150 years of steel
1869-71 William Cavendish, 7th Duke of Devonshire
1871-73 Sir Henry Bessemer
1873-75 Sir Lowthian Bell Bt FRS
1875-77 William Menelaus
1877-79 Sir C William Siemens FRS
1879-81 Edward Williams
1881-83 Josiah Timmis Smith
1883-85 Rt Hon Sir Bernard Samuelson Bt FRS
1885-87 John Percy MD FRS
1887-89 Danie Adamson
1889-91 The Rt Hon Lord Airedale of Gledhow DSc
1891-93 Sir Frederick Augustus Abel Bt GVCO KCB FRS
1893-95 Edward Windsor Richards
1895-97 Sir David Dale Bt DCL
1897-99 Edward Pritchard Martin
1899-1901 Sir William Chandler Roberts-Austen KCB DCL FRS
1901-03 William Whitwell [2]
1903-05 Andrew Carnegie LLD
1905-07 Sir Robert Abbott Hadfield Bt DSc FRS
1907-10 Sir Hugh Bell Bt CD DCL LLD
1910-12 Victor, Ninth Duke of Devonshire KG
1912-14 Arthur Cooper LLD
1914-15 Adolphe Greiner DSc
1916-18 Rt Hon Lord Invernaim of Strathnairn
1918-20 C P Eugene Schneider DSc
1920-22 John Edward Stead DSc Dmet FRS
1922-24 Francis Samuelson
1924-25 Sir William Ellis GBE DENG
1925-26 Sir Frederick Mills Bt DL
1926-27 Sir W Peter Rylands JP
1927-28 Frank William Harbord CBE
1928-29 Benjamin Talbot
1929-31 Henry Louis MA DSc
1931-33 Col Sir W Charles Wright Bt KBE CB
1933-35 William R Lysaght CBE
1935-37 Sir Harold Carpenter FRS
1937-38 Alfred Hutchinson MA
1938-40 The Rt Hon The Earl of Dudley DC
1940-42 Sir John Craig CBE DL
1942-44 James Henderson
1946-48 Dr Cecil Henry Desch DSc PhD LLD FRS
1948-50 Sir Andrew McCance LLD DSc FRS
1950-51 James Robert Menzies-Wilson OBE
1951-52 Richard Mather BMet
1952-53 Captain Hector Leighton Davies CBE JP
1953-54 James Mitchell CBE
1954-55 The Hon Richard Glynne Lyttelton
1955-56 Sir Chales Bruce-Gardner Bt
1956-57 Herbert Henry Burton CBE DMet
1957-58 Arnold Hugo Ingen-Housz
1958-59 Charles Reginal Wheeler CBE
1959-60 William Barr OBE
1960-61 William Frederick Cartwright DL
1961-62 Sir Charles Goodeve OBE DSc FRS
1962-63 Maurice Alberic Fiennes
1963-64 Frank Bernard George
1964-65 Frank Henry Saniter OBE DSc (Tech) BENG
1965-66 William Frederick Gilbertson
1966-67 Sir Douglas Bruce-Gardner Bt
1967-68 Norman E Jones CMG DSc ASTC
1968-69 Dr John Hugh Chesters OBE FRS
1969-70 Niall Cambell Macdiarmid
1970-71 Norman Cecil Lake CBE
1971-72 Thomas Rae Craig CBE TD
1972-73 Geoffrey Thomas Harris CBE
1973-74 Lionel Roger Price Pugh CRD DL
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150 years of steel – what this talk is about

- Physical properties
- Periodic Table
- Technology
- Chemistry
- People
- The future
- End uses
- Geopolitics
- Microstructure
- Types of steel

Chemistry

Resources
Ironbridge – 1779 – Abraham Darby III – cast iron
Position of cast iron

![Graph showing the position of cast iron on a plot of Tensile Strength (MPa) vs. Elongation (%)]
### 150th anniversary of the Periodic Table – knowledge in 1869

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### Knowledge in 1869

- Hydrogen (H), the first element, was discovered in 1869.
- The Periodic Table was first published in 1869 by Dimitri Mendeleev.
- Mendeleev's table predicted the existence of undiscovered elements, such as boron and silicon.
- The table was expanded with the discovery of new elements in the late 19th and early 20th centuries.

