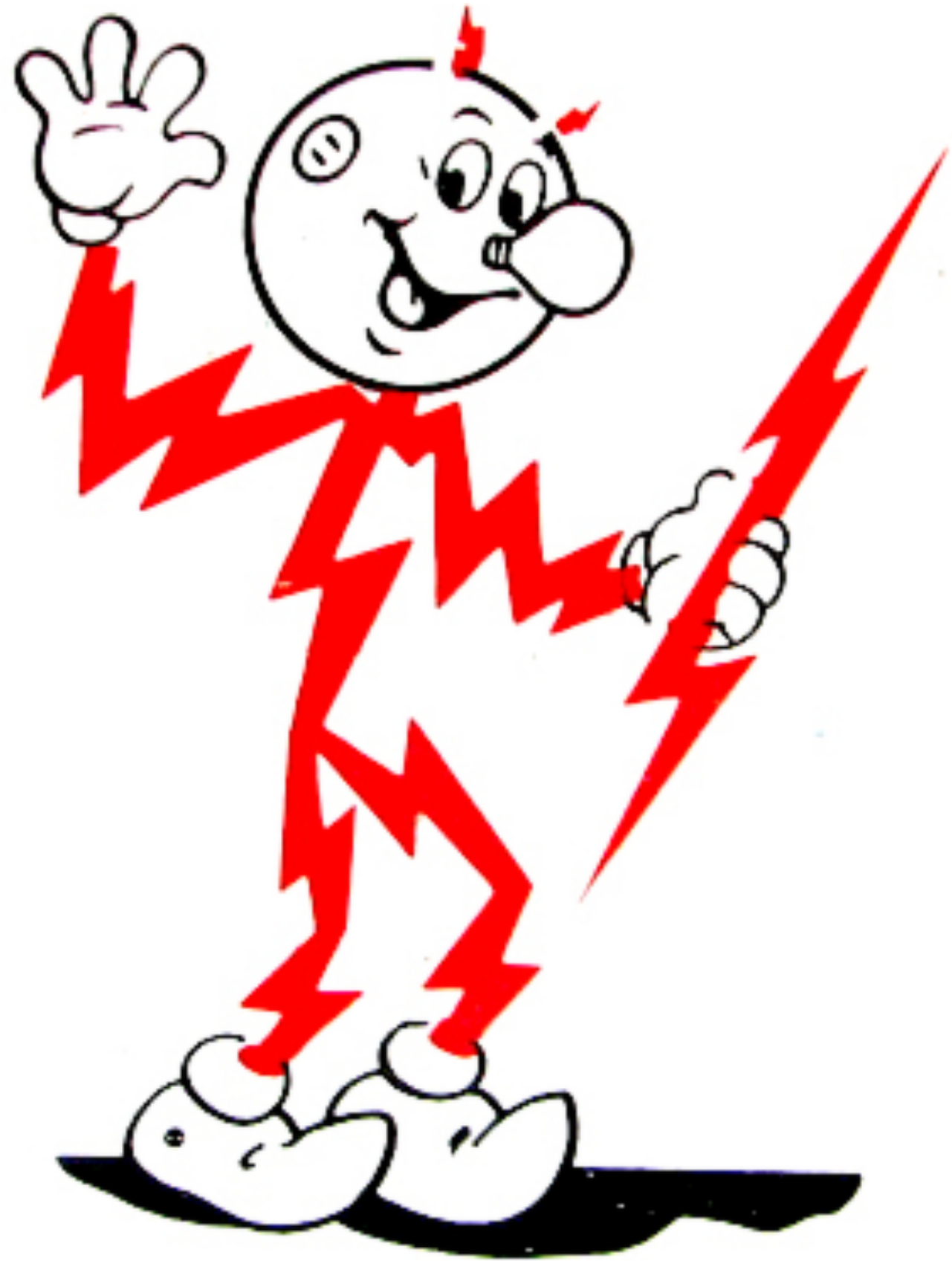


13 Industry



3200 GWt power today

Cement

Plasma arc temperatures

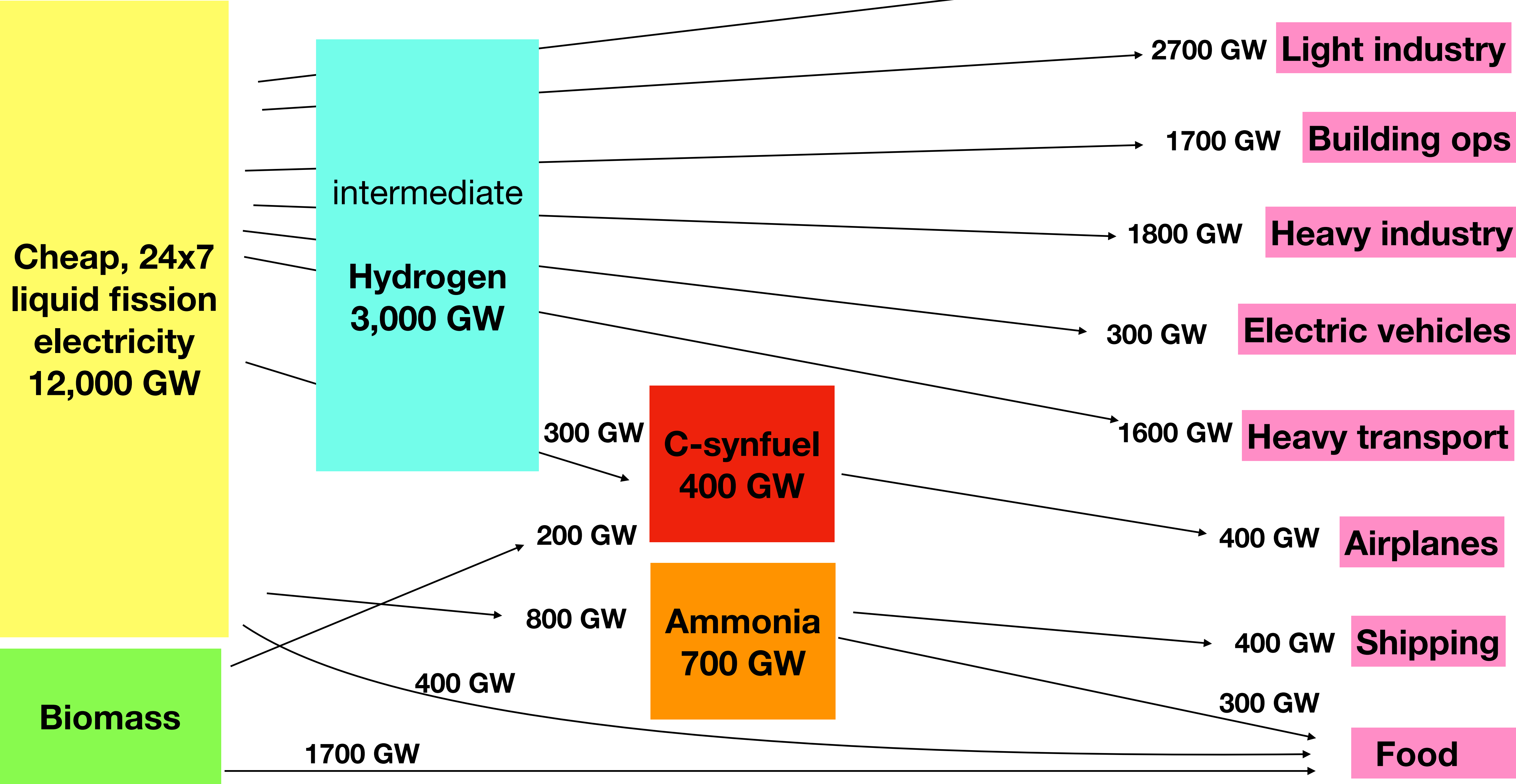
Iron reduction, electrolysis

Aluminum, solid electricity

Shipyard building factories

Fission is in Fashion

Energy to change industrial processes



IRENA has industry power use estimates.

