WBA fact sheet

ROLE OF BIOENERGY IN A CLIMATE NEUTRAL ENERGY SYSTEM

A SCENARIO COMPARISON

SUMMARY

Climate change today is what's happening here and now. Transition to a climate neutral energy system has multiple pathways, but fundamentally is underpinned by renewables, energy efficiency and conservation, electrification, hydrogen and its derivatives, and carbon capture and storage. Bioenergy as a versatile renewable source, with improved appliances and technologies, can facilitate this process through direct supply of green electricity, heat and fuel, indirect electrification in terms of conversion between biomethane and hydrogen, and carbon sequestration with biochar and BECCS equipments. In the power and heat sector, bioenergy functions as the best replacement for fossil fuels to provide grid flexibility, and feedstock blending can share the existing infrastructure while reduce the emission intensity. In transport sector, biofuel will keep being the major renewable substitute and blend for fossil fuels before the extensive electrification, then gradually shift and take up a large share in shipping and aviaion. In industry sector, bioenergy will play an active part in circular economy by managing industrial waste, providing process heat and feedstock for chemical production. In building sector, bioenergy will enable the wide public access to green residential heating and clean cooking, and help improve the socioeconomic and health conditions of rural residents.

INTRODUCTION

Figure 1: Climate change and the secondary disasters. Source: NASA

Climate Change

Human activities have induced unprecedented change across our climate system, and it is no longer just an image about a floe silently melting into the distant polar sea. Perceivably, the occurrence of extreme weather events, such as heat and cold waves, droughts and heavy precipitation, wildfires and tropical cyclones, especially their compound, turns out to be increasingly frequent and intense. The 6th Assessment Report (AR6) Working Group 1 (WG I) released by the United Nation's Intergovernmental Panel on Climate Change (IPCC) in August made it clearer than ever the urgency and gravity we are facing. Unless "immediate, rapid, and large-scale" actions can be taken to drastically cut emission, 1.5 °C of warming will come in a very near future.

Climate Neutrality

Since anthropogenic emission, especially burning fossil fuels, is the major climate forcer, to mitigate climate change foremost is to accelerate the transition of energy system. A climate neutral energy system, as defined by United Nations Climate Change (UNFCCC) in the 2015 action Climate Neutral Now, is an energy system with greenhouse gas emissions (GHG) equal to or less than which can be naturally absorbed by the planet, such that it has "net-zero" emissions. Transition towards a climate neutral energy system therefore will be a task with multiple objectives. First, phase out the energy sources with positive emissions and compensate their shares with low- or zero-emission sources. Second: reduce, remove or offset the positive emissions from sources difficult to phase out. Third, maintain and improve the capability of natural sinks.

Energy Transition

Energy transition, given the objectives above, can mainly be factored into renewables, energy efficiency and conservation, electrification, hydrogen and its derivatives, carbon capture and storage (CCS). In a variety of ways can bioenergy facilitate this process. As the main constituent of renewable mix today, bioenergy is characterized by its capability to supply electricity as well heat and fuels directly without losing carbon neutrality, while provide flexibility as fossil fuel power plants at a lower cost. Equipped with improved cook stoves, boilers or combustors, the efficiency of generation can be further enhanced. This procedure can even be carbon negative if combining with hydrogen or CCS (i.e., BECCS). Methane is interchangeable with hydrogen by nature, and power-to-gas is essentially indirect electrification as a means of energy storage. During those conversions, CO2 can be reformed either into biomethane or into solid carbon for industrial and agricultural uses. In terms of another GHG, methane, better management of agricultural residues and waste streams will significantly reduce its emissions, as well provide feedstocks for bioenergy in different forms. Before unfolding prospects on these interesting topics, we can first outline the status of bioenergy in the energy system today.

WHERE ARE WE NOW?

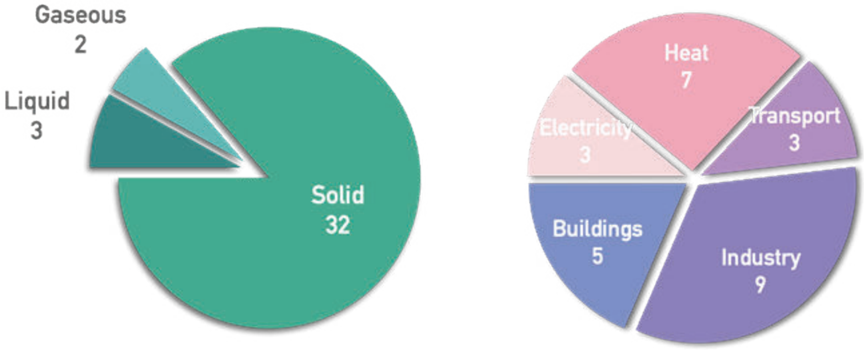

Figure 2: Bioenergy in 2020 by form and use (EJ) Data source: IEA (2021)

