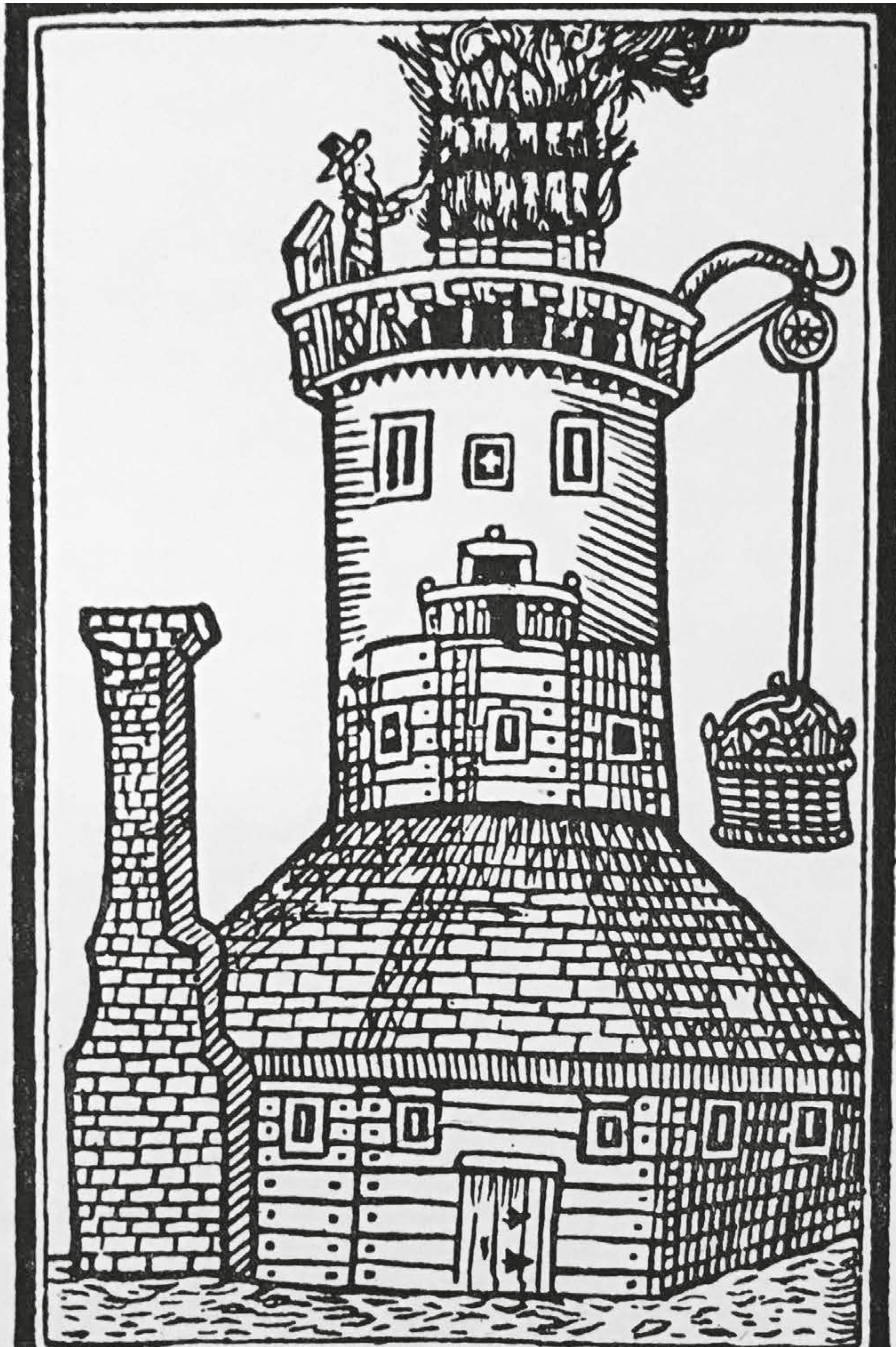


Early Navigational Lights

Extracted from: Light On The Forelands by Ken & Clifford Trethewey, Jazz-Fusion Books (2022)

Birth of an Industry

Although known about since the Classical era, the principle of providing lighted aids to navigation was extremely limited before 1700; Association of safety at sea with the Christian religion; The early technologies are very under-developed.

It could be argued that it was the coal industry that initiated the building of lighthouses on the English coastline. The transport of coal away from the developing coalfields of the northeast greatly increased shipping traffic up and down the east coast, and the hazards seamen encountered along the way caused many to focus their minds on improvements to safety.

By 1600 there was a fleet of two hundred colliers supplying London with coal; yet more sailed to Edinburgh where the Isle of May light at the entrance to the Firth of Forth was established in 1635. By 1700 the London fleet had increased to a thousand ships employing ten thousand seamen.[1] Yet, by 1600 there was hardly a single working lighthouse in England, in the way it would be recognised today.[2] The image on the facing page is of Dungeness, established in 1615 and could be claimed as the earliest structure that met the criterion for a lighthouse in the new age. Others might argue that the Tynemouth Castle light took the prize. It is known to have been alight on a turret at the east end of the priory church in 1582, and was almost certainly in use much earlier, but, set up and managed by monks, falls into the category of Ecclesiastical light. So there is no common agreement on the answer to the ambiguous question of which was the earliest lighthouse since there are many criteria such as purpose, design, management and finance to be applied. Tynemouth and Dungeness were open coal fires on elevated platforms that, by a modern definition should be better called lightstructures rather than lighthouses.[3]

Ecclesiastical Lights

The earlier aids to navigation (later called Ecclesiastical Lights) that had been shown randomly right through the Middle Ages from hermitages, monasteries, abbeys and other

1 Long, Neville: *Lights of East Anglia*, Lavenham Press (1983), p1.

2 It is always difficult to be exact in statements like these. The leading lights at Tynemouth were certainly lighthouses, and therefore would qualify as being the first, but were intended only to assist ships at the entrance to the river.

