunities for technology developers and the creation of a new local industry.
4. Although governments generally try to attract manufacturing industries to their countries, the ultimate decision to open new production facilities lies with the companies themselves. Economic, but also social, political and environmental drivers, can impact these decisions. In this context, a shift of production activities to areas where renewable resources are abundant could result in a transformation of the industry. Governments could play a pro-active role in attracting manufacturing industries by promoting an environment where cheap and reliable renewable resources are available for use.
5. Realising the potential of renewable energy technologies requires dedicated policies. Compared to the transport or power sector, there are limited policies that specifically focus on renewable energy deployment in the industry sector. For example, separate targets could be developed that encompass the barriers (e.g., lack of awareness on technologies), needs (e.g., finance) and structure (e.g., capacity stock turnover, temperature levels) of energy-intensive and less energy-intensive sectors.

Progress indicators

REmap 2030 will be an ongoing process to explore effective pathways to increase renewable deployment through different technologies and resources, in both different countries and end-use sectors. The results of REmap 2030 have formed the starting point for this

analysis, and subsequently the results of this roadmap will be shared with the national REmap experts. Furthermore, as technology progresses, energy demand structures change, and economic and social drivers change the perspectives and actions of stakeholders, information and projections on the techno-economic potential need to be updated. It is therefore important to continue to monitor progress and evaluate priority areas and actions.

To conclude this roadmap, Table 10 suggests a number of indicators to track the progress of renewable energy technologies in the industrial sectors of the OECD and non-OECD countries, as well as the world as a whole. These indicators are helpful to monitor the progress on the action items this roadmap has suggested, and assist decision makers in choosing and following through on the next steps for action and accelerating the deployment of renewables in the manufacturing sector.

Table 10: Progress Indicators for Renewable Energy Technologies

	Unit	2010			2030		
		OECD	non-OECD	Global	OECD	non-OECD	Global
<i>REmap 2030 Reference case (estimated capacities):</i>							
Fossil fuel	(GW _{th})	800-1 100	1 800-2 200	2 600-3 300	700-1 000	2 100-2 500	2 800-3 500
Biomass	(GW _{th})	100-150	50-100	150-250	90-130	80-120	170-250
Solar thermal	(GW _{th})	-0.02	-0.02	-0.04	0.02	0.02	0.04
<i>Ambitious policy scenario (estimated capacities and renewable energy shares):</i>							
Fossil fuel	(GW _{th})	-	-	-	400-550	1 700-2 200	2 100-2 750
Biomass (additional)	(GW _{th})	-	-	-	220-300	300-500	520-800
Solar thermal (additional)	(GW _{th})	-	-	-0.03	70-150	400-700	470-850
Geothermal	(GW _{th})	-	-	-	60-100	80-120	140-220
Heat pump	(GW _{th})	-	-	-	5-20	30-70	35-90
Share of renewable energy in the fuel mix (excl. electricity, feedstock)	(%)	12%	9%	10%	45%	28%	34%
Share of feedstock use (excl. electricity)	(%)	21%	15%	17%	24%	24%	24%

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Annex 1. Scoring the Importance of Stakeholders

IRENA organised two stakeholder workshops to determine priority areas for action to accelerate the deployment of renewables. For each priority area, a number of actions have been defined. For each stakeholder, we have assessed the stakeholders' importance in the associated action areas.

The stakeholders' importance is assessed based on three criteria: A) The role of the stakeholder in initiating action, B) The time between the stakeholder action and the impact on the renewable deployment acceleration, and C) The extent to which stakeholders' action impact renewable deployment at a global, regional, national or local level. The total score for a stakeholders' importance are based on a weighted average with the weights being 50%, 25% and 25%, respectively (Table A1).

The total scores range between 1 and 4 depending on the role, impact, and geographical scope of the

stakeholders' action. The higher the score, the more important the role of the stakeholder in initiating action. Stakeholders with scores in the top 25% (3.25 or above) are colour-coded in red and indicate a crucial role for the stakeholder. Stakeholders that score above the median (2.5) are colour-coded orange and indicate an important stakeholder role. Scores below the median are left blank indicating a much lower importance of the stakeholder's role (Table A2).

The scoring of stakeholders' role provides a semi-quantitative overview of their roles in promoting renewable energy deployment in the manufacturing sector at the time of the development of this roadmap. The scores themselves are only indicative as the role and importance of stakeholders changes as technology, markets and deployment progresses.

Table A1: Weighting and scores of assessment criteria

	What is the role of the stakeholder?	When will the action by the stakeholder have an impact?	Where will the action by the stakeholder have an impact?
Weight	50%	25%	25%
Score - 1	Indirect	Long-term: >2030	Local
Score - 2	Support	Medium-term: >2020	National
Score - 3	Part of team	Short-term: > 2015	Regional
Score - 4	Lead	Continuous	Global

Table A2: Methodology to Assess Stakeholder Priorities within the Areas of Action

Stakeholders / Activities	Action area 1	Action area 2	Action area 3
Stakeholder	White indicates scores below or equal to 2.5	Orange indicates scores greater than 2.5 up to 3.25	Red indicates scores greater than 3.25



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