Traditional Bioenergy

Sourcing from organic materials, versatility is the key attribute of bioenergy. Its feedstock ranges from plants with short rotations, crops containing sugar and oil, to forestry and agricultural residues, industrial and residential waste. It is so easy to obtain that its utilization largely stagnates at a rather basic level, open wood logs burning, for instance. The direct combustion of biomass with primitive devices is what we called "traditional bioenergy", as compared to "modern bioenergy". In many developing countries, people rely on conventional use of biomass for cooking and heating. However, besides the low efficiency, the aerosol emissions from burning and over exploitation of vegetations might lead to health and environmental problems, thus it is also what to shift away from. Today, traditional bioenergy accounted for 4% of primary energy supply and 40% of bioenergy supply, and more than 2.6 billion people still don't have access to clean cooking (IEA, 2020). Both in the scenario of Net-Zero Emission from International Energy Agency (IEA) and in the scenario of 1.5 °C Pathway from International Renewable Energy Agency (IRENA), traditional bioenergy is to be phased out by 2030, meanwhile a universal access to clean cooking is to be realised.

Modern Bioenergy

Versatility of bioenergy is not limited to its feedstock. Transformation of solid biomass to liquid and gaseous phases can be easily made through fermentation, gasification, pyrolysis and other biological or chemical treatments. With functional properties resembling coal, oil and natural gas, bioenergy is taken to be the best substitute for fossil fuels. Products of modern bioenergy like pellets and biocoal, bioethanol and biodiesel, biogas and biomethane, can be cofired with coal or blended in petrol and natural gas. In 2020, 32 EJ solid, 3 EJ liquid and 2.1 EJ gas together amounted to approximately 38 EJ modern bioenergy, which made up 6% of total primary energy supply. 171 GW of bioenergy-based power has been installed and 718 TWh (about 2.58 EJ) of electricity has been generated, while heat generation reached 7.42 EJ. On the demand side, biomass, biofuels and biomethane each contributed 14 EJ, 3 EJ and less than 1 EJ to fuel consumption, of which 9 EJ went to industry, 3 EJ went to transport and 5 EJ went to buildings, comprising 6%, 3% and 4% of each sector. Notably, 1 Mt of CO2 was removed during the production of biofuel for transport.

WHERE SHOULD WE GO?

Though the penetration of renewables in the energy system has been fast growing recent years, with regard to the climate target, it is still far from enough. This, on the other hand, left it open how the changes could be made, and there is no single road but dynamics of pathways. Agencies like IPCC, IEA and IRENA all give their pictures of an energy system with a climate neutral future. Their strategies have different emphases and the roles of bioenergy in their scenarios are not necessarily the same. A comparative view is therefore needed to capture how we can give full play to bioenergy's potential. Here scenarios including IEA's Net-Zero Emissions in the report Net Zero by 2050, IRENA's 1.5 °C pathway in the report Global Energy Transition Outlook, and IPCC's pathways with low overshoot and high overshoot in the report Global Warming of 1.5 °C, are of concern to us.

Figure 3: Modern Bioenergy. Source: max renewables

In IEA - NZE, bioenergy is expected to take over the roles currently played by fossil fuels as they gradually withdraw from the market, especially in electricity sector, which requires dispatchable sources to balance the grid from time to time. Mixing biofuels with fossil fuels can make full use of the existing infrastructure, while effectively reduce the emission intensity of the same facility. IRENA - 1.5 highlights more how bioenergy can meet the needs of transport and industry as fuel and feedstock. Advanced biofuels are to be deployed in heavy freight, shipping and aviation, while various chemicals and plastics can be made from biomass. Heating in industry and for residential uses covering space, water and cooking will also partially be bioenergy-based. Alternatively, in IPCC - low and IPCC - high, bioenergy functions mostly as an emission offset by removing cumulative CO2 from the atmosphere, especially in the high overshoot scenario. Compared to natural forms of carbon sink, BECCS can store CO2 for a longer time and in a stabler way if sequestrating in geological formations.

In general, the role of bioenergy can be classified into three categories:

- as renewables for direct use;
- as the replacement for fossil fuels;
- as a removal method of CO2 emissions.

Even if they each have a purpose to serve in the above scenarios, they are not separate but highly entangled. By placing them in the context of energy mix we will better understand how they can collectively impact the system.

Total Primary Energy Supply

Aligning the total primary energy, renewable energy and bioenergy supply of all the scenarios as is shown in figure 4, features of each pathway become distinct. Among the four, IEA - NZE is the only one with a monotonic downward trend for total primary energy supply. The other three follow a "U" shape curve with the turning point at year 2030, but compared with the start, IPCC - low points to a future with an energy system scaled down, and the rest two a future relatively energy-intensive. IRENA - 1.5 fosters the greatest expansion in renewables, while IPCC - high needs most bioenergy to compensate emissions from other sources.

From the figure we can meanwhile find that, it is common to all scenarios that between 2020 and 2030, fossil fuels, at this stage also traditional biomass, are phased out at a rate faster than the growth of renewables. However, deducting the traditional part of bioenergy, the increase in modern bioenergy given by IRENA - 1.5 is still significant. From 2030 to 2050 this trend reverses except for IEA - NZE. Though renewables are more than doubled during this time, the decrease of fossil fuels and improvement in energy efficiency seems to largely reduce the overall scale of energy supply. The growth of renewables in IPCC scenarios is considerably motivated by bioenergy, whereas the remaining non-renewable part of which is also larger, thus the growth indeed aims for compensation.