3 The topic is discussed at length in the book, *Ancient Lighthouses* by Ken Trethewey and in the article http://www.pharology.eu/whatisalighthouse/What_Is_A_Lighthouse.pdf

Above: A satellite image of the British Isles showing the most significant sites of lights shown for navigational aids before 1700. White pins are just some of the early Ecclesiastical lights that had been extinguished by 1600. Yellow pins are sites of lights shown in the 17th century, except for those at Tynemouth that slightly preceded them. They are the first lighthouses of what might be called the British Industrial Age. Details are given in Table 1. Some of these lights were shown only over a short period, often subject to political arguments between lighthouse entrepreneurs, representatives of the Crown and of mariners themselves over financial arrangements and the effectiveness or otherwise of the lights. The idea that lighthouses could be a business from which profits could be made, as well as a tax upon sea trade, took a long time to achieve popular acceptance. But by the 18th century, lighthouse building was in full development. In the 17th century, with Hook Head, St. Catherine's extinguished, Eddystone and St. Agnes not lit until the very end of the century, and a light shown from St. Ann's Head for only five years, it is clear that the most significant activity was along the east coast - especially in the southern North Sea, where the biggest problems to shipping were caused by sandbanks.

Lighthouse Site	Year
Tynemouth (2) (candles)	1540
Tynemouth Castle (coal)	1582
Caister (aka Caistor) (2) (candles) (TH)	1600
Lowestoft (2) (candles) (TH)	1609 and 1676
Dungeness (coal)	1616
Wintertonness (aka Thwart Lights) (2) (coal)	1617
Lizard (2) (coal)	1619-1630
Isle of May (coal)	1635
Orfordness (2) (coal)	1637
North Foreland (coal)	1634
South Foreland (2) (coal)	1634
Harwich (2) (coal at rear; candles at front)	1665
Hunstanton (2) (coal)	1666
Milford Haven (aka St. Ann's Head)	1662-1668
Spurn Point (2) (coal)	1674
Flamborough Head (coal)	1674
Corton (2) (coal)	1675-1678
Scilly (aka St. Agnes) (coal) (TH)	1680
Eddystone (candles)	1698-1703

Table 1: List of the earliest lighthouse sites of the British Industrial Age from 1540 to 1698. [Stevenson, p96, p258-9] Whilst the majority of lights were established to assist the shipping of coal between London and Edinburgh, clearly the East Anglian and Kentish coastlines were significant from an early age for other reasons, not least of which was to combat the ever-changing sandbanks. This is indicated by the number of sites where two lights - indicated by (2) - were shown. Apart from those managed by Trinity house of London, indicated by (TH), the remainder were privately owned and operated. The majority of lights were lit by coal, the rest by candles.

Above: St. Catherine's Oratory on the Isle of Wight, the best preserved Ecclesiastical lighthouse in the UK dating to 1323. The outline of the chapel that was originally attached to the structure is clearly visible.

Christian sites had been lost from 1538 onwards when Henry VIII ravaged the established Roman Catholic church during what is politely called the Reformation. One of the casualties was a long-established light shown from a dangerous headland called Hook Head in southern Ireland. Legend tells of a light having been shown from a monastery established by a monk called Dubhan in the sixth century. After the Romans left and extinguished the Dover Pharos for the last time, this becomes a strong candidate for the next oldest known location for a navigational light in the British Isles. Later, the Hook Head site[4] became a coal fire lightstructure - possibly quite similar to those at Dungeness or north Foreland shown here. Hook Head is a contender for the first lightstructure of its kind and we are confident that the monks who tended it were the first formally recognized lightkeepers. Like so many others, Hook Head lighthouse - essentially an Ecclesiastical light - ceased to operate for a long period after 1538, if not before.

In England, another Ecclesiastical light that suffered the same fate during the Reformation was St. Catherine's Oratory on the Isle of Wight. Monks showed a light from a tower from 1323 onwards after the Pope ordered Walter de Godeton to build a lighthouse as a penance for his sin of stealing wine.

It is unfortunate that no firm evidence has been found to suggest the existence of an early lightstructure on Spurn Point, the entrance to the river Humber and the port of Hull. Henry VI had granted a Patent to Richard Reedbarrow in 1427 to show a light from a tower there:

4 Hook Head lightstructure was built by the Lord of Leinster in the period 1210 - 1230.

ABOVE: The two lighthouses at Tynemouth which, when aligned, show the safe channel into the River Tyne at Tynemouth. These two towers date from 1810 and replaced two earlier lighthouses of 1727, but the earliest lights were shown in similar fashion from 1540 after the granting of a Patent by Henry VIII to the Trinity House of Newcastle upon Tyne in 1536.