Energy-intensive industrial sectors



Iron and steel

1000 GW

In 2017:

- ➔ Consumed 32 exajoules (EJ) of energy
- ➔ Only 4% was from renewables
- ➔ Emitted 3.1 gigatonnes (Gt) of CO₂

3 Gt/y



Chemicals and petrochemicals

1500 GW

In 2017:

- ➔ Consumed 46.8 EJ of energy
- ➔ Only 3% was from renewables
- ➔ Emitted 1.7 Gt of CO₂

2 Gt/y



Cement and lime

500 GW

In 2017:

- ➔ Consumed 15.6 EJ of energy
- ➔ Only 6% was from renewables
- ➔ Emitted 2.5 Gt of CO₂

3 Gt/y



Aluminium

150 GW

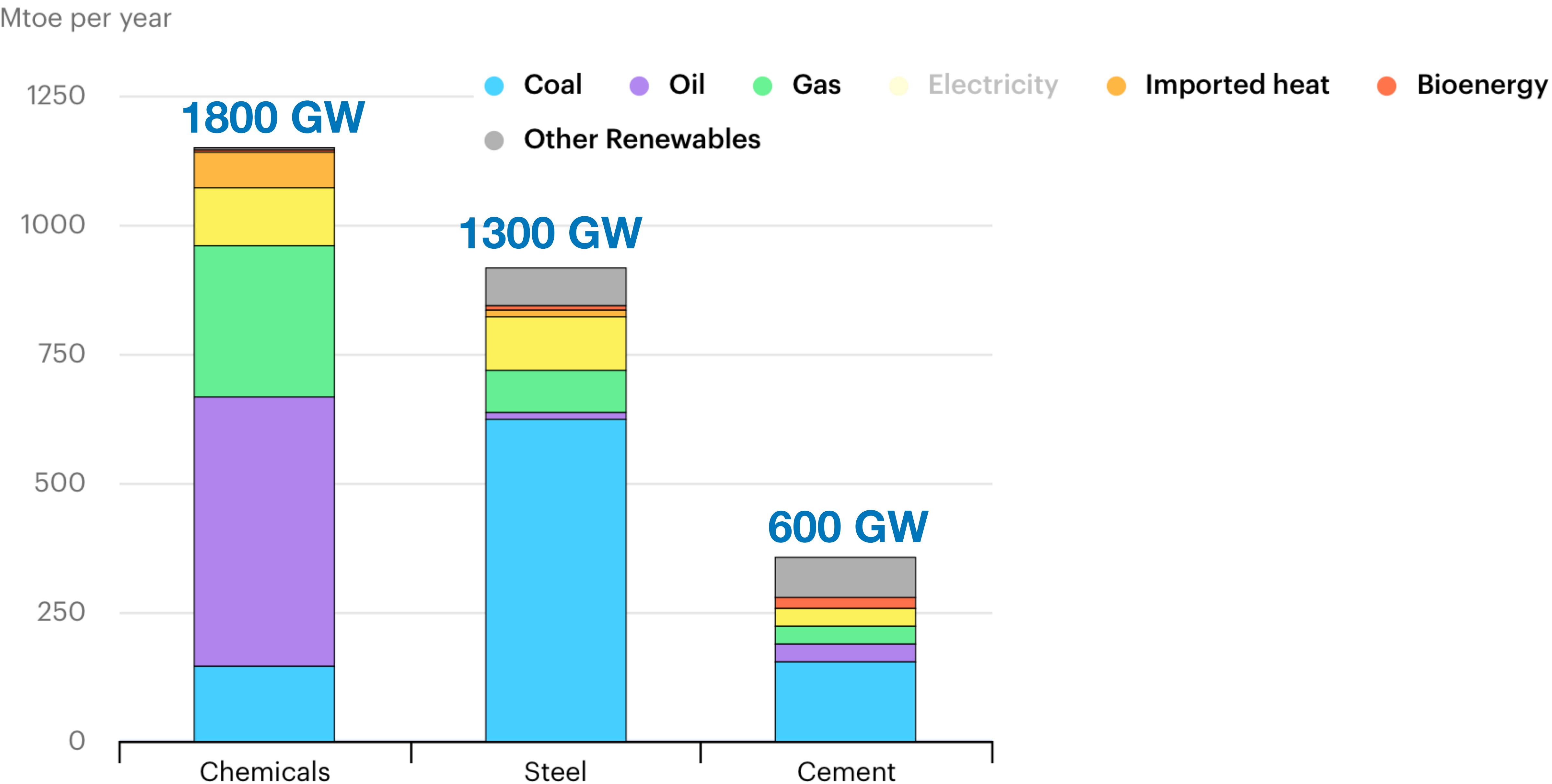
In 2017:

- ➔ Consumed 4.5 EJ of energy
- ➔ 16% was from renewables
- ➔ Emitted 0.4 Gt of CO₂

<1 Gt/y

Some of 1500 GW of chemical and petrochemical power consumption related to fuel refining will not be needed.