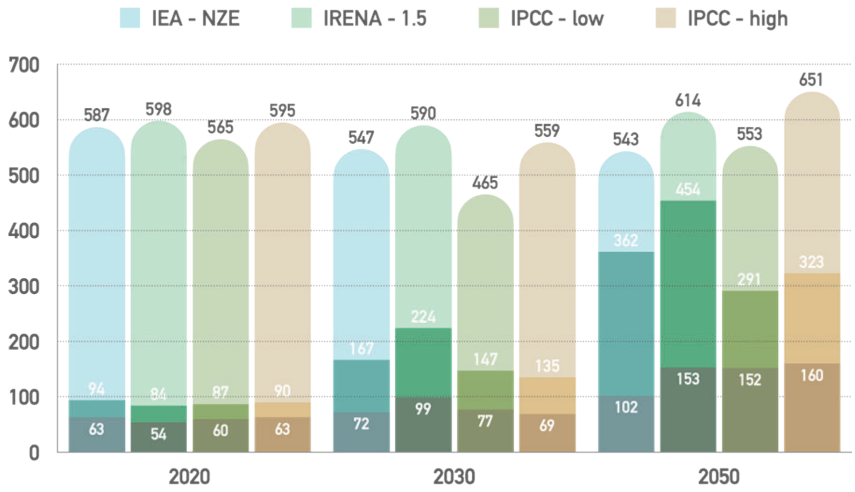

Figure 4: Scenario-specific energy supply (EJ)
[total primary energy (light) / renewable energy (medium) / bioenergy (dark)]
For uniformity, here traditional bioenergy is included in renewables and bioenergy in IEA - NZE 2020 scenario; statistics up to 2018 is adopted for IRENA - 1.5 2020, the actual number for 2020 is subject to change; IPCC - low 2020 scenario and IPCC - high 2020 scenario are both predicted values given the time AR5 was published.

As we have mentioned above, in IRENA - 1.5 and the two scenarios of IPCC, bioenergy takes up a more constructive part either for direct uses or CO2 removal, while in IEA - NZE it has a more supportive responsibility. This can be reflected right from the target amount of bioenergy supply in the four pathways. However, it is also clear that the more the energy system depends on bioenergy, the more it subjects to the constraint, hence the uncertainty of land availability. This comparison rather implies the trade-off among our different expectations: maintaining the current pattern of human activities or reconstructing it to the utmost could profoundly alter the present landscape, while a conservative transition could not be feasible without resort to other low-carbon sources, nuclear for instance. Only if we manage the balance with great care could we make the transition all-round sustainable.

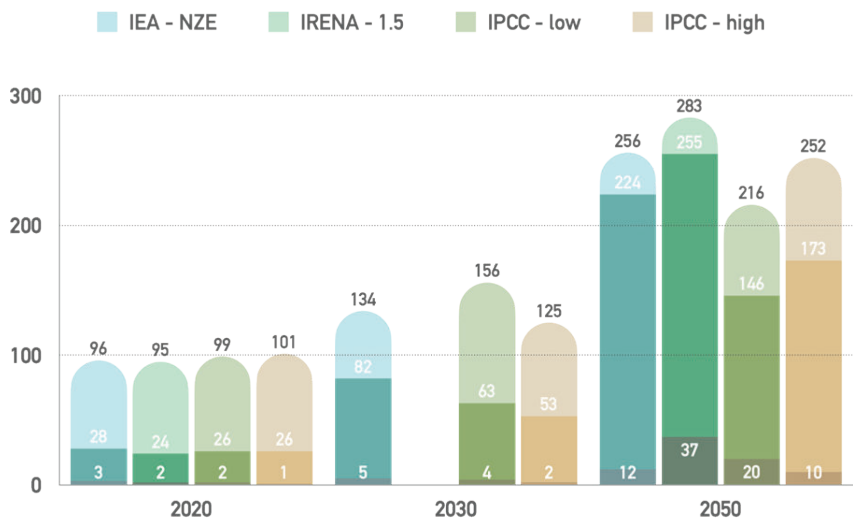

Figure 5: Scenario-specific power generation (EJ)
[total power (light) / renewable-based power (medium) / biopower (dark)]
For uniformity, here statistics up to 2018 is adopted for IRENA - 1.5 2020 scenario, the actual number for 2020 is subject to change, and the value for 2030 is yet to be published; IPCC - low 2020 scenario and IPCC - high 2020 scenario are both predicted values given the time AR5 was published.

Energy Supply by Sector

Electricity

Decarbonizing the power sector, the biggest source of emissions and to which most renewables can apply, coupled with electrification of the final consumption, is the core of energy transition. Power supply is to account for half of the total primary supply in IEA - NZE and IRENA - 1.5 in 2050, of which about 90% will be based on renewables. Two IPCC scenarios suggest a less radical path, but the direction is clear. The expansion of renewables in the electricity system is mostly attributed to the soaring of solar and wind power, and the share of biopower seems modest. However, increasing integration of distributive variable renewable energy (VRE) will also increasingly challenge the security and reliability of current power infrastructure. To cover or hedge the intermittency, either an installed capacity far surpassing the demand is needed, which is likely to result in considerable waste of resources, or a corresponding amount of flexibility should be added in. Theoretically any interruptible load or dispatchable source can be considered as a flexibility provider, but bioenergy outperforms in terms of its technical maturity and potential to be carbon negative.

As a dispatchable source, it is already widely applicable and there has been a substantial amount of established power plants or combined heat and power plants (CHPs) based on biomass or biogas, which start up fast and can be easily ramped up and down on demand. In mid-term it can make up for the seasonal and diurnal variations in demand or supply, in short term it can compensate the forecast errors or output fluctuation of VRE. Additionally, with the exits of power plants based on fossil fuels, there will be less synchronous units in the power system thus the grid inertia will decrease. Compounding with the large share of VRE, the grid stability could be under risk. Biopower plants equipped with gas or steam turbines, or fossil fuel plants repowered with bio-feedstock should then take over. More synchronous units connected to the network means ampler time left for response, especially when grid faults occur, thereby the overall resilience of the power system could be enhanced. Bio-feedstock for repowering or blending purpose meanwhile can reduce the emission intensity of the same facility. In India, co-firing biomass in thermal coal-fired power plants has been proposed by the Ministry of Power to be a national mission and is supposed to contribute to the National Clean Air Program.

As an interruptible load, surplus power can be used to upgrade biogas to biomethane, reform biogas to hydrogen as well hydrogenate waste CO2 to biomethane. In this way the excessive power can be stored in tank or in the natural gas grid instead of being curtailed, and the products of these conversions can again be fed to generate power when needed. Methanation is obviously a carbon negative process as CO2 is captured and converted into useful forms, but so do those transformations in an indirect manner. Biomass pyrolysis (i.e., thermal decomposition in the absence of oxygen, normally powered by electricity) turns the carbon content initially absorbed from the atmosphere into biochar, together produces bio-oil and syngas. Likewise, by pyrolyzing biomethane we can obtain solid carbon and the so-called “turquoise” hydrogen. These carbon products can be further used as industrial raw materials or applied to soil fertility amendment. With better water holding capacity and less nutrient loss, the food production can be therefore improved. IEA - NZE gives an anticipation of 570 Mt of CO2 reduction per year from BECCS in power sector by 2050. No matter as a dispatchable source or an interruptive load, even with a modest share in the mix, the part played by bioenergy can be decisive.

Figure 6: Pellet fuel for electricity amd heat production. Source: Bioenergy Insight

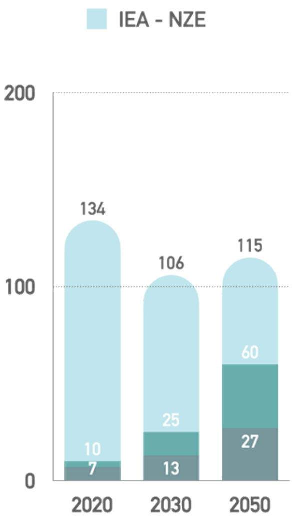

Figure 7: IEA - NZE heat supply (EJ) total heat (light) / renewable heat (medium) / bioheat (dark)

Heat

Bioenergy is the dominant renewable source in heat sector, which has a wide application covering industrial process heating, district heating, space and water heating as well cooking in buildings. The heat can be supplied by heat-only plants as well CHPs. With the waste heat from power generation recovered, the total fuel use efficiency of cogeneration can be up to 90%. Again, biomass can be cofired with or replace coal to reduce facility emission at a competitive cost. As a successful example, in Lithuania, biomass has provided energy for about 75% of total heat supply and 85% of district heat supply in 2020, while led to a 45% fall in national heat price and a 70% drop in CO2 emissions (WBA, 2021).

Since the estimation of heat in the scenarios are more specific to end-use sectors, the comparison will be conducted in the next chapter. For a basic idea, despite the significant reduction in the use of traditional biomass for space heating and cooking plus extensive electrification, the role of bioheat is nevertheless indispensable. In IEA - NZE, the overall supply of heat tends to shrink again as a result of phasing out fossil fuels and traditional biomass together with the improvement in energy efficiency, while the amount of renewable-based heat and bioheat will double at each stage of transition. Apart from providing half of the district heat, in subsectors hard to electrified, for instance industrial high-temperature heating, bioheat will be the major source to supply the heat and approach to reduce the emission intensity as a substitute of fossil fuels. BECCS will again be adopted in heat production and contribute to CO2 removal. In IRENA - 1.5, cumulatively 36 Gt of CO2 is to be reduced by BECCS in power and heat sectors by 2050, which accounts for 28% of the 126 Gt total removal goal.