> *"to make a Toure to be uppon day light a redy Bekyn, wheryn shall be light gevyng by nyght,"*[5]

Whether Reedbarrow actually built his lighthouse is not known. There was no record of a light of any significance at Spurn Point until two lightstructures were definitely built there by Justinian Angel in 1674. Even if it indeed was built in that earlier time, we must place it in the category of Ecclesiastical lights. Nevertheless, it is clear that the 1427 document established the principal for obtaining planning permission in this, the first Patent of its kind, as well as the principle by which it was paid for - that of charging light dues from passing ships. It is possible that the application was made through Reedbarrow's links to the charitable guild of mariners called the Trinity House of Kingston upon Hull. Again, there is no proof that this was the case, but, if it were, it would predate any similar agreement with the Trinity House of London who, after being given their own Charter by Henry VIII in 1514, were very slow to assume their responsibilities in this regard.[6] Even as late as 1786, Trinity House was responsible for only four lighthouses, and it was not until 1832 that they finally took control of all lighthouses in England and Wales.[7]

Soon after the London Trinity House began to take responsibility for some lights from the start of the 17th century. In 1607 they took charge of two leading lights already erected at Caister without authority by a man called Bushell. A channel through sandbanks close to shore at the busy fishing port of Lowestoft was given two leading lights in 1609.[8] The approach was to assign a fixed site on which to build a rear light, higher than the front light that was less permanent and could be moved to change the alignment when the channel was affected by the movement of the sandbanks. This was a common feature along this coastline, with similar pairs of lights shown from Corton, Harwich, Orfordness, Lowestoft, Caister and Wintertonness. Intended for local boats entering and leaving ports, they were not really designed for passing ships, but assisted offshore mariners nevertheless.

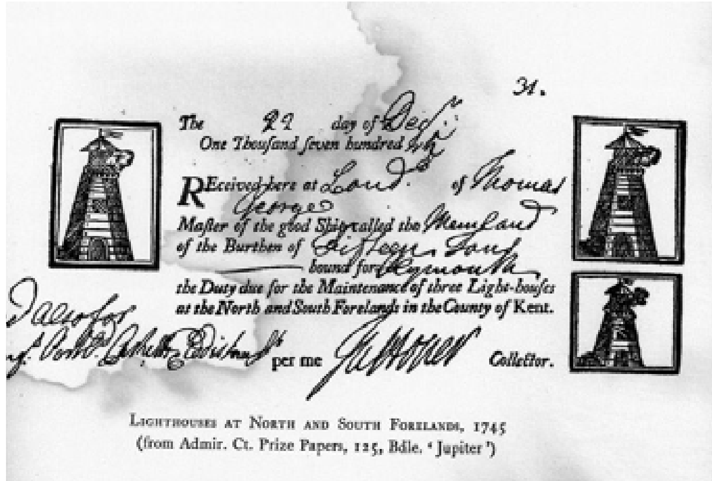
5 De Boer, G: *A History of the Spurn Lighthouses*, East Yorkshire Local History Society (1964), p5.

6 Despite being given the authority by Royal Charter, the Corporation's efforts were directed more towards their pilotage and charitable work.

7 Stevenson, David A: *The World's Lighthouses Before 1820*. Oxford University Press (1959), p65.

8 Stevenson, p97, says these were candle lights, though other sources talk of coal fires.

ABOVE: The high, rear light of a pair of leading lights established in the 17th century at Harwich. A low light was located on the beach some 200 m distant.



ABOVE: A very rare image of a receipt for light dues paid for passing the Forelands lighthouses in 1745, by which time the practice was well established. It is still the method used to finance lighthouses today.

The Industrial Age Begins

Then, came the rise of the coal industry; the traffic between Newcastle and London focused minds. Whilst, on the one hand, Henry VIII had brought about the termination of the Ecclesiastical Lights, he also played a critical role in the process of building lighthouses according to the modern formula - what we might call "Lighthouses of the Industrial Age." It was his 1536 Charter that authorized the Trinity House of Newcastle upon Tyne to:

> *"build and imbattle two towers, one at the entrance of the haven of Tyne, the other on the hill adjoining, in each of which a light was to be maintained every night, for the support of which they were empowered to receive 4d for every foreign ship and 2d for every English vessel entering the port of Tyne."*

From this Charter came the two leading lights (above) that have been shown at the entrance to the River Tyne ever since. This is of great significance to us as a very early reference to three principles of lighthouse provision:

The maintenance of a light, not on a casual basis but every night;

The right to tax shipping in support of the provision;

The use of two lights that, in alignment, indicate a safe channel.

With finance now a vital consideration the establishment of lighthouses became a business rather than just a charitable act performed by members of the Church. The tax with regard to lights was called *lightage* or *light dues*.

Two of the earliest sites were at the North and South Forelands in Kent. A Patent was awarded to Sir John Meldrum for both sites in 1634 and he successfully initiated three elevated coal lights - one at North Foreland and two leading lights at South Foreland - that were in use almost continuously thereafter. Only the lower of the two South Foreland lights was discontinued in 1904.

Table 1 lists eighteen sites of the new British Industrial age from 1540 to 1698. Inspection shows that no fewer than fourteen sites were on the east coast. Yet in these very early times there was no blueprint for aspirant lighthouse builders. Even worse, the methods of lighting them were primitive to say the least.

In the mid-1660s, two lights were set up by a senior naval officer, Sir William Batten at Harwich, an important port to the Royal Navy. During his appointment as Surveyor of the Navy, Sir William

The old "lighthouse" at Flamborough was built of highly visible white chalk in 1674. Local historians suggest it may have shown a swape light but the use of a coal fire on the top for a navigational aid cannot be ruled out if only for a short time. There was plenty of precedent to be found elsewhere in England, as Table 1 shows.

Above: The rugged chalk cliffs of Flamborough Head always presented a hazard to shipping. Even in Roman times, there is evidence to suggest that the lofty position was a perfect location for a signal station, a practice that was to find use again in the 18th century from the tower shown on the opposite page. A lighthouse of the Industrial Age was to be built here in 1806 and features later in this book (see p120-31).

Batten came into frequent contact with the Chief Secretary to the Admiralty, the famous diarist Samuel Pepys, who wrote with frequent disdain about his colleague. Batten's Will contained the most unusual bequest:

> *"I Sir William Batten of London Knight ... give and bequeathe to my servant Mingoe a Negroe that now dwelleth with mee the somme of Tenne pounds to be paid within Twelve monthes next after my decease And I doe alsoe give unto the said Mingoe the Custody and keeping of my Light houses Att Harwich..."* [9]

Batten had used his position in the Navy to build two lighthouses at Harwich in 1665 when it was of great significance to the Navy. We might today recognize this as a 'dodgy practice' since besides his naval rank Batten was also one of the Elder Brethren of Trinity House. Pepys must have been well aware of it for he wrote that it was "the gift of a fortune." According to the practices of the time, they would have yielded him significant revenues in the form of light dues. Batten died in 1667; sadly, we do not know the extent to which Mungoe made use of his custodianship of the two lights at Harwich. After a number of modifications and rebuilds, the Harwich lights were eventually provided in 1863 by the two lighthouses that still exist there.

A site at Flamborough Head in Yorkshire is of relevance to this book and is included in the list in Table 1. Here a tower made of white chalk, was built as a lighthouse by Sir John Clayton and partner George Blake in 1674.[10] It was from the top open platform that either a coal fire or a swape light (see p39) with a brazier was shown for a short time. The intention was to make a voluntary charge on passing ships, but the business partners could not make their plan succeed. Fortunately, the tower was found to be very useful as a signalling station during Napoleonic times and even later for semaphore in the mid-19th century.

The First Navigational Lights

Today, we take so much for granted. Even as late as the 21st century, lighting technology has been revolutionized by the introduction of the light emitting diode or LED. It is tiny, very bright for its

9 The National Archives, PROB 11/324, q144.

10 Local Information reports 1674, whilst Wikipedia records 1669.

ABOVE: The Beacon Light by JMW Turner.

size and uses only small amounts of electricity.

Four centuries ago when the earliest lighthouses of the Industrial Age were in a primitive form, the only methods for providing light suitable for use as navigational aids were by the physical burning of fuels:

Small fires of wax in the shape of candles;

Medium-sized fires of animal or vegetable oils;

Larger fires of wood or coal.

Elevation was a long-established idea. Even members of the flat-Earth Society might agree that an observer on a high point of land can see further to the horizon than from a low point. The very tall Pharos of Alexandria[11] had provided worldwide inspiration by combining a high visibility for its light with a distant view of approaching enemies. Its fame had cemented the suggestion that, in an organized society, a tower topped with a fire was a good way of achieving a successful night light for navigators. The idea probably emerged from Greek thinking and was developed by the Romans, but fell into disuse during the Dark Ages.

The Pharos had been built at sea level, but on a high cliff or foreland, the elevation was already present and all that was necessary was to provide the light. Nevertheless, consideration would have been given to the presence of trees or other buildings in the vicinity of a proposed light and therefore elevation in addition to that of the high ground was often provided by a tower at least as high as a single storey house.

In his painting *The Beacon Light* (above), the British artist, JMW Turner was not trying to accurately reproduce the South Foreland lighthouses, even though he had made contemporary sketches of them during an unidentified period sometime around 1834-45 (see p98-9). However, the work gives a clear indication of the earliest kind of navigational light and there is little doubt that South Foreland was the inspiration for the setting of this dramatic scene. A blazing fire on a cliff top was an ancient warning signal, in English known as a beacon, and who knows if this was not the case at South Foreland when Celtic Britons first observed the Saxon invaders coming to tea? As the idea increasingly

11 The total height above sea level is thought to have been 145 m. Trethewey, Ken: *Ancient Lighthouses* (2018) p182.

ABOVE: An illustration of an early coal fire that could be recognized as a lighthouse.

came to be used for navigational purposes, it was the management of a fire from the top of a purpose-built structure that evolved into a lighthouse. The principle of an elevated light contained the requirement for a platform of some kind, a brazier, a supply of fuel and a human - usually, but not always, a man - to keep it alight throughout the night. In this way, the lighthouse became a specific form of navigational aid that even now remains common and instantly recognizable.

There are very few images of these structures and the few descriptions we have of these early lighthouses are generally converted into artists' impressions, as shown for Dungeness at the start of this chapter and here in work by Mark Lewis. It is obvious that fires burning atop wooden structures were clear invitations to disaster and there are instances reported later of such setbacks on the Forelands. Indeed, it was a fire that began in the lantern of the Eddystone lighthouse designed by Rudyerd[12] which destroyed the lighthouse in 1755 and resulted in John Smeaton turning to stone for his Eddystone tower, thus setting a pattern for many other future designs. But the lack of availability of stone for building in remote locations often necessitated the use of wood.

In any case, a fire was lit in a fire-proof container known as a grate, a brazier or a chauffer. Wood was, of course, the fuel of choice for the majority of fires until coal became more readily available at the start of the Industrial Age. Oil technology was still very under-developed - no better than candles - and in the 1600s lights for navigational aids - in the British Isles at least - were almost always made by candles or coal fires. All available methods were inefficient and unreliable, especially in the care of humans who were not paid enough to take seriously the hard labour in difficult circumstances. In that sense, technology was not ready for lighthouses.

Coal

It is not known when the light at Tynemouth Castle was established, but there is reference in 1582 to:

> *" ... the kepinge of a continuall light in the night season at the easte ende of the churche of Tinmouthe castle, as in former times had ben, for the more safegarde of such shippes as should passe by that coast".*[13]

12 The fire is described in detail in Trethewey, Ken: *Lighthouses of Cornwall and Devon* (2020) p395-401.

13 http://www.twsitelines.info/SMR/731

ABOVE LEFT: The St. Agnes lighthouse (1680) on the Isles of Scilly which was lit by coal burned in the cast iron chauffer (grate) ABOVE RIGHT. The unique item can be seen in the gardens of Tresco Abbey.