### Atomic Masses (rounded)

- Hydrogen (H): 1.008
- Helium (He): 4.003
- Lithium (Li): 6.94
- Beryllium (Be): 9.012
- Sodium (Na): 22.99
- Magnesium (Mg): 24.31
- Silicon (Si): 28.09
- Phosphorus (P): 30.97
- Sulfur (S): 32.07
- Chlorine (Cl): 35.45
- Argon (Ar): 39.95
- Potassium (K): 39.10
- Calcium (Ca): 40.08
- Scandium (Sc): 44.96
- Titanium (Ti): 47.88
- Vanadium (V): 50.94
- Chromium (Cr): 52.00
- Manganese (Mn): 54.94
- Iron (Fe): 55.85
- Cobalt (Co): 58.97
- Nickel (Ni): 58.71
- Copper (Cu): 63.55
- Zinc (Zn): 65.38
- Gallium (Ga): 69.72
- Germanium (Ge): 72.63
- Arsenic (As): 74.92
- Antimony (Sb): 79.92
- Bismuth (Bi): 80.91
- Gold (Au): 197.0
- Mercury (Hg): 204.4
- Thallium (Tl): 204.4
- Lead (Pb): 207.2
- Bismuth (Bi): 209.0
- Polonium (Po): 209.0
- Radon (Rn): 222.0
- Radon (Rn): 222.0
- Oganesson (Og): 280.0

### Notes

- The table includes elements that were discovered before and after 1869.
- The table is arranged in order of increasing atomic number.
- The elements are divided into periods and groups based on their properties.
- The table represents a significant milestone in the history of chemistry.
6000 puddling furnaces in the UK make 2 million tonnes of wrought iron - 1869
Henry Clifton Sorby – Father of Metallography – 1826 - 1908

Wrought iron
Position of wrought iron

![Graph showing the comparison between cast iron and wrought iron in terms of elongation and tensile strength. Cast iron has a lower elongation and lower tensile strength compared to wrought iron.](graph.png)
Isambard Kingdom Brunel (1806 – 1859)
Henry Bessemer 1813 – 1898 Invention of Bessemer converter, 1856
Henry Bessemer 1813 – 1898 Invention of Bessemer converter, 1856
Henry Bessemer 1813 – 1898 Invention of Bessemer converter, 1856
Carl Wilhelm Siemens 1823 – 1883 Pierre Emile Martin 1824 – 1915 Open Hearth Furnace 1865
Sidney Gilchrist Thomas 1850 – 1885 Elimination of phosphorus – basic converter - 1878
Brooklyn Bridge 1880 – wrought iron
1880 steel production worldwide – UK and USA have 31% each
Dr James Burgess Readman - first operational; EAF - 1888
Eiffel Tower 1889 – wrought iron – 10,000 tonnes
Development of the thermocouple – commercial Pt/Rh by 1900

Early sketch by Ohm, 1820s

Le Chatelier, uses platinum/rhodium Thermocouple, 1885

Edward Matthey commercial version of Pt/Rh thermocouple 1900
Taking temperature of Open Hearth Furnace
The Fe/C equilibrium phase diagram – emerges after 1900
Stress strain curve for low, medium and high carbon steels
Steel begins to be understood and classified

Carbon steel, or plain carbon steel, is steel where the main alloying element is carbon. Manganese must be less than 1.65%, silicon 0.60% and copper 0.60%

1. **Low carbon** steels have 0.05% - 0.29% carbon. A large proportion of steel has carbon contents within this range

2. **Medium carbon** steels have 0.30% - 0.59% carbon, and often some alloying elements. These are harder, stronger steels, modified by heat treatment

3. **High carbon** steels have 0.60 – 0.99% carbon. These have high strength and good wear resistance – forgings, automotive components

4. **Ultra high carbon** steels have 1.0 – 2.0% carbon. Very hard, sharp (knives)

5. **Over 2% carbon** – material becomes cast iron not steel
Steel poured into ingot moulds for subsequent rolling – 1800s onwards
Hot Strip Mill – developed from 1904
Empire State Building  - 1930
Empire State Building - 1930
Sydney Harbour Bridge – 1930 photo – bridge opened 1932 – 86% steel from UK
Barrow Steelworks, 1936
Barrow steelworks, 1936
A blast furnace
Tongsman – Barrow - 1936
Robert Durrer  1890 - 1978  Oxygen blown steel, 1948
Russia – 1955 – first hot metal produced at Cherepovets (Severstal)
One cannot advance without mistakes... It is necessary to make mistakes.