Total Final Energy Consumption

As another pivotal pillar of energy transition, energy conservation and efficiency improvement will boost an economy less energy intensive. IEA - NZE and IRENA - 1.5 achieved a consensus on the decreasing of final consumption, though the descent in IEA - NZE is steeper comparing the two. If combining with the primary supply, it turns out that the final form of IEA - NZE is a more “compact” energy system, while IRENA - 1.5 directs to a rather “loose” one. In IEA - NZE the supply and demand shift in the same direction and result in an overall down-sized system, while in IRENA - 1.5 they change in reverse, and the supply is way surpassing the demand. This is conceivable, as a greater capacity is needed to cover the temporal and spatial unevenness of the larger amount of renewables in the energy mix, and the energy industry itself will be the engine of economic growth in terms of investment and jobs, rather than just a support. On the other hand, both pathways suggest an electrification rate of around 50% by 2050. In another words, almost half of the end-use sectors are hard to electrify, and bioenergy would be the ideal option to decarbonize those sectors if not the sole. In the following sections we will discuss the specific shares of bioenergy in transport, industry and buildings in the two pathways , as well the potential for sector coupling as a form of electrification.

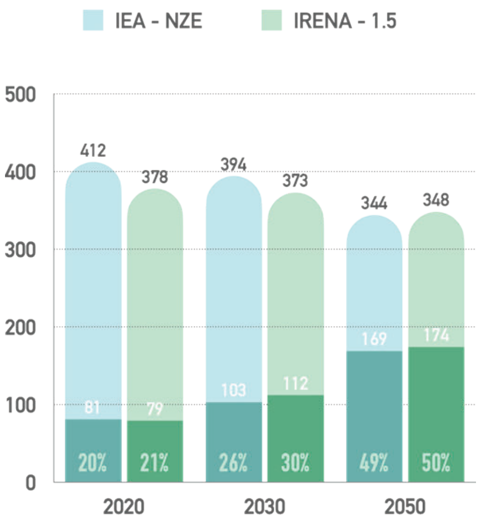

Figure 8: Scenario-specific energy consumption (EJ) [total final energy (light) / electricity (medium)] – [electrification]
For uniformity, here statistics up to 2018 is adopted for IRENA - 1.5 2020 scenario, the actual number for 2020 is subject to change.

Figure 10: Biofuel in aviation (United Airlines). Source: Bioenergy International

Energy Consumption by Sector

Transport

Transport is the sector dominated by fossil fuels most, but relatively easy to be electrified. The rate of electrification will rapidly increase from 2030 to 2050, corresponded with the remarkable drop in fossil fuel consumption. IEA - NZE and IRENA - 1.5 have basically the same pace regarding the change in each type of sources, though the remaining portion of fossil fuels in IEA - NZE is slightly higher than in IRENA - 1.5. Up to this point bioenergy is the major renewable source. It currently mainly consists of bioethanol and biodiesel, but other types of fuels, such as biomethane and biokerosene, in replacement of compressed or liquified natural gas and kerosene, are about to grow in the upcoming years. Between 2020 and 2030, bioenergy in transport will quadruple while electricity and hydrogen-based fuels gradually rise their shares. During this period, biofuels will mostly be applied to road transport, and the blending share in oil will reach 13%, finally 41% by 2050 according to IEA - NZE. With the improvement of infrastructure and the fall in costs for electric cars and fuel cell vehicles, the application of biofuels will shift to shipping and aviation. After 2030, transport sector, especially road transport, will be massively decarbonized by electricity and hydrogen added, while 21% of demand in shipping and 45% demand in aviation will be met by biofuels by 2050 in IEA - NZE. It also expects that, equipped with carbon capture and storage, biofuel production will reduce 625 Mt of CO2 per year.

Regarding automotive, the common bio-blends for petrol including ethanol E5, E10, E85 and E95, biodiesel B5, B10, B25 and B99, methanol M3, M15 and M85, as well ethanol-methanol alcohol fuels A20 and A30, with the number denoting the highest blending share. The low blends are normally compatible with most modern vehicles, while high blends sometimes require special designs for the engine. Compressed biogas (CBG) and liquified biogas (LBG) are also options for natural gas blending. As for marine transport, ethanol and methanol blends are also compatible fuels, while the application compared to biodiesel is currently limited. In terms of diesel replacement, biodiesel based on hydrotreated vegetables oils (HVO), or the "renewable diesel", functions better than biodiesel based on fatty acid methyl esters (FAME). Shipping companies like CMA CGM and Hapag-Lloyd have started trials for 20-percent biofuel blends. Again, LBG can be blended in vessel powered by liquid natural gas (LNG). Destination Gotland, which ferries passengers between mainland Sweden and the island of Gotland, has increased LBG share up to 10 percent in its LNG ships. In aviation, available bio-jet fuels mainly include HEFA-SPK, Bio-SPK, FT-SPK and ATJ-SPK , with the first being the most mature. As an industrial leader, United Airlines, which made a commitment of 50% reduction in its GHG emission by 2050, has agreed in 2019 to purchase up to 10 million gallons of aviation biofuels from World Energy, a company aiming to fully convert its paramount facility to produce biodiesel and bio-jet fuel.

Industry

Electrification of industry sector is trickier, and the strategies provided by IEA - NZE and IRENA - 1.5 are rather different. Above all, the total industry consumption in the two scenarios goes up from 2020 to 2030, but afterwards, the curve of IEA - NZE goes down while IRENA - 1.5's keeps going up. It suggests that in IEA - NZE, the decrease in fossil fuels is greater than the increase in renewables regardless of types, and vice versa in IRENA - 1.5. Both scenarios have industry consumption in 2050 higher than the consumption in 2020,

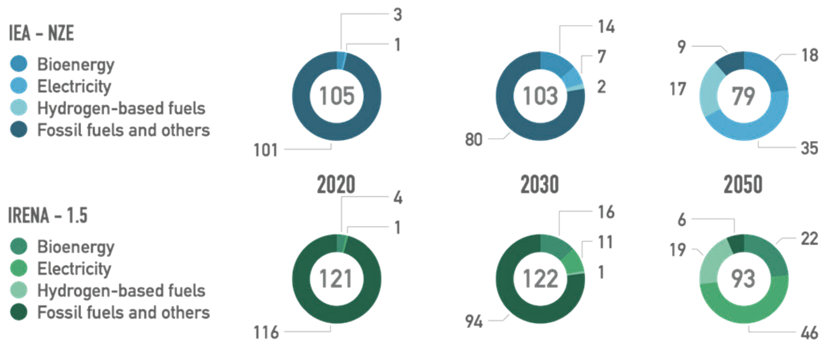

Figure 9: Scenario-specific energy consumption by sector: transport (EJ)
For uniformity, here statistics up to 2018 is adopted for IRENA - 1.5 2020 scenario as it is the latest, the actual number for 2020 is subject to change.

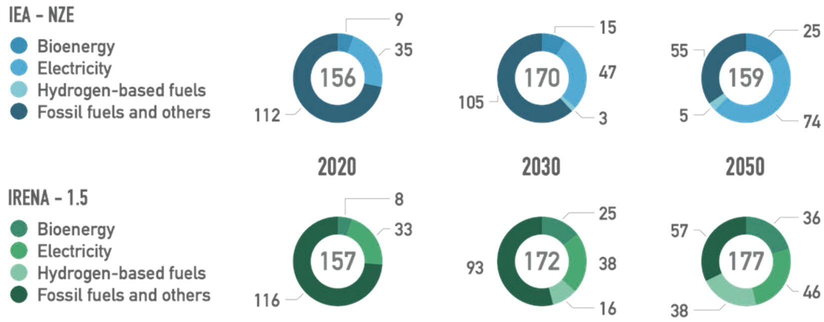

Figure 11: Scenario-specific energy consumption by sector: industry (EJ)
For uniformity, here statistics up to 2018 is adopted for IRENA - 1.5 2020 scenario as it is the latest, the actual number for 2020 is subject to change.

which runs counter to the trend of shrinking total consumption. Since phasing out fossil fuels here requires more renewables to offset, decarbonization of industry sector turns out to be the costliest. In terms of electrification, IEA - NZE adopts a direct mode. Increase in electricity consumption is ahead of others and about to accelerate after 2030. By 2050 it will make up nearly half of the energy demand in industry. IRENA - 1.5, by contrast, opts for a more indirect mode. The increasing part of electricity in IEA - NZE is largely taken by hydrogen, which grows from almost none to 38 EJ in 2050, while the growth of electricity is comparatively slow. Bioenergy is also assigned a higher weight in this scenario. The amount of bioenergy in 2030 in IRENA - 1.5 is supposed to achieve the level of 2050 in IEA - NZE, though the growth tends to slow down in the following 20 years. After all these efforts, there will still be over 50 EJ of fossil fuels remained and relying on CCUS to decarbonize, or the emission of which needs BECCS or other methods to offset. According to IEA - NZE, annually 180 Mt of CO2 will be captured by BECCS in industry sector by 2050, and this number even rises to 1.5 Gt per year in IRENA - 1.5.

Bioenergy will participate in industry mainly in two forms: as feedstock and as heat provider, but it does not necessarily mean this is a one-way process. IRENA - 1.5 emphasises the utilization of biomass in petrochemical industry for chemical and bio-plastic production, as part of the circular economy. Genecis in Canada, for instance, makes polyhydroxyalkanoates (PHA) from organic food waste as a substitute for plastics. As for process heat, bioenergy will be the major provider for heating at low or medium temperature, as well meet 15% of high-temperature heating demand in IEA - NZE. It underlines the application of bioheat in heavy industries, especially in cement and paper: by 2050, 30% of heating in cement industry and 60% of heating in paper industry will be bioenergy-based. Some heat-intensive industries, paper included, also steel, brewery, dairy, sugar and so on, not only deploy bioheat in the production process, but the other way around can turn their wastes into energy. Gasum in Sweden is to use the waste process water from the paper and pulp production of Stora Enso at Nymölla, to generate LBG for customers like Destination Gotland. ArcelorMittal, as a leading steeling company, besides deploying biomass for steelmaking process, uses the waste gas to produce bioethanol, as well biomethane to meet the power and heat needs in bioethanol distillation. Brewery Göss in Austria makes beer using heat from biomass district heat and waste heat from nearby wood processing plant, and the spent grains from brewing are used to ferment biogas in replacement of fossil-fuel gas, with the excessive part going to power production and waste heat for water heating. More and more dairy factories are investing to build biomethane plants from manure or food wastes for the internal electricity and heat needs. Though industry sector is the hardest to decarbonize, it is in return the part that engages various groups and communities most.