Important is the phrase that indicates a longer tradition of showing lights there, but unfortunately we cannot assign an earlier date with confidence. Once again we should consider it as an Ecclesiastical light rather than an Industrial one, yet Tynemouth later became the primary source of the coal, obtained from the fields of northeast England and that fired the Industrial Revolution.

Coal was often contained in a metal holder and raised to a given height above the surrounding area to give it increased visibility over the sea. An original example of a coal chauffer can still be found in the botanical gardens on the island of Tresco in the Isles of Scilly, England. This chauffer was used from 1680 onwards in the old lighthouse known as Scilly, which is today a private house on the island of St. Agnes.[14]

Wooden lever-arm arrangements were sometimes constructed to give further elevation to coal-burning braziers. The invention is attributed to a Dane called Pederson Groves in 1624.[15] Called swape lights or *vippefyr*, such a design was used for two lights at Spurn Point from 1674, the lever arm of each light being placed on top of a stone tower, to provide the leading lights for entry into the Humber.[16] Because of their nature, there are no known examples of these old lights in existence today, but replicas of *vippefyr* can be found in Denmark and Sweden. The image on p39 shows the replica at the important sea crossroads of Skagen.

A much-quoted statistic is that in 1698, the annual consumption of coal was 100 tons at each of the Forelands lights.[17] Once again, a lack of clarity fogs the data. The record gives the name only as 'Forelands: 100 tons each'. We must assume that three similar fires consumed 300 tons in total. Elsewhere it was described as 32 chaldrons of coal a year at an average of 30 shillings a chaldron or small cart load.[18] As with lights shown from high elevations, these figures are fogbound.

We are confident that the first Dungeness lighthouse was coal-burning from the start in 1615, but the report that it consumed 400 tons of coal per year - four times the amount consumed by just one light on the Forelands and more than one ton per night - is less believable.[19]

Our present understanding is that the chaldron is

14 Trethewey, Ken: *Lighthouses of Cornwall and Devon*, (2020) p56-65.

15 https://uslhs.org/lighthouse-lamps-through-time

16 de Boer, p24.

17 Stevenson, p276.

18 Jewell, John: *St Margaret's Bay - The Piccadilly of the Sea*; St Margaret's Historical Society (1988), 24pp, p12.

19 Carpenter, Edward: *Dungeness Lighthouses* (1996) p3.

Above: A painting of the North Foreland lighthouse in its form from 1691 to 1793. The tower is of stone and a coal-filled chauffer was kept burning throughout the hours of darkness.

a unit of measurement of grain or coal that was used extensively from around the fifteenth century.[20] As is often the case, there was some variation, the more so in this case because each chaldron load was taxed and it was in the coal merchants' interests to make their chaldrons larger than it might otherwise have been. Since coal was exported from Newcastle, there was a unit of measure called the Newcastle chaldron that was used only for coal. Before 1695 its weight was 42 hundredweight, that is 4705 lb (2134 kg) - about two tons. In fact, one chaldron was enough to fill three wains (wagons). The London chaldron was defined by a law of 1665 whereby 1 chaldron = 36 bushels, weighing 25 1/3 hundredweights - about 2837 pounds (1287 kg).

By 1700 fifteen major navigational lights existed in Britain, of which twelve were coal fires.[21]

Above: A replica of a swape light or vippefyr that was used at Spurn Head (1674). This one is at Skagen in Denmark, here on a hill rather than a stone tower.

20 https://www.sizes.com/units/chaldron.htm
21 Stevenson, p273.

Candles

It is hard for us to imagine that many lights that were set up to keep mariners safe were simple candles - often just one! When candles were used it was clearly necessary to protect the delicate flames in some way - that is, behind glass in a lantern or in the window of a house. Here we can see how, in the English culture, language plays a part since the showing of a light from a house introduced a new word into the English language.[22]

It was at Caister-on-Sea (aka Caistor), just north of Great Yarmouth in Norfolk, that a builder called Bushell had - without authority - erected two candle-lit lights around 1600. A few years later, in 1607 these were the first lit navigational aids to be acquired by Trinity House who found it difficult to ensure that those appointed to look after them did so efficiently and reliably.[23] Although an important event in the timeline of lighthouses, the structure he used to show the lights is not known.

Similar reliability issues were experienced at Lowestoft where in 1609, Trinity House, for the first time, pro-actively responded to a demand for lights. Two lanterns containing candles were set up on the beach where they offered a leading line into the Stanford Channel and marked the southern approach to Yarmouth Roads which, in the seventeenth century, was a key roadstead and anchorage, in frequent use both by vessels engaged in the local herring trade and by colliers on the route from Newcastle to London.[24]

Candles were made in proportion to the pound weight (1 lb = 454 g - approximately half a kilogram).

22 A complete discussion of the etymology of lighthouses is given in the book, *Ancient Lighthouses*. Also available at http://www.pharology.eu/resources/journalarticles/01_Literature.pdf and https://www.academia.edu/38933752/Ancient_Lighthouses_Part_1_The_Literature

23 Stevenson, p97.

24 Wikipedia, *Lowestoft lighthouse*, downloaded 2021.

ABOVE: A replica of the candelabrum used by John Smeaton to light his lighthouse on the Eddystone in 1759.