Chairman Mao, 1956
China – Great Leap Forward - 1958
“The Britain that is going to be forged in the white heat of this revolution will be no place for restrictive practices or for outdated methods on either side of industry.”

Harold Wilson, Labour Party Conference 1963
British Admiral – built Barrow 1965 – scrapped 1976 in Taiwan
British Steel Corporation (BSC) – nationalised in 1967

- Key people – Lord Melchett and Sir Monty Finniston
- 269,000 people in the newly formed BSC
- The BSC board had consensus that growth lay ahead
- The plan for growth included an unprecedented £6bn over 10 years

Lord Melchett - Chairman

Sir Monty Finniston - CEO
“You say you want a revolution
Well, you know
We all want to change the world
You tell me that it's evolution
Well, you know
We all want to change the world...

...but if you go carrying pictures of
chairman Mao
You ain't going to make it with anyone
anyhow
Don't you know it's gonna be
All right, all right, all right...”

Songwriters: John Lennon / Paul McCartney
Revolution lyrics © Sony/ATV Music Publishing LLC
Moon landing, 20 July 1969
Evolution of continuous casting

Share of global crude steel output produced via continuous casting
Cobble in concast billet – Barrow - 1970
China – 1970s (Dong Biwu – Acting Chairman, 1972 – 1975)

• China needs to grow
• Needs new technology, larger more modern plants
• Seeks technology from Austria (BOF steelmaking)
• Japan – Baosteel modelled on Nippon Kimitsu
• Target 60mt crude steel by 1990
• $60bn investment over 2 decades

CIA study (1979)
“With its abundant raw materials and the infusion of Western technology,
China should be able to develop a steel industry comparable in size to the steel industries of the USA, USSR and Japan”.

(Embargoed until release in 2000)
Transmission electron microscope – 1970s onwards

Dislocations in steel
Lakshmi Mittal (1950 - ) formed his first steel company, PT Ispat Indo, in 1976
Seawise Giant - Jahre Viking – Mont - 657,019 tonnes – built in Japan 1979 – scrapped India 2010
Country X and Country Y by 1984

Million tonnes crude steel

Country X and Country Y


Country X
Country Y

Country X and Country Y
Thin slab casting – commercialised by Nucor, 1989
POSCO Gwangyang works, built 1985 – 1992, capacity 22 million tonnes per annum
Castrip – development started in 1988, first commercial plant 2002
Country X and Country Y revealed – by 2000

China and UK, production of crude steel

Million tonnes crude steel

China

UK


China

UK
HMS Bulwalk – built Barrow 2001
Shipyard, China 2000s
Aditya Mittal (1976 - ) Formation of ArcelorMittal, 2006
Burj Khalifa – Adrian Smith – Skidmore Owings & Merrill - 2008
Blast furnaces at Baosteel, China 2010
Barrow steelworks site, 1936 and 2018
A modern EAF
EAF improvements 1965 - 2015
Development of high strength automotive steels
Complex microstructures of high strength steels

Dual phase steel

HSLA steel
### Periodic Table

**Period 1**

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**Atomic Mass** (rounded)

Figure 7  Steel structural systems and the number of storeys
Height and time

- Great Pyramid (Giza)
- Eiffel Tower (Paris)
- Empire State Building (New York)
- Petronas Towers (Kuala Lumpur)
- Taipei 101 (Taipei)
- World Trade Center (New York)
- Willis Tower (Chicago)
- KVLY-TV Mast (Blanchard)
- CN Tower (Toronto)
- Burj Khalifa (Dubai)