IEA has similar power use data.



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SUSTAINABLE MATERIALS WITH BOTH EYES OPEN

Materials, transformed from natural resources into the buildings, equipment, vehicles and goods that underpin our remarkable lifestyles, are made with amazing efficiency. But our growing demand is not sustainable, so this optimistic, entertaining and richly informed book evaluates all the options . . . with both eyes open.



**Julian M Allwood
Jonathan M Cullen**

with Mark A Carruth, Daniel R Cooper, Martin
McBrien, Rachel L Milford, Muiris C
Moynihan, Alexandra CH Patel



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Top 5 materials produced

Sustainable Materials
with Both Eyes Open

Material	Global annual production (Mt)	Energy intensity (GJ/t)	Carbon intensity (tCO ₂ /t)	Power
Cement	2,800	5	1	444 GWt
Steel	1,400	35	3	1553 GWt
Plastic	230	80	3	583 GWt
Paper	390	20	1	247 GWt
Aluminium	70	170	10	377 GWe

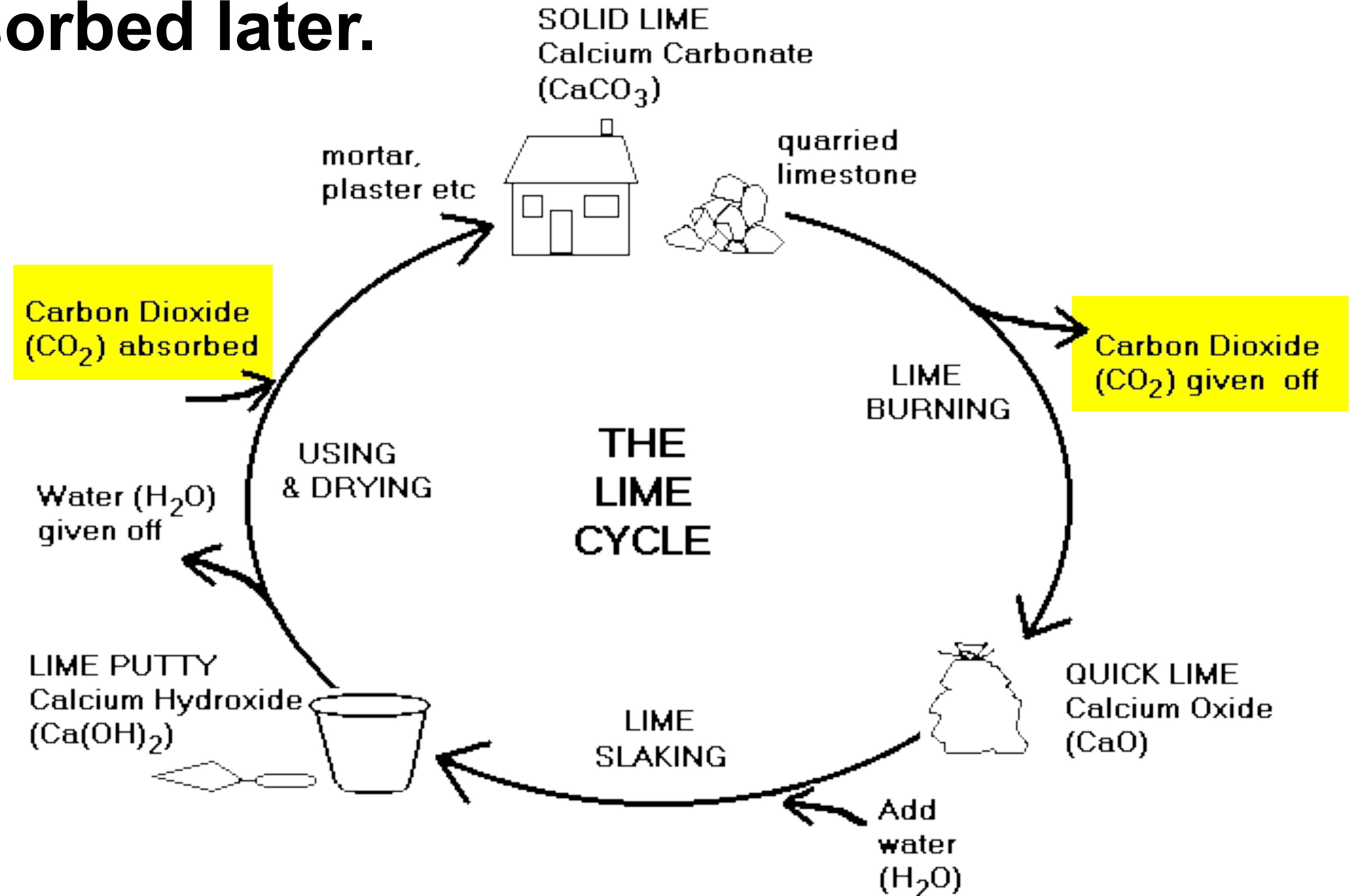
Cement is critical for infrastructure construction.

<u>Annual cement use</u>	<u>M tonnes</u>
US consumption	106
China consumption	1800
World consumption	3300

circa 2010

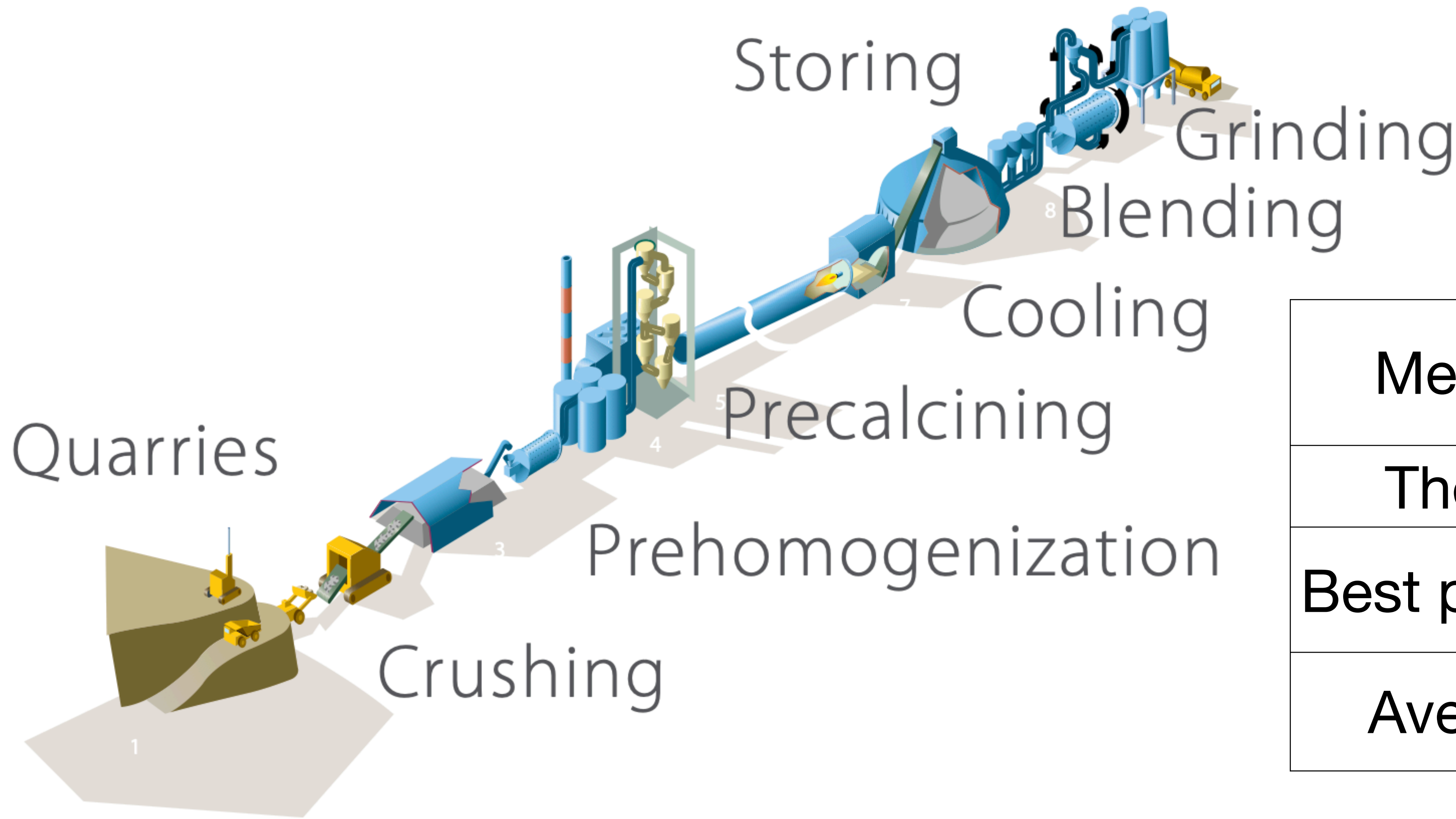


Making cement by heating limestone drives off CO₂ that is reabsorbed later.



Cement energy use and emissions can be improved.

Sustainable Materials
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Method	Energy use GJ/t
Theory	1.8
Best practice	2.9
Average	5.0

Fission-powered plasma arc heating to 1500°C for cement?

Alternatives to Ca-Si cement? to road surfaces?

<u>CO2 emissions avoided</u>	<u>M tonnes</u>
Cement production	829
Production emissions	35
Asphalt production	124
Future oxidation	~400
WORLD TOTAL	1264



1400 Mt of steel are used every year.

Sustainable Materials with Both Eyes Open

Steel product catalogue

Transport

Cars and light trucks
93 Mt
9%



An average car contains 960 kg of steel and iron. 34% is in the body structure, panels and closures (doors and bonnets), consisting of welded, profiled sections produced by stamping formable cold rolled sheet. This provides high strength and energy absorption in case of a crash. 23%

is in the drive train, consisting of grey cast iron for the engine block and machinable carbon steel for the wear resistant gears. 12% is in the suspension, using rolled high strength steel strip. The rest is spread between the wheels, tyres, fuel tank, steering and braking systems.

Trucks and ships
28 Mt
3%



The basic steel components described for the car also apply to trucks, but unlike cars, all truck engine blocks are steel. Frame rails and cross members are usually high tensile steel, and the cab structure and outer skin is often made from galvanized steel. Steel for the ship hull is rolled primary mild steel, providing strong, tough, dimensionally consistent plates that are welded together.

Industrial equipment



Electrical equipment
27 Mt
3%

30% of steel in electrical equipment is high silicon content electrical steel forming the cores of transformers or the stator and rotor parts of electrical motors. Other major uses include pylons (constructed from bolted, cold-formed, galvanized L-sections forming a light-weight durable tower); and steel reinforced cables (where wound galvanized steel wires provide the strength to carry conducting aluminium in long span transmission cables).

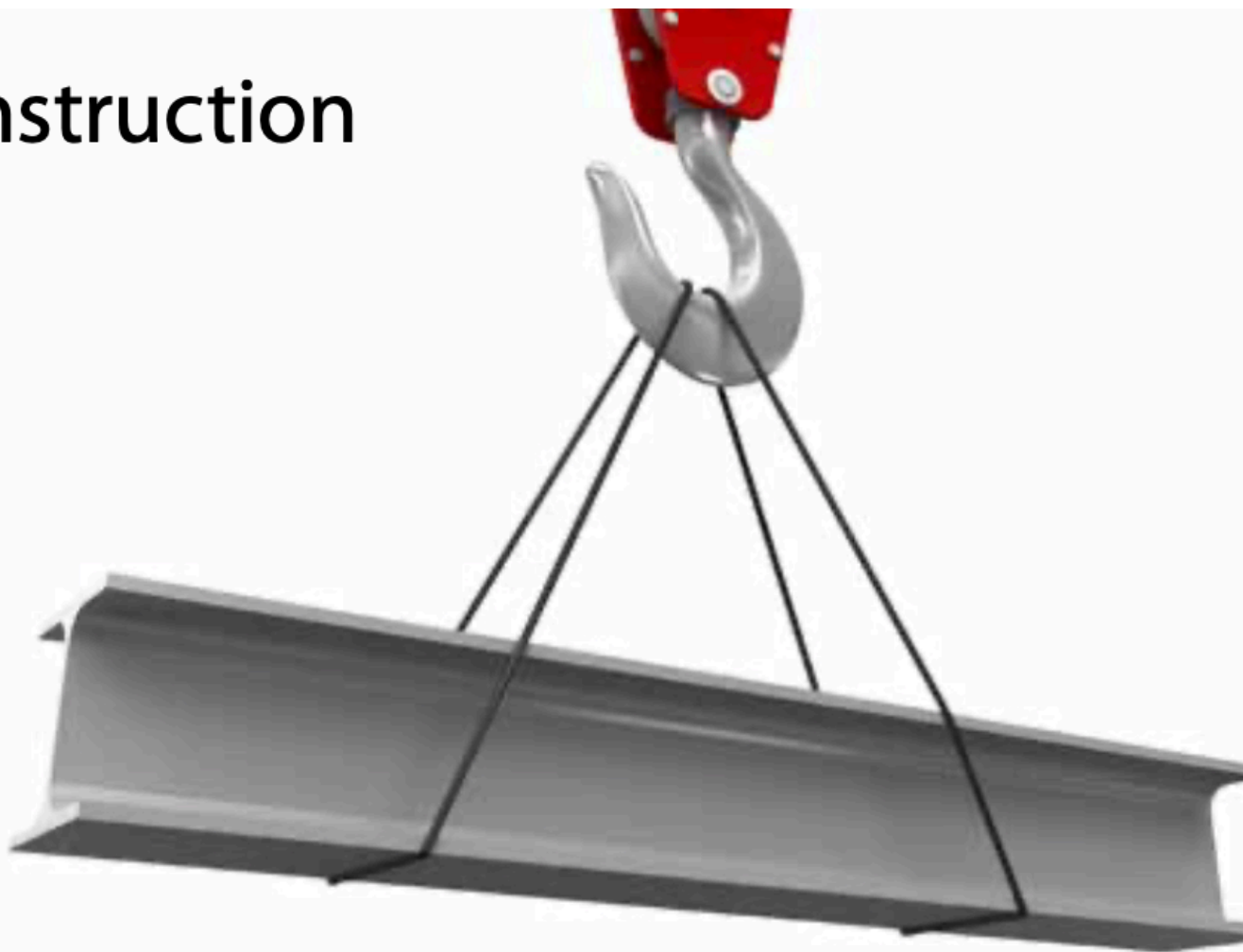
Mechanical equipment
137 Mt
13%



This covers a wide range of equipment from small workshop tools to large factory-based robotic machinery and rolling mills. 40% of the steel is plate or hot

rolled bar; tubes contribute a further 22%, as do hot and cold rolled coils. Cast products and wire rod contribute the remainder.

Construction



Infrastructure
150 Mt
14%

For infrastructure: 24% of steel is in structural sections; 54% is reinforcing bars; 6% is hot rolled train rails (providing a strong, wear and fatigue resistant contact surface); 16% is in pipes formed by welding rolled steel, with high corrosion and fatigue resistance, and high strength to resist internal pressure and installation stresses.



Buildings
433 Mt
42%

25% of the steel in buildings is in structural sections, mainly hot rolled sections but also some welded plate. Sections form a strong, stiff structural frame. 44% is in reinforcing bars, adding tensile strength and stiffness to concrete. Steel is used because

it binds well to concrete, has a similar thermal expansion coefficient and is strong and relatively cheap. 31% is in sheet products such as cold-formed purlins for portal frame buildings and as exterior cladding.

Metal products

Metal goods
134 Mt
12%

Other metal goods include a multitude of products, from baths and chairs to filing cabinets and barbed wire. 30% of steel entering this product group is hot rolled coil; 20% is hot rolled bar; and the remainder is either plate, narrow strip, or cast iron.



Consumer packaging
9 Mt
1%



Steel use in packaging is dominated by tin-plated rolled steel, which doesn't corrode. 60% of this steel is made into food cans, providing durable packaging for the subsequent cooking and distribution. 40% is used for aerosols.

Domestic appliances
29 Mt
3%



Appliances are dominated by white goods (up to 70%). The vast majority of steel used here is cold rolled coil, often galvanized or painted. Most of this steