The Transition to Low Carbon in Alumina Refining

Stephan Beaulieu[1] and Rioch Magan[2]
1. Process and Efficiency Coordinator
2. Energy Decarbonisation Coordinator
Rusal Aughinish, Aughinish Island, Askeaton, County Limerick, Ireland
Corresponding author: stephan.beaulieu@augh.com

Abstract

The Rusal Aughinish Alumina (AAL) refinery is located on Aughinish Island on the shore of the Shannon Estuary, 33 kilometres west of Limerick city in the South West of Ireland. The plant, commenced operation in 1983 and has a current production capability of 1.99 million tonnes per annum. The source of bauxite is predominantly from Guinea and Brazil, which is used to produce alumina via the Bayer process. AAL started its decarbonisation investment journey nearly two decades ago with the installation of a high efficiency Combined Heat and Power (CHP) plant which was best available technology at the time in Ireland, and today is still second only to renewables such as wind or solar for low carbon intensity. In the intervening years AAL has progressively converted the entire refinery from fuel oil to natural gas. In December 2019, the introduction of the European (EU) Green Deal to reduce carbon emissions by 55 % by 2030 gave a clear signal to the world that a transition to renewable energy technologies is required in society and in industry sectors, including the aluminium value chain where alumina refining belongs. Beyond 2030, the EU Green Deal also provides a framework to carbon neutrality by 2050 with many other countries recently providing similar pledge. With this goal in mind, each industrial sector and individual facility must identify the optimum decarbonisation path based on geographical location and available renewable energy technologies, now and in the future. Many of the decarbonisation technologies are currently not commercially viable at the scale required for alumina refining. Private and public stakeholders have to work together to provide solutions that are practical, can be made viable and implemented at an historically fast pace to meet this goal. This paper provides details of the decarbonisation plan for an alumina refinery based in Ireland.

Keywords: Alumina refinery, decarbonisation, renewable energy.

1. Introduction

Alumina production started in 1983 with a production name plate capacity of 800,000 tonnes per annum using a single production chain. Over the years, production capability was increased to 1,990,000 tons per annum while remaining a single chain operation. Protecting the surrounding environment has been an integral part of the management of the refinery for decades. For nearly two decades, the focus to reduce emissions to air and more specifically Greenhouse gas (GHG) emissions has been paramount for AAL.

AAL's approach to reduce emissions used in the early 2000s was three-fold:

- Improve energy efficiency in the refinery to reduce primary energy consumption.
- Implement new technology to significantly reduce carbon emissions
- Transition to new fuel type to reduce emissions

This resulted in a complete transition to natural gas for all process heat requirements and the installation of a high efficiency CHP plant to generate electricity for internal use and also to export to the National electricity network.

Nearly 20 years later, a much more ambitious transition is being developed in Europe under a program called the European Green Deal (EU Green Deal) which was released in Dec 2019. The European Green Deal is a set of policy initiatives introduced by the European Commission (EU COM) with the overarching aim of making Europe climate neutral in 2050 [1]. On July 14th 2021, the EU COM released a set of proposals to make the EU's climate, energy, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55 % by 2030, compared to 1990 levels. Achieving these emission reductions in the next decade is crucial to Europe becoming carbon neutral by 2050 and making the European Green Deal a reality.

AAL has been actively involved in understanding how to implement the EU Green Deal which will be both a major challenge to our industry sector to remain competitive globally and an opportunity to participate in the development and integration of new technologies which will be necessary to protect the environment and climate of the planet.

The following sections of the paper provide details on the carbon journey so far and an insight into transition options open to AAL.

2. Carbon Journey so Far

The migration from fuel oil to natural gas was delivered with a major multi-year investment programme.

In 2006, a new 160MW natural gas High Efficiency Combined Heat and Power plant (or CHP) was installed which supplies 300 tph of steam to the refinery and 45 MW of electricity to supply the plant equipment. The excess power is exported to the National electricity grid. The electricity produced by AAL CHP (240 g CO_2 per kWh) has had much lower carbon content compared to the National electricity grid carbon content which was at 635 g CO_2 per kWh when CHP was commissioned and at 324 g CO_2 per kWh in 2019 [7] (see figure 1). In 2021, AAL CHP still produces the lowest carbon power on the grid after renewables such as wind and solar in Ireland. CHP will remain the best technology until a renewable fuel is commercially available and economically viable to industry in Ireland which is many years away.

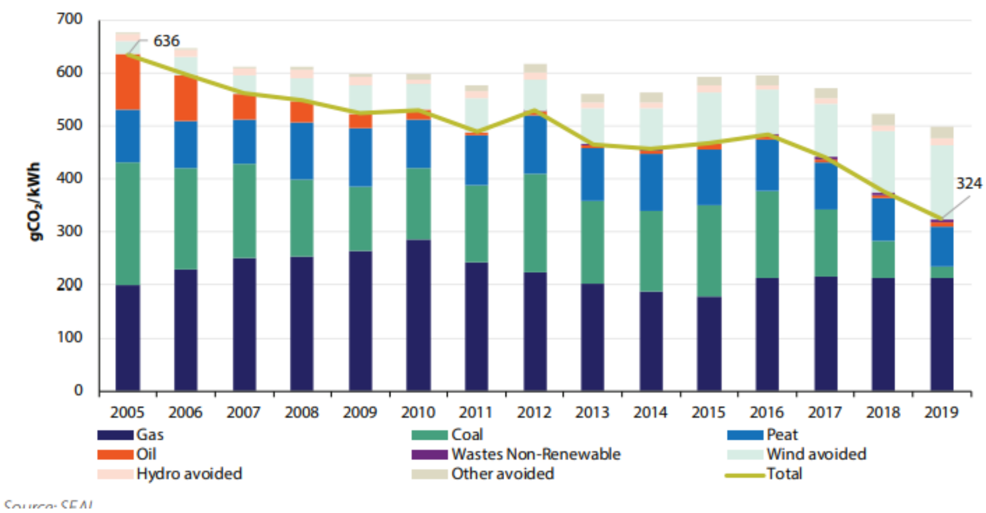


Figure 1. CO_2 Intensity of electricity in Ireland [7].

The AAL transition to natural gas continued with the conversion of the three alumina calciners completed by 2012. In 2014, two new gas boilers were installed to replace the fuel oil boilers fully completing the transition to natural gas (see Figure 2).

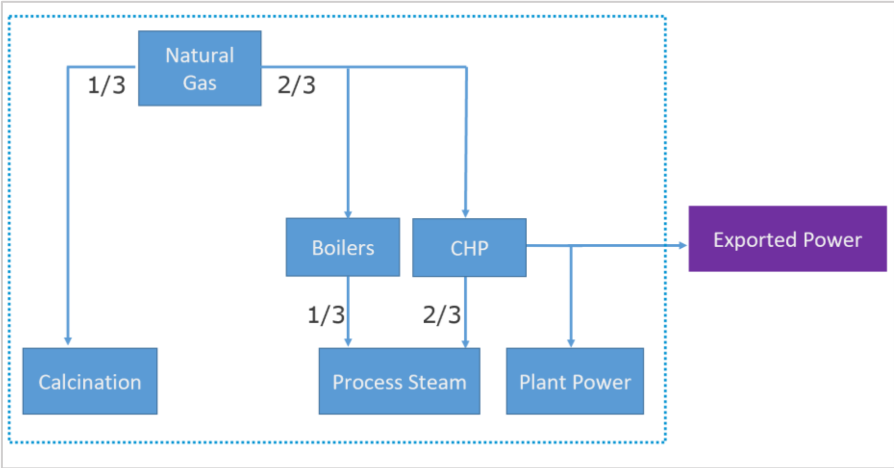


Figure 2. 2021 Energy flow chart.

A significant reduction in air emissions was achieved during this transition, and continuous improvement projects were also delivered in parallel to reduce gas consumption and air emissions further. Overall, carbon emissions have reduced by 40 % since pre-CHP, sulphur oxides eliminated with near 100 % reduction, and nitrogen oxides reduced by 90 % (see Figures 3 and 4).

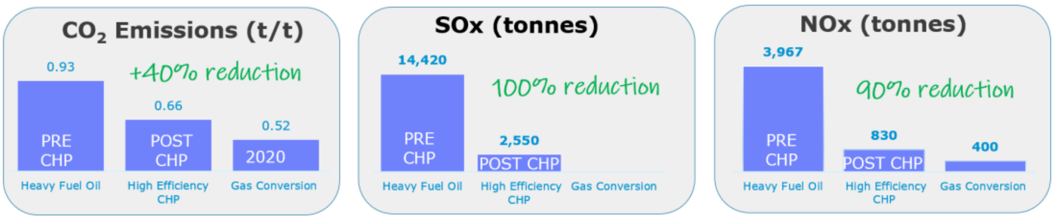


Figure 3. Air emissions reduction.

An additional source of carbon reduction at the refinery is from the natural carbonation and neutralization of bauxite residue with CO_2 from the air during the Dry Stacking method of storing bauxite residue at Aughinish. This process sequesters approximately 11,000 tonnes of carbon dioxide per annum.

The carbon intensity of the refinery is one of the lowest in the world at 0.516 tonnes of CO_2 per tonne of alumina in 2020. While this is a significant milestone in the operation of the refinery, the most ambitious technological and commercial challenge is being developed in Europe and globally to combat climate change, with the European Union and many countries pledging to deliver carbon neutrality before 2050 and 2060 for China.

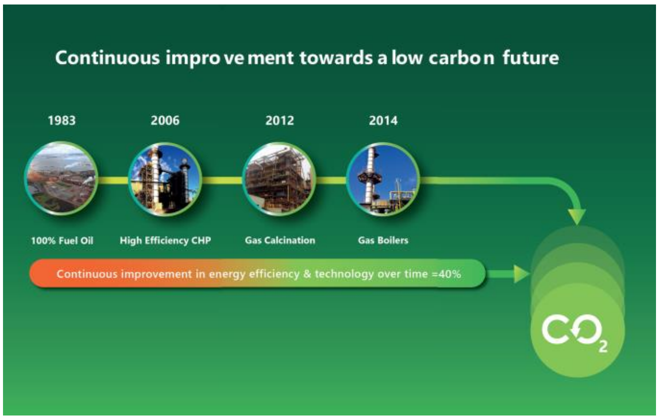


Figure 4. 2006 - 2020 Transition to lower carbon.

3. Alumina and Aluminium Part of a Low Carbon Future

In modern society, smelter grade alumina and aluminium play a key role in low carbon and energy efficient applications. Aluminium offsets the emissions associated with its production by providing significant emissions savings through its use in many applications.

The properties of aluminium that make it the metal of choice:

1. Low Density – aluminium is one third the density of steel which means lighter transport vehicles, with lower fuel consumption and associated emissions.
2. Aluminium used in construction such as windows, ventilation systems and cladding, improving the energy performance of buildings.
3. Many uses in multiple forms as aluminium can be made hard, soft, stiff, smooth, flexible, heat resistant depending on the need.
4. Aluminium can be recycled repeatedly without losing its properties, with a fraction of the energy required to produce new metal.

For these reasons, aluminium is a preferred material in the automotive, aerospace, packaging, building and electronic sectors. Those low carbon technologies, which are and will increasingly require aluminium, include electric vehicles and solar panels.

Increasing the aluminium content of cars alone plays a significant role in enabling the EU to achieve its target for vehicular CO_2 emissions.

The World Bank has identified that the production of low carbon technologies from materials such as aluminium will increase very significantly with global demand for aluminium expected to double from 50 to 100 million tonnes per annum (see Figure 5). Minerals that are both "high-impact" and "cross-cutting" will be used in a wide range of technologies and a great amount of them will be required to meet projected demand in a low-carbon world. One example is aluminum, used widely for both energy generation and storage technologies, with roughly 103 million tonnes of aluminum needed to supply 87 % of solar PV and a range of other clean energy technologies to achieve a below 2 °C future. Aluminum is thus a "critical" mineral because it will be necessary for the clean energy transition, regardless of which scenario plays out [5].

World Bank Group

Figure 5. Aluminium - Critical mineral.

4. Overview of the European Green Deal and Carbon Reduction Ambition

In December 2019, the EU COM released the most ambitious climate plan ever produced in Europe. The European Green Deal provides a roadmap with actions to boost the efficient use of resources by moving to a clean, circular economy and stop climate change, reverse biodiversity loss and cut pollution. It outlines investments needed and financing tools available, and explains how to ensure a just and inclusive transition [3].

More specific and relevant to carbon, all 27 EU Member States committed to achieving a climate neutral continent by 2050. To get there, they pledged to reduce emissions by at least 55 % by 2030, compared to 1990 levels.

The commitment is real and has been put into law. In June 2021 the EU Parliament approved the first EU Climate Law. The EU Climate Law sets into law the goal in the European Green Deal – for Europe’s economy and society to become climate-neutral by 2050. This means achieving net zero greenhouse gas emissions for EU countries as a whole, mainly by cutting emissions and investing in green technologies.

With the European Climate Law, the Commission proposes a legally binding target of net zero greenhouse gas emissions by 2050. The EU Institutions and the Member States are bound to take the necessary measures at EU and national level to meet the target, considering the importance of promoting fairness and solidarity among Member States [4].

The Irish government has approved the Climate Bill in March 2021 to reduce carbon emissions by 51 % by 2030 versus 2018. The Irish economy emits 60 million tonnes of carbon annually. Eight million tonnes are emitted by the industrial sector of which AAL alumina refining is a part with approximately 0.95 million tonnes of carbon. As a result of this bill, the Irish climate plan is being prepared for the next decade, with AAL clearly having to make further significant carbon reductions to support the National and European requirement.

Reducing greenhouse gas emissions is a key strategic goal of RUSAL. The Company has announced its ambition to achieve net zero carbon emissions by 2050 and to reduce greenhouse gas ("GHG") emissions by at least 35 % by 2030 (Scope 1 and 2) [6].

AAL has been working for some time to establish the best options to deliver major carbon reductions in line with Rusal's ambition and in support of the Irish Government Climate Action Plan.

5. The Green Deal and its Impact on Industrial Sectors

As part of the Green Deal, new technologies will be explored, developed, demonstrated and implemented using the European Emissions Trading System (ETS) Innovation fund. While these technologies are currently not commercially viable, it is expected that some have the potential to become major enablers in the transition to carbon neutrality.

Probably most important of all for any alumina refinery is that this transition to low carbon will require extremely high capital investment and deliver high operational costs for the initial development phase (which could be many years).