Height range: 0 m to 800 m
Bishopsgate 2009
Bishopsgate 2010
Almost complete, 2019
What is this?
Tuned mass damper, 700 tonnes of computer controlled steel plates
Crude steel growth by region

Evolution of world crude steel production tonnage by key region, 1980 - 2020f

Crude steel production, million tonnes

UK
Other
Europe
USA
China
Evolution of world steel production by region 1870 - 2020

Evolution of world steel production by key region, 1870 - 2020f

UK 31%
Other 8%
Europe 30%
USA 52%
China 52%
UK 0.4%
Other 35%
Europe 8%
USA 5%
China 0%
UK and China – different growth patterns – or are they?

**UK: relationship of True Steel Use (TSU) and GDP/capita**

**China: relationship of True Steel Use (TSU) and GDP/capita**
Production of crude steel, China and UK, 1968 - 2018

China and UK, production of crude steel

Million tonnes crude steel

China

UK

0 100 200 300 400 500 600 700 800 900 1000

China

UK
In 2018, crude steel production in China was:
- 120 x UK
- 22 x Germany
- 13 x Russia
- 11 x USA
- 9 x Japan
- 9 x India
A view of the future

World crude steel forecast 2020 - 2040

Thousands of tonnes crude steel

- 2020
- 2030
- 2040

EAF crude steel world
BOF crude world
Acknowledgements

- **Thanks to MinSouth for inviting me to speak**
  - Many sources were used in the preparation of this talk, including:
  - [https://archive.org/details/journal187201iron/page/n8](https://archive.org/details/journal187201iron/page/n8) for early details of Iron and Steel Institute
  - [https://en.wikipedia.org/wiki/Iron_and_Steel_Institute](https://en.wikipedia.org/wiki/Iron_and_Steel_Institute) for Past Presidents
  - [https://extrudesign.com/how-tensile-test-is-conducted/](https://extrudesign.com/how-tensile-test-is-conducted/) for details of cast iron and other stress strain curves
  - Mr Bigler for the periodic table
  - [http://shropshirehistory.com/iron/iron_making.htm](http://shropshirehistory.com/iron/iron_making.htm) for puddling furnaces
  - [https://en.wikipedia.org/wiki/Wrought_iron](https://en.wikipedia.org/wiki/Wrought_iron) for wrought iron details and microstructure
  - [https://en.wikipedia.org/wiki/Isambard_Kingdom_Brunel](https://en.wikipedia.org/wiki/Isambard_Kingdom_Brunel) for image of Brunel
  - Bessemer converter image from photo in Bessemer Room at IOM3
  - Bessemer steel artefacts from display in Bessemer Room at IOM3
  - [https://en.wikipedia.org/wiki/Pierre-%C3%A9mile_Martin](https://en.wikipedia.org/wiki/Pierre-%C3%A9mile_Martin) Image of Carl Emile Martin
Acknowledgements

- Many sources were used in the preparation of this talk, including:
  - Early steel statistics from Zimmerman, World Resources and industries
  - Portrait of Andrew Carnegie from Bessemer Room at IOM3
  - Barrow Steelworks, Stan Henderson and Ken Royall, various images and maps of the steelworks
  - Iron carbon equilibrium diagram, various sources
  - [https://www.pinterest.co.uk/pin/345721708865045232/?autologin=true](https://www.pinterest.co.uk/pin/345721708865045232/?autologin=true) Hot Strip Mill, Sparrows Point
  - Many steel statistics from WorldSteel, formerly IISI, from 1900 to 2018
Acknowledgements

- Many sources were used in the preparation of this talk, including:
- Map of Gwangyang Steelworks, South Korea, Shanghai Baosteel and Barrow in Furness from Google Maps
- Mr Da Nym – image of HMS Bulwark
- Various photos (China blast furnaces, Harold Wilson, rebuilding 22 Bishopsgate by Roger Emmott)
- Engineering Architecture: The Vision of Fazlur R. Khan by Yasmin Sabina Khan (his daughter) – details of his work with structural steels and high rise buildings
- Crude steel forecasts by MCI/James F King [www.steelonthenet.com](http://www.steelonthenet.com)