Buildings

Compared to transport and industry, building sector has the lowest ratio of fossil fuels to electricity and can be decarbonized through various approaches. Basically, energy consumption in building sector can be divided into electricity for appliances, space heating and cooling, water heating and cooking. Besides power production, bioenergy again functions mainly as a heat provider for space, water and cooking. Though there are other clean alternatives such as heat pumps, which is electricity-based and to be widely applied, also solar thermal and geothermal, their limitations are nevertheless clear. The efficiency of heat pumps may decrease when the environmental temperature is too low, while solar thermal and geothermal subjects to temporal and spatial constraints. The versatility of bioenergy enables its use when conditions for these alternatives are not satisfied. Most importantly, for regions temporarily with limited access to stable power supply, it is still possible for people to improve their circumstances with improved cooking stoves and boilers. On the other hand, as is mentioned, bioenergy together with electricity and hydrogen-based fuels will be used in district heat to decarbonize the sector. With the sources above, both IEA - NZE and IRENA - 1.5 propose a rapid decline in fossil fuels and a rather high degree of electrification in building sector: 67% and 73% respectively. Regarding bioenergy, as is mentioned, they both target to phasing out the traditional part by 2030, despite marginal divergence about whether to raise or lower the demand of modern part given their overall strategy.

Comparing to the traditional uses of biomass like open fire burning, which contribute to pollutants emission including CO, NOx, PM2.5 and PM10, modern bioenergy with appliances such as pellet

Figure 12: Bioenergy in brewery (Brewery Göss). Source: Edie.net

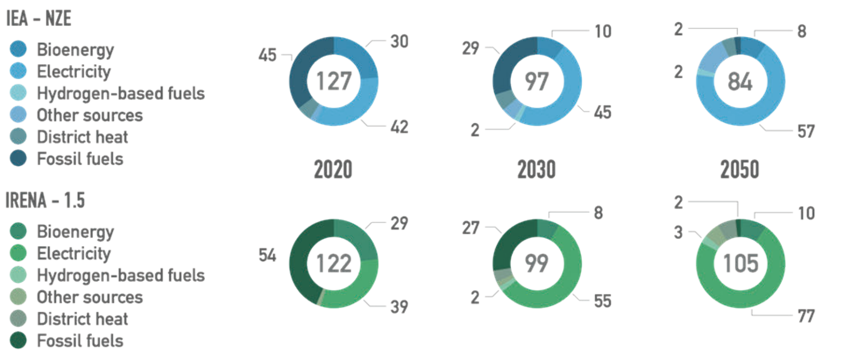

Figure 13: Scenario-specific energy consumption by sector: buildings (EJ)
For uniformity, here traditional bioenergy is included in renewables and bioenergy in IEA - NZE 2020 scenario; statistics up to 2018 is adopted for IRENA - 1.5 2020 scenario as it is the latest, the actual number for 2020 is subject to change.

Figure 14: Traditional cook stoves and improved cook stoves. Source: left – ISO; right – ipsnews.net

boilers and stoves, can have an emission level twenty-times lower. These appliances are efficient, easy for building upgrade, and not necessarily coming with a higher price. With sustainably managed feedstock and improved equipment, not only the methane emissions induced by waste decomposition and aerosol emissions by inefficient combustion will be largely reduced, but also, the health and economic conditions of rural residents, especially women and children freed from fuel collection, will be much better off.

Sector Coupling

Given this much end-use electrification, a stable and secure power supply is the cornerstone that makes the transition possible. However, it is the essence of the power system that the supply must be always kept matching the demand. As we have mentioned in the electricity section, the integration of VRE poses challenges to the current grid therefore the stability and security of power supply, which requires a higher level of flexibility to better control. Sector coupling namely is to fix a connection between supply and the demand that we know for certain and under our control, such that we can make demand match supply. The aim, according to IRENA's definition, is to decouple "the timing of demand for final energy from electricity demand". The power-to-gas technologies we have discussed are also of concern here. When the biomethane or hydrogen generated by surplus power is fed into gas grid for heating or processed into fuels and chemicals, we are coupling power with heat, transport and industry. Therefore, when we decarbonize the power sector, we are also decarbonizing sectors like heat, transport and industry. These technologies have yet to be matured and the existing power-to-gas projects mainly concentrate in Europe especially Germany, north America and Japan. But considering the combining share of hydrogen and bioenergy in the end use sectors, as well the target for carbon reduction, the market potential will be widespread and huge. Only with the synergies among renewable electricity, bioenergy and hydrogen, will we have the chance to make the transition within the time limit.

HOW TO REACH THERE?