The Green Deal provides a holistic approach to climate change but lacks in providing the required support to industry to deliver it. This transition can only be achieved in the given timeline with high financial support to install and operate these new technologies without compromising the European industry.

6. Energy Position in the World and More Specifically in Ireland

Before going into the details of possible options open to Ireland and more particularly to alumina refining in Ireland, it is important to note that most industrial sectors in the world are just initiating a transition from coal, oil and peat to natural gas. This is also the case for much of the alumina sector where most installations around the planet are operating on coal and fuel oil and recently moving to natural gas or planning the transition.

6.1 Why is the Industrial World not Moving Faster to Renewable Energies?

6. Renewable energy is not available in quantities required for industrial sectors. There is currently no renewable gas/fuel readily available at the required quantity and commercially viable in Europe or globally to supply the industrial sector or the alumina sector. Technologies are being developed and most of them are at pilot stage or demonstrator scale. Examples of this are the production of green hydrogen, energy storage technology or carbon capture.

7. Fossil fuels are relatively cheap in comparison to renewable energy. Carbon capture and green hydrogen will potentially be part of the solution but current commercial capital and operational costs are prohibitive and uneconomical. Process electrification would need to be provided at much lower price to be viable for an alumina refinery.

8. There is insufficient infrastructure in place to provide these new renewable energies.

9. Many renewable energy sources are intermittent and will require storage capacity (wind is only blowing sufficiently a relatively low percentage of the time and solar energy cannot be captured during night time so very large storage infrastructure will be required to release energy in periods of no wind or no light. Hydrogen and carbon capture will also require major storage infrastructures similar to what is currently available for fossil fuels.

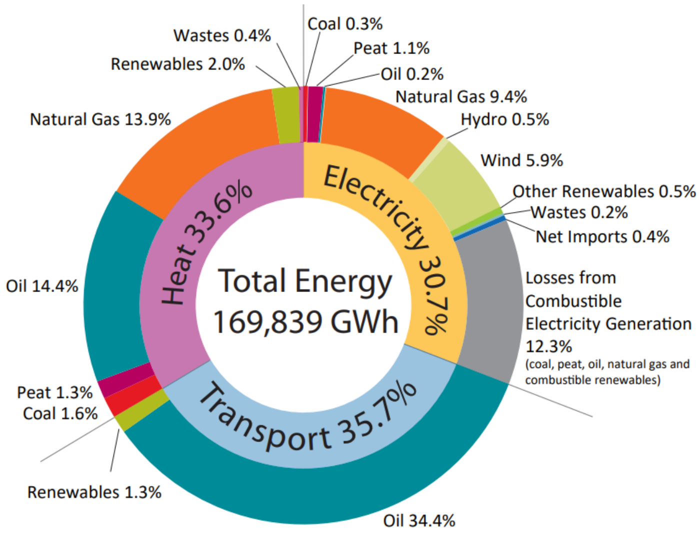
6.2 Position in Ireland

AAL is located on an island where the wind is a natural resource that can contribute to the decarbonisation of the country. Even though a lot of work has been done to install renewable energy in Ireland in the past 15 years, its share in 2019 was only 11.2 % (from 2.3 % in 2005) of the primary energy sources (with wind at 5.9 %). Most of the primary energy sources used in Ireland in 2019 were fossil fuels with a share of 87.5 % (from 96.6 % in 2005) with fuel oil leading at 49.3 % followed by natural gas at 31.3 % [7]. See Figure 6 below for more details from latest published data (December 2020) by Sustainable Energy Authority of Ireland (SEAI) [7]. In Ireland, the transition away from coal and peat should be completed in near future.

	Overall Growth %	Average Annual Growth %				Quantity (ktoe)		Shares %	
	2005 – 2019	'05 – '19	'10 – '15	'15 – '19	2019	2005	2019	2005	2019
Fossil Fuels (Total)	-16.6	-1.3	-2.0	0.3	-3.0	15,311	12,774	96.6	87.5
Coal	-79.8	-10.8	3.4	-28.5	-53.3	1,882	380	11.9	2.6
Peat	-20.5	-1.6	0.0	-4.8	-8.3	791	629	5.0	4.3
Oil	-21.3	-1.7	-1.8	2.0	0.1	9,134	7,193	57.6	49.3
Natural Gas	30.5	1.9	-4.4	4.9	2.0	3,503	4,571	22.1	31.3
Renewables (Total)	339.8	11.2	10.9	9.4	10.3	370	1,629	2.3	11.2
Hydro	40.4	2.5	6.1	2.4	27.7	54	76	0.3	0.5
Wind	801.1	17.0	18.5	11.1	16.0	96	862	0.6	5.9
Biomass	45.3	2.7	2.3	3.5	-3.9	180	262	1.1	1.8
Other Renewables	971.0	18.5	8.7	11.9	7.0	40	429	0.3	2.9
Wastes (Non-Renewable)	-	-	51.7	20.6	-0.1	-	145	-	1.0
Electricity Imports (net)	-68.5	-7.9	7.4	-1.1	-	176	55	1.1	0.4
Total	**-7.9**	**-0.6**	**-1.1**	**1.2**	**-1.2**	**15,857**	**14,604**		

Figure 6. Primary energy sources used in Ireland – SEAI 2020 report [7].