The Caistor light in 1628 used candles at three to the pound; at Harwich in 1676 they were one pound each. As the science evolved the light emitted became standardized in the form of a 'standard candle' that was made of spermaceti wax extracted from the heads of whales. The candles were six to the pound and burned at a rate of 120 grains (7.77 g) per hour. The standard candle thus became a unit of light measurement used through the centuries and later evolved into 'candle power'; later still, the candela.[25]

Navigational aids made from candles were naturally weak at first, but were easy to maintain. At the end of their useful life candle ends were of some monetary value to poor people; candles made of tallow and beeswax could even be eaten as a last resort! A wick is a material woven into cord, string or sheets of fabric that can then be incorporated into a burning device such as a candle or an oil lamp. The wick does not burn well itself, but soaks up a liquid fuel and aids evaporation of that fuel so that it can be set on fire and a light produced. Wicks of candles needed to be trimmed frequently so that they burned regularly and reliably. When they did not,

25 Scientific measurements of the brightness of lights involve the amount of energy falling upon unit surface area at a given distance. (See p42-43.)

the process was called guttering.

Candles were considered to be rather better than oil lamps in terms of ease of transport and storage of supplies, but candle lights were more expensive to maintain. A candle-end was the stump of a used candle. It had significant value to those in service, including lighthouse keepers because they could be recycled for various other uses.

Candlepower is the old unit of light intensity used to measure brightness, based upon the light given out from a candle of defined composition and rate of burning. At the Eddystone, there were 24 candles weighing about half a pound each. About twelve inches (300 mm) in length, they were arranged in two circular tiers. Each candle gave the equivalent of 2.8 standard candles, making the total light intensity about 67 candlepower. Snuffing was a practice of reviving the wicks of candles so that they burned more brightly, evenly and with less smoke. At Eddystone, the keepers had to lower the candelabrum (two concentric metal rings with equally spaced candle holders) so that they could snuff the wicks. If they did not raise the candelabrum completely afterwards, the lower tier of candles was not high enough to shine out properly from the lantern. This meant that the light was much reduced and complaints were received from seamen that the Eddystone light was not shining brightly enough.

Glass And The Lighthouse Lantern

From ancient times, wood and coal fires were originally used for beacons on headlands and, over the years, would have been refined by the use of improved containers to allow the fuel to burn more efficiently, i.e. with more light emitted per given quantity of fuel and with less smoke. This latter is always a problem because it obscures the light and creates soot which causes other disruption. Later, as the need for more reliability increased, lighthouse fires were enclosed inside structures made of arrays of panes of glass, called lanterns. Unfortunately, unless great efforts were made to control the smoke, the glass was frequently coated in soot which reduced the visibility of the fires. The enclosure of a coal fire behind glass to make a lighthouse lantern seems an obvious improvement to us today, yet it was not easy for seventeenth century engineers. It was all about the glass, the quality of which was random and generally poor until the nineteenth century. In northern Europe, the main method of producing glass from the Middle Ages onwards had been devised in Germany. Molten glass was blown into spheres, which, while still hot, were swung to form cylinders that were cut and flattened before they cooled.

An important variation which specifically targeted the manufacture of window glass was devised in Venice. This resulted in crown glass whereby hollow spheres were blown, reheated and spun into large discs. Panes were cut from these discs, and the best glass was to be found at the edge of the disc where it was clearest and thinnest. In the centre, where it was thickest, the glass was least translucent and these regions known as the bullion or bull's-eye were used on smaller windows.

Glass was manufactured from a few common ingredients – specifically sand, potash, and lime, heated in a furnace. In medieval times, much glass was made in Sussex where good supplies of timber were available for the hot furnaces. However, the timber was valuable for other purposes and glass manufacturers were forced to move to the Midlands and other locations where they could use more readily available coal.

Prior to the 18th century, glass manufacture was primitive and most products were of poor quality. Even by the early 19th century supplies of good quality glass for optical purposes was in poor supply in England, most of the best quality materials being obtained from Europe and especially France. Between 1827 and 1830, Michael Faraday spent much time experimenting with improvements to glass which were largely unsuccessful. Across the channel, however, George Bontemps was one of most notable French glass makers and his work undoubtedly gave great advantage to the French in the advancement of optical science. In his short life, the great French scientist Augustin-Jean Fresnel (1788-1827) was to revolutionize the manufacture of specialized optical devices for use in lighthouses based upon the high quality glass made available in his own country, whilst in England, it was not until the Smethwick (Birmingham) company called Chance Brothers became established as the leading glass manufacturer that English lighthouse technology caught up with French. Their greatly improved processes of glass manufacture enabled the successful construction of the Crystal Palace for the Great Exhibition of 1851 by supplying most of the glass for the innovative structure.[26]

26 Chance, Toby and Peter Williams: *Lighthouses - The Race To Illuminate The World,* New Holland, (2008). ISBN: 978-1-84773-174-6.