To achieve the goal of a climate neutral energy system, bioenergy is supposed to be extensively scaled up, which depends on production essentials including but not limited to natural resources, human resources and investments. How the land and water are developed, how the development will affect the local community even the whole value chain, determines the sustainability of this activity. As is discussed above, IEA - NZE, IRENA - 1.5 and the two IPCC scenarios each has a focus regarding the role of bioenergy in their own context. IEA - NZE dedicates to attaining transition with the least add-on human activities and the highest efficiency, IRENA - 1.5 seeks to make renewable a boom industry that fuels economic growth especially in a post-pandemic era, while IPCC scenarios try every means to cut emissions in every possible circumstance, despite the internal trade-offs between the approaches or sustainable development goals. How to dispose these essentials is thus pretty much context specific.

Land and Water

Wide deployment of biomass for power or fuel production or BECCS relies on a substantial amount of feedstock supply. However, the land and water used for energy crops cultivation might be competitive with afforestation and food production. As forest is one of the major carbon sinks, overdependence on BECCS might result in the reduction of sequestrated by other vegetation. If too much cropland is occupied by energy crops, the food supply might be under risk or the food price might be coupled with uncertainties of energy price, and the food security might be impacted. Therefore, carefully managing the land and water use is crucial for the transition to be truly sustainable. IEA - NZE proposes to add extra 80 Mha to current 330 Mha of land use for biomass supply, which

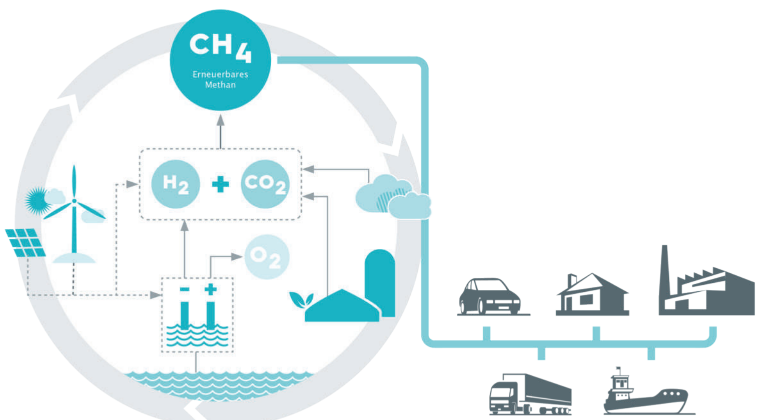

Figure 15: Participation of bioenergy in sector coupling. Source: DVGW | ebi

will consist of 270 Mha for forest and 140 Mha for energy crop, mainly short-rotation woody crops. Without this add-on, it is likely for the bioenergy to be 10% less and the expense in transition to be USD 4.5 trillion higher. In IPCC - low, the land used for energy crops ranges from 20 to 280 Mha, while in IPCC - high, the number jumps to 780 Mha. Particularly, BECCS has the potential to annually reduce 0.5 – 5 Gt of CO_2, which requires 31 – 58 Mha of land and 60 km3 of water per Gt CO_2, while biochar has the potential to annually reduce 0.3 – 2 Gt of CO_2, which requires 16 – 100 Mha of land per Gt CO_2 without usage of water. This kind of resource consumption is huge and will significantly affect other segments of the whole society, thus is to be handled with great discretion.

Job

The lifecycle of a project, from conception, development, construction, operation and maintenance, and finally decommission, requires participation of people from various functions all along the supply chain, and in return, gives people sources of income, stimulates consumption and boost economy for local community or for even greater scope. IEA - NZE expects that the thriving bioenergy industry will provide additional 1.67 million jobs by 2030, given the 3.22 million level in 2019. As is mentioned, IRENA - 1.5 considers bioenergy as an engine of economic growth instead of a support, thus this pathway has a rather optimistic anticipation. Bioenergy in 2021 has created overall 5.34 million jobs, while as the second largest driver of job growth, this number will rise to 11.11 in 2030 and 13.67 in 2050, of which mostly are for biofuel production. Given its labour-intensive feature, especially for biomass feedstock supply from agriculture and forestry, job created by biofuel from today's 4.6 million will reach 9.4 million in 2030 and 11.2 million in 2050, which constitutes 26% of the 43 million jobs generated by renewable energy.

Investment

To realize all that has been envisaged, a vast amount of investment is to flow in bioenergy industry. IEA - NZE estimates a great increase in investment during this decade, from annually USD 33 billion to USD 181 billion, which is likely to support the fast growth in transport and industry application. With the maturing of electrification, this number will drop to USD 133 billion after 2030. From 2040 to 2050, the annual investment will rise back to USD 150 billion in order for the goals to be met. IRENA - 1.5, on the other hand, gives a general yearly investment of USD 226 billion by 2050, with a breakdown of USD 87 billion for biofuel, USD 69 billion for biopower, USD 21 billion for bioenergy direct use, USD 2 billion for bio-based district heat, USD 22 billion for bio-based ammonia, USD 12 billion for bio-based methanol, and USD 13 billion for bio-based plastics and organic materials. To attract and reassure investors, policy makers are supposed to release strong and clear signals about the target and the direction, as well improve the industry regulations, simplify the permission procedures and provide financial support if possible. With less political uncertainty, investors will have more confidence to enter the market and facilitate the transition.

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