Energy used to generate electricity accounted for 30.7 % of all energy use in Ireland in 2019 (Figure 7). A significant proportion of this is lost in the form of waste heat during the electricity generation process (12.3 %). The largest share of the electricity generated came from natural gas at 51 % (9.4 % of primary energy) followed by wind which accounted for 32 % (5.9 % of primary energy). Coal generated electricity represented 0.3 % of primary energy in 2019, and peat 1.1 % [7]. The figure below shows the latest published data for Primary energy sources by mode and fuel type.



Source: SEAI

Figure 7. Primary energy Ireland by mode and fuel - SEAI 2020 report [7].

The overall share of fossil fuels used in electricity generation was 71.1 % in 2019 (93 % in 2005) and renewables at 25.7 % (Figure 8). Coal, peat and oil are being phased out for electricity generation. Natural gas' share of the energy used in electricity was 56 % in 2019 (40 % in 2005).

	Overall Growth %	Average Annual Growth %				Quantity (ktoe)		Shares %	
	2005 – 2019	'05 – '19	'10 – '15	'15 – '19	2019	2005	2019	2005	2019
Fossil Fuels (Total)	-33.0	-2.8	-4.1	-3.5	-7.8	4,756	3,186	93.0	71.1
Coal	-89.3	-14.8	5.4	-39.4	-68.9	1,422	152	27.8	3.4
Peat	-12.5	-0.9	2.4	-5.9	-8.2	496	434	9.7	9.7
Oil	-90.1	-15.2	-8.9	-2.3	125.9	794	78	15.5	1.8
Natural Gas	23.4	1.5	-8.9	7.3	2.5	2,044	2,521	40.0	56.2
Renewables (Total)	541.5	14.2	15.3	11.3	13.0	180	1,153	3.5	25.7
Hydro	40.4	2.5	6.1	2.4	27.7	54	76	1.1	1.7
Wind	801.1	17.0	18.5	11.1	16.0	96	862	1.9	19.2
Other Renewables	621.6	15.2	9.2	16.8	-1.1	30	215	0.6	4.8
Wastes (Non-Renewable)	-	-	-	37.5	-2.3	-	89	-	2.0
Combustible Fuels Total	-29.1	-2.4	-3.8	-2.7	-7.4	4,786	3,391	93.6	75.6
Electricity Imports (net)[12]	-68.5	-7.9	7.4	-1.1	-	176	55	3.4	1.2
Total	**-12.3**	**-0.9**	**-1.8**	**-0.1**	**-1.9**	**5,112**	**4,483**		

Figure 8. Electricity generation fuel mix - SEAI 2020 report [7].

The carbon intensity of electricity produced in Ireland has reduced to 324 g CO_2 per kWh in 2019 and is the lowest level since the 1940's (Figure 1). AAL electricity production at 240 g CO2 per kWh is helping the reduce the National carbon intensity of electricity production.

6.3 Climate Action Plan for Ireland

Ireland is now on a legally binding path to net-Zero emissions no later than 2050, and to a 51 % reduction in emissions by the end of this decade.

Minister of Environment, Climate and Communications and Minister for Transport Eamon Ryan announced on the 23rd of July 2021:

"Today is a landmark day, as we turn climate ambition into law, and set out on a journey to net zero emissions. The extreme weather events around the world over the past month have shown us all that we must act quickly, to protect ourselves and our planet. Our immediate target of halving emissions by 2030 is challenging, but it is also an opportunity to transform our economy, create new jobs, protect our environment and build a greener and fairer future. We will all need to work together to achieve this, in renewable energy, active and sustainable travel, in business, agriculture and across government. But the signal we are sending today is that now is the time for action."

The Climate Action Plan 2021 will be published in early autumn. This will set out the measures to be taken to reach the targets in each sector of the economy.

7. Decarbonisation Road Map Options for AAL

7.1 Decarbonisation Pathways as Proposed by International Aluminium Institute

The International Aluminium Institute (IAI) has collected data (Figure 9 below) on the aluminium sector covering a 15-year period, which covers all processes in the value chain. This is the most comprehensive, detailed and up to date sector-wide dataset that exists for aluminium [6].

	Bauxite mining	Alumina refining	Anode production	Electrolysis	Casting	Recycling*	Semis production	Internal scrap remelting	Total
Electricity (indirect)	0.6	16.9	-	670.6	-	3.1	9.5	2.5	703
Non CO_2 GHGs (direct)	-	-	-	35.4	-	-	-	-	35
Process CO_2 (direct)	-	-	6.4	92.6	-	-	-	-	99
Ancillary materials (indirect)	-	14.8	19.3	6.4	-	-	-	-	41
Thermal energy (direct/indirect)	2.6	124.3	6.4	-	6.4	15.6	19.0	8.4	183
Transport (indirect)	-	15.4	-	18.7	-	-	-	-	34
Total (cradle to gate)	3	171	32	824	6	19	29	11	1,095

Figure 9. Aluminium sector emissions (Mt CO2e) by process and source - IAI 2021 [6].

IAI developed generic pathways to decarbonise the aluminium sector including alumina refining (see Figure 10). Alumina production requires significant heat and steam: technologies to decarbonise these energy carriers are not unique to the aluminium industry. Electrification with renewables offers a potential pathway to decarbonisation. Fuel switching to green hydrogen, concentrated solar thermal energy and carbon capture utilisation and storage (CCUS) present opportunities where electrification may not be feasible, such as alumina calcining [6].

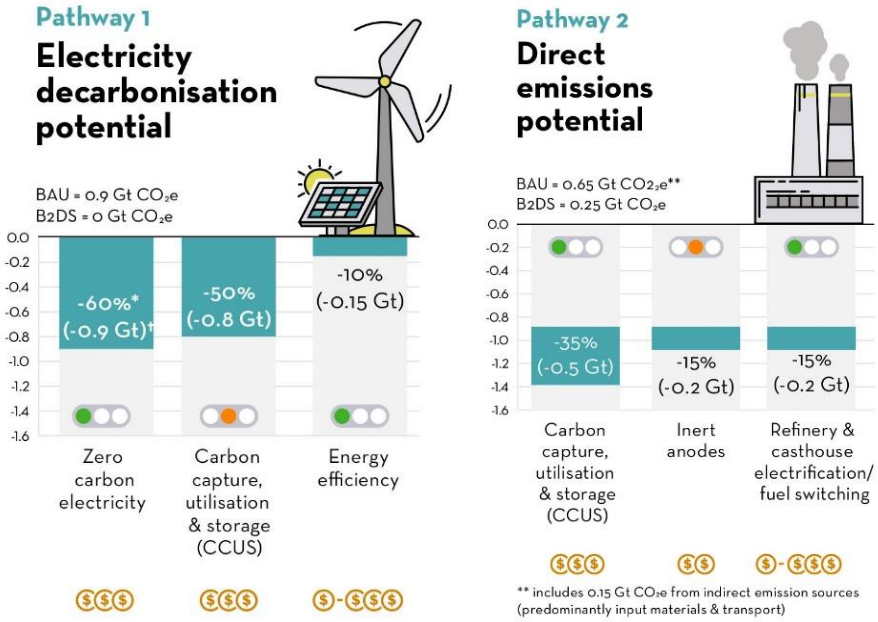


Figure 10. Decarbonisation pathways as per IAI road map [6].

7.2 Options Explored for Alumina Refining in Ireland

7.2.1 First Step to Take - Energy and Carbon Efficiency Improvement

This is the obvious first protocol and sounds simple on the surface. In reality, AAL needs to turn towards efficiency improvements that are more capital intensive and at higher level of technological/economic risk such as waste heat recovery and low-grade heat recovery and make it work. Technologies such as Mechanical Vapour Recompression (MVR), heat pump systems, Organic Rankine Cycle have been known for a long time but have not been implemented in alumina refining because they are expensive to install and expensive to operate. These technologies will become more economically viable in the future but might still require financial support for another few years. The new EU and Irish Climate Action Plan supports this type approach and it will become reality in the coming decade for AAL and across most industrial sectors.

7.2.2 Major Decarbonisation via Electrification or Fuel Switch

Biomethane:
An option would be a change of fuel from natural gas to the use of biomethane. AAL is connected to the gas transmission system. If the transmission system could supply biomethane the combustion equipment could change over seamlessly to burning biomethane.

AAL uses 7 TWh of gas per year or 19 GWh per day. Anaerobic Digestion systems (AD) range in size from 10 GWh/annum up to 100 GWh/annum, a typical size for Ireland could be 40 GWh/annum which would have a capital cost of ~€8 million, an 80 GWh/annum plant has a capital cost of over €10 million. Supplying the AAL requirement would require the construction of 175 of the 40 GWh/annum sized AD plants at a capital cost of €1400 million or the construction of 88 of the 80GWh/annum sized plants at a capital cost of €880 million. This could not be implemented on AAL's site but could be provided to the existing natural gas network as a substitute fuel.

Ireland has the potential to supply 30 % of its gas demand through biomethane. Until recently Gas Networks Ireland had a target to supply up to 20 % of Ireland's demand with biomethane by 2030. This has however since been revised downwards in line with the government's climate action plan to 1.6 TWh (or 3 to 4 % of demand) by 2030. Biomethane is not available at present but it should become available in future years although not in sufficient quantities to replace 100 % of refinery natural gas demand. It is estimated it will only be available to support one quarter of AAL's demand in 2030, but this might be part of the solution if the price is competitive then.

The price of biomethane is multiples of the price of natural gas (May 2021): approximately 8 ct/kWh versus natural gas at 2 to 3 ct/kWh). So along with the large capital investment which would be required at a national level, the conversion to biomethane would currently lead to much higher operational costs which would be prohibitive.

Hydrogen:
A new and widely discussed alternative in Europe, particularly intended for the hard to abate industrial sectors such as aluminium, steel and heavy vehicle transport, is to move to the use of green hydrogen. Green hydrogen can be produced by electrolysis using excess power from the grid with a conversion efficiency of about 70 %. AAL is involved in the first Research and Development project on Hydrogen in Ireland called HyLight, which will provide valuable insight to the government on the possibilities and obstacles to create a transition to green hydrogen.

The use of green hydrogen instead of natural gas for an alumina plant would require the replacement of the existing gas boilers, the replacement of the gas turbine of the CHP and major changes to the calcination system. It would also require the replacement of the supply piping and preparation infrastructure to be capable of handling hydrogen, as the present carbon steel materials would be subject to stress corrosion cracking.

In addition, hydrogen is not available in any quantities at present in Ireland, and will not be available in sufficient quantities for many years to come as major investment is required to build the plants and distribution network. As a reference, it took more than a decade to install the natural gas distribution and transmission network in Ireland. The investment requirement to construct the electrolyser and the distribution infrastructure for both electricity and Hydrogen will be in the hundreds of millions of euros, but no detailed costing is available at the moment. Ideally, a hydrogen network would be created in Ireland and distribution provided to sites like AAL. The vision is to use off-shore wind in the West of Ireland (near AAL), convert coal power stations (for example Moneypoint a few kilometres away from AAL) into electrolysers and distribute Hydrogen to users such as AAL.

Hydrogen is at present, priced at about 16 to 20 cent per kilowatt hour, or three times the price of natural gas. This would increase the operation costs of the alumina refinery and is unlikely to be economically viable for many years.

Process Electrification:
Electrification is another obvious option for AAL being located on the windy island of Ireland. The move from natural gas to electrification can be seen as decarbonizing because the electricity grid target is to be 70 % decarbonised by 2030 and fully decarbonised by 2050. Ireland already has large amounts of renewable power. It has very significant potential for more due to its location with amongst the highest potential for wind generation both onshore and offshore in Europe and has an excess of power at times. Renewable electrical generation penetration was 36.5 % in 2019. Renewable generation is limited by the system non-synchronous penetration (SNSP) limit of 70 %. As renewable electrical generation capacity has risen so has curtailment where in times of high wind, excess renewable generation above the limit is turned down, "curtailed" or wasted.

The Irish government climate action plan has targets to double onshore wind generation capacity to 8.2 GW by 2030 and to achieve 3.5 GW of offshore wind capacity by the same date, and vision to increase further the offshore capacity after 2030.

AAL has developed two separate innovative electrification projects to decarbonise steam production for the alumina plant. Referring to the breakdown of energy usage this could account for 76 % of the carbon emissions of the plant if implemented in full.

The first project is high voltage, high pressure, electric boilers, which use large amounts of electrical power to convert water to the steam required for the alumina plant (Figure 11). This electrical demand would be dispatchable such that it can be used by the grid to reduce curtailment of wind generation. This has the added advantage of solving the national problem of curtailment of wind, which has been a growing issue over the last number of years and curtailment now stands at 12 %. Electrical power can be converted to steam using the electric boilers at an efficiency of 99%. This is an ideal technical solution, as there is sufficient supply of power and almost no loss of efficiency in the conversion. It does require a capital investment to install the electric boilers, and to install the grid infrastructure connection to bring additional electrical power. There are however regulatory economic barriers to electrification. This is in the form of consumption charges on the use of electrical power; charges on top of the electrical wholesale price, which are levied on those who consume power. They consist of supplier charges, transmission use of service charges and the public service obligation levy and add up to €52 per megawatt hour to the cost of wholesale power. Removing these regulatory barriers is necessary to provide economic viability of the electrification solution. However, the present average wholesale price of electrical power is about three times the price of natural gas. In summary, electrical power would need to be provided at an economic price.

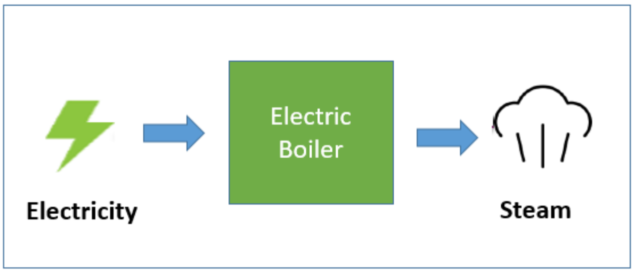


Figure 11. High pressure electric boiler.

The second electrification project combines high voltage, high pressure electric boilers with thermal energy storage (Figure 12). This has all the advantages of the above electric boiler project in that it can convert electrical power to steam at a high efficiency of 99 %, also reduces curtailment of renewable wind generation and takes advantage of the plentiful renewable electrical resources in the country, and the planned increase of those resources. In addition, it has the added advantage of being able to store power for periods of hours to days depending of installation. This allows the charging of the system in times of high wind and excess renewable power and the usage of that power in times of low wind. The project can also be extended with the facility of re injecting electrical power back into the grid in times of low wind or sun. It has the ability to decarbonise the steam demand of the alumina plant, and provides storage of electrical power over long periods, much longer than that, available from batteries. There are capital costs to overcome, and to be viable, power would need to be provided at economically competitive prices and the regulatory economic barriers in the form of consumer charges would need to be removed.

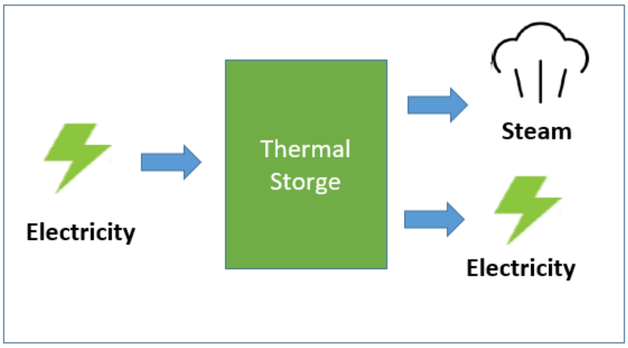


Figure 12. High voltage, high pressure electric boiler with thermal energy storage.

Carbon Capture and Storage (CCS):
A further option for decarbonisation is the abatement of carbon through CCS. This solution will require the construction of a carbon capture and storage plant on the AAL site. The exhaust gases from the CHP plant, the gas boilers and calcination plant need to be fed to the new CCS plant. Additional energy, over and above the present requirement to the AAL site is then required to compress the exhaust gases. Typically, this is of the order of 15 % of the present required energy, thus utilizing this technology would in fact mean an increase in the amount of natural gas consumed in the plant for compression of the exhaust gases.

The captured carbon dioxide then needs to be transported off site. Gas Networks Ireland as part of the government climate action plan are studying the viability of CCS at a concentration of plants in the Cork area around the Whitegate oil refinery and the neighbouring combined cycle gas turbine power plants. They have signed a Memorandum of Understanding (MOU) with multinational energy company Equinor which will see both companies assess the potential for Ireland for CCS and work together in the wider 'Northern Lights' project. If successful, the project will see carbon emissions from Ireland's electricity production and large industry captured and exported via ship to be permanently stored in Norway's geological reserves in the North Sea.

In further steps the carbon would be permanently stored in the now depleted Kinsale gas field. From the AAL plant, carbon would require transport to a port from where it would be sent to Norway, or eventually Kinsale. Carbon capture and storage has a significant capital cost for the CCS plant on the AAL site, requires additional natural gas usage and requires the carbon to be transported off site to be permanently stored in a suitable location, which will increase the operating cost of the refinery. The capital investment would be similar to green Hydrogen and operating cost similar to process electrification.

Summary:
Hydrogen and biomethane are not currently available in sufficient quantities, and will not be for at least a decade, but could become potential players once the technology, regulation and supply network are established. Electrification is a viable technical solution, available in sufficient quantities, matches the country's ambitions for installation of further renewable generation, and reduces curtailment. Electricity can be converted to heat, with almost no loss of efficiency. However, there are barriers to overcome in terms of the capital and operating cost. Foremost are the regulatory economic barriers to the consumption of electricity, these are the additional charges levied on top of the wholesale price: supplier charges, transmission use of service charges and public service obligation levy adding up to €52/MWh to the wholesale price of power. Furthermore, renewable electricity needs to be provided at an economically competitive price relative to natural gas to allow Irish produced alumina to compete on a global market.

8. Conclusion

The European Union, including Ireland, have signed up to the EU Climate Law under the Green Deal Initiative to reduce carbon emissions by 55 % by 2030 towards carbon neutrality by 2050. Many other countries have made similar pledges to carbon neutrality around the globe by 2050 - 2060. This represents the greatest of technological, commercial and policy challenges, but also presents a major opportunity to make real difference for climate and environment for this and next generations.

AAL is facing this challenge with a clear commitment by Rusal to deliver a comprehensive carbon reduction road map. The road map for the coming decade will be achieved using two routes; efficiency improvement across the plant and substitution of natural gas by process electrification while following closely development in future energy sources such as bio-fuels, carbon capture and storage and green hydrogen.

AAL will prioritise carbon reduction via efficiency improvement and follow with renewable energy source to complete the decarbonisation when technologies are available in required quantity and economically viable.

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