Candles in the Timeline of Lighthouses

1445 For at least another 30 years after this date, a light is shown from a tower at La Rochelle, France. It was a round turret carrying a stone lantern of six windows surmounted by an elegant spire and containing a thick wax candle as illuminant.[1]
1532 The Gollenberg light at Coslin in Pemerania is recorded as having several lamps or candles in front of a polished becken, a term which might apply to a plane or a concave mirror or glazed.[2]
1541 A dozen pounds of candles for the North Shields lighthouses cost 18 pence (18 pence = 1s 6d.) Thirty-three pounds of candles were purchased for 4s. 3d.[3]
1628 Candles used at Caistor lighthouse were three to the pound.[4]
1628 Candles were three to the pound weight in 1628 at Caistor, one pound weight each at Harwich in 1676 and of two pounds each in 1777.
1676 Candles used at Harwich were each of one pound in weight.[5]
1712 The lantern in the low lighthouse at Harwich contained candles from this date until 1813.[6]
1751 From the earliest times a lamp or candle stuck in the window of a house guided a man to his home and there are several instances in England before 1600 of lights being shown nightly from churches and other buildings to direct travellers over moorlands. A late example is Dunstan Pillar, or Lincoln lighthouse, which gave guidance across a heath between Lincoln and Sleaford. In 1751 Francis Dashwood erected this square tower 92 feet high, as a land lighthouse, and topped it by a lantern raising it another 15 feet. In 1810 a statue of George III was substituted for the disused lantern and this in turn was removed about 1940 as a possible danger to aircraft. This curiosity in lighthouses, being so far from the sea coast, offered no service to shipping.[7]
1756 After the destruction by fire in 1755 of Rudyerd's lighthouse on the Eddystone Rocks, John Smeaton (1724-92) designed a tower in 1756 to consist entirely of stone, a choice of material resulting from a study of the advantages and defects of the previous Eddystone lighthouses. This stone tower, described in Section VIII, was the first to be exposed directly to the ocean, and was an achievement in construction much in advance of contemporary navigation lighting. Until 1810 its light came from merely 24 candles.[8]
1759 Most importantly oil lamps required less work than candles of equivalent light intensity. With a large reservoir, they could be used for hours with little attenuation. However, smoke and soot would be created after a few hours if it were not adjusted. Smeaton tried oil lamps for the Eddystone in 1759, but was dismayed to find that the glass panes of the lantern soon became coated with sooty deposits because of smoke from them. He was forced to revert to his candelabrum.
1760 21 out of the 25 major navigational lights in Britain use coal, excluding Eddystone and two lightships which, by their nature, must use candles or oil lights. Of the six French lighthouse, four burned coal and one wood or coal. In Sweden, four out of six lighthouses burn coal.[9]
1777 Hutchinson reports the use of candles each weighing three pounds.[10]
1785 The harbour light at Dieppe consists of a one candle lantern. People complained that it was indistinguishable from the lights of ordinary houses nearby.[11]
1794 Sir Benjamin Thomson, an American who had received the papal title of Count Rumford, announced that he had developed an oil lamp of Argand design producing 12 times as much light as one candle, but seven times was a normal amount in most experiments.[12]
1802 In 1802-3 Ezekial Walker proposed that illumination from a candle was dependent upon the material consumed by combustion; the faster this occurred, the better the light. He showed that if a candle was set at a 30 degree angle, the light burned more brightly, more material was consumed and snuffing was not required.
1810 At the Eddystone, oil lamps and reflectors take the place of 24 candles weighing about half a pound each. About twelve inches (300 mm) in length, they were arranged in two circular tiers. Each candle gave the equivalent of 2.8 standard candles, making the total light intensity about 67 candlepower.[13]
1819 About this time, most lightships showed either two or three fixed lights from candles or oil lamps in lanterns as the best distinction from the lights of other vessels, all under 5 candle.[14]
1820 The snuffless candle is created, but by this time, candles had ceased to be of significant use in lighthouses.[15]
1820 A candle is a cylindrical solid of variable diameter made from a combustible oily or waxy material. Combustion is assisted by the presence of a wick through the centre of the candle. Snuffless candles were formed by dipping plaited wicks in chemicals. These were not invented until 1820 when candles had ceased to be of significant use in lighthouses.
1828 One of the Wintertonness lights was the last in Britain to use candles which were discontinued in 1828.
1959 By the modern system of evaluating light intensity Smeaton's original twenty-four tallow candles are estimated to have produced something like 67 candle-power. The introduction in 1810 of Argand lamps and catoptric reflectors raised the strength of the lantern to 1,125 candle-power. In 1845 a non-revolving Fresnel dioptric frame-rather like a glass bee-hive made up of prisms and lenses-stepped it up to 3,216 candlepower. In 1872 a better lamp increased the candle-power figure to 7,325. Only ten years later Douglass's first apparatus jumped the figure to 79,250. In 1959 the same optic was producing a beam of 358,000 candle-power. The Eddystone light had come a long way.[16]

The Visibility of Candles

Some years ago I was intrigued by Smeaton's report that he had been able to observe the light from his new lighthouse from the deck of his ship. I felt compelled to examine the claim with some simple calculations. Inevitably, this subject is necessarily given to a number of approximations for a variety of reasons, so we need to adopt a pragmatic approach to our science.
For many years, candles have been approximately 1 foot in length (300 mm) and 1 inch in thickness (25.4 mm). In his Eddystone

1 Stevenson, 1959, p20.
2 Ibid, p27.
3 Ibid, p272.
4 Ibid, p271.
5 Ibid, p271.
6 Ibid, p272.
7 Ibid, p47.
8 Ibid, p49.
9 Ibid, p273.
10 Ibid, p271.
11 Ibid, p272.
12 Ibid, p278.
13 Ibid, p272.
14 Ibid, p281.
15 Ibid, p271.
16 Majdalany, 1959, p199.

lighthouse of 1759, Smeaton used a chandelier comprised of 24 candles with approximately these dimensions. He also recorded that 5 candles weighed 2 pounds, so we can calculate that each candle weighed 181 g. The first pragmatic approximation is to say that we have a conventional candle, and that its output, or luminous flux, is 1 candela, which falls upon 1 steradian of area at a distance of 1 metre from the flame. If we divide by 4π, and also by 683 (to convert into watts), we arrive at the light energy from a candle falling on 1 square metre of area at a distance of 1 metre as 0.0184 W.

I am now going to branch in two directions. Firstly, let us consider the human eye, which has an area considerably smaller than 1 m^2. Taking a typical iris radius in total darkness as 0.005 metres, the total sensory area of a human eye is calculated as 7.85×10^{-5} m^2. From this we calculate that the eye receives 9.15×10^{-9} W at 1 metre distant. Now it is said that the eye can detect a minimum threshold of 100 photons per second, which is equivalent to 3.57 $\times 10^{-17}$ W. Using the inverse square law, we calculate that a single candle could in theory be seen at a distance of 16 km. However, we must recognise that there are many factors that will reduce this visibility. For example, weather conditions such as bright moonlight or rain in the atmosphere will significantly reduce this visibility. The efficiency of the human eye is no small consideration and our calculation used a value for iris radius that assumed total darkness. In reality, the iris could be much smaller, and this would reduce the distance much further. For example, an iris radius of 2 mm reduces the maximum visibility to 6.4 km. So there are a number of uncertainties in our calculations that make it difficult to be precise.

For my second approach, I am going to consider a slightly more realistic situation. Smeaton used 24 candles in his lighthouse on the Eddystone. He also wrote in his diary that when he was on board the Neptune Buss (the ship he used to travel the 20 km distance from Plymouth to the Eddystone), he could see the light from his lighthouse when he was close to the shoreline of Plymouth Hoe, and that the light was equivalent to a star of magnitude 3 or 4, naturally depending upon the weather conditions. (Smeaton was a man of great precision, experienced in astronomy, and we can accept his observations as being quite accurate).

We learned above that 1 candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} Hz and that has a radiant intensity in that direction of 1 / 683 watt per steradian, i.e. 0.001464 W sr^{-1}. In the case of a sphere of radius 1 m, 1 sr = 1 m^2. So let us say that 24 candles alight in Smeaton's Tower would give 24 x 0.001464 W / m^2 at the lantern glass = 0.0351 W/m^2. This energy of illumination is reduced by the inverse square law to 8.785×10^{-11} W/m^2 at 20 km - the approximate distance to Plymouth Hoe.

Allowing for the small size of the human eye, this energy must be reduced by the appropriate factor, so we get 6.9×10^{-15} W entering an eye with an iris of 5 mm, i.e. under perfectly dark conditions. As I said earlier, it would not be perfectly dark for an observer, whose iris might have a smaller radius of, perhaps, 2 mm, in which case this amount would be reduced still further to about 1.1×10^{-15} W.

Now let us check out Smeaton's observations comparing the light from his lighthouse with that from stars. He estimated that the brightness of his lighthouse light was comparable to a star of magnitude 3 or 4.

A brief explanation is required. In astronomy, the apparent magnitudes of stars are measured on a scale where negative numbers are brighter and positive numbers are darker. The scale is not logarithmic to the base 10, but the difference between each unit is x2.5. Therefore, a star of magnitude 4 is 2.5x dimmer than a star of magnitude 3. The Sun, being the brightest thing we see on Earth is large and negative at -26.74. The dimmest star visible to the naked eye is at 6.5. (The use of the word 'apparent' simply means that it is as we see them; it takes no account of how far away stars are. Thus the Sun is by no means the brightest star in absolute terms, it's just that other stars are a lot further away so the Sun appears brighter because it is closest.) If we take some standard values from astronomy as follows: the apparent luminosity of the Sun at the surface of the Earth = -26.74, the luminous intensity of the Sun at its surface as 3.846×10^{26} W and the distance of the Sun from the Earth as 1.5×10^{11} m. Now we can calculate that the energy received by an eye seeing a star of apparent magnitude 3 is 2.17×10^{-14} W, and for a star of magnitude 4 is 8.63×10^{-15} W. From these calculations, with answers firmly in the range of 10^{-14} to 10^{-15}, and allowing for inevitable errors of approximation implicit in the approach, we confirm that Smeaton was correct in his observation! (Did we ever think otherwise?)

What Is The Threshold For Visibility Of Light By A Human Eye?

We considered above that a human eye can detect about 100 photons per second. If we use the standard physics values of 3 x 108 m/s for the speed of light (c), and the value for Planck's constant (h) of 6.6×10^{-34} Js, we take the optimum wavelength (l) visible to the eye as 555×10^{-9} m and calculate the energy (E) of one photon by the formula E = (h x c)/l, i.e. E= 3.567×10^{-19} J. So for 100 photons per second, the eye is receiving 3.567×10^{-17} W. Any smaller amount is invisible. We can use this threshold value to determine how far a light can be visible, given that, as the distance from the light to the observer increases, the energy diminishes according to the inverse square law. Let's try it out...

How Far Can A Light Be Seen?

Let's begin by considering a single candle. For the moment we shall ignore the curvature of the Earth and the effect known as the horizon. Consider 1 candle placed at a distance of 1 metre from a glass window of area 1 m^2. For a sphere of radius 1 metre, the equivalent of a steradian is 1 m^2, and we know that the luminous energy falling on the window is 0.001464 W/m^2. Adjusting now to the area of the human eye, we get a value (E1) of 9.151×10^{-9} W. If this energy decreases over distance until the eye is at such a distance (d) that it can only just see the equivalent of 100 photons per second, i.e. 3.567×10^{-17} W (E2) then we can calculate the distance from the inverse square law thus: d = sqrt (E1/E2), i.e. 22.7 km.

If we do the same calculation based upon the threshold of visibility of a star being at a magnitude of 6.5, then the minimum amount of energy received by the eye is 9.96×10^{-16} W and this occurs at a distance of 4.53 km. These calculations would indicate that the minimum level of light visibility is greater than 100 photons per second, but there are many errors and approximations associated with each method and we cannot be too strict in our interpretations. Amongst other possibilities for discrepancy, the calculation is sensitive to the values of energy we use because there is a square of the distance involved.

Conclusions

1. The light from a single candle placed in a window by a monk or a hermit can be seen at a distance of approximately 5 km in good weather conditions.

2. Smeaton's use of 24 candles in his lighthouse is calculated to have a maximum visibility of 22.2 km. This accords well with his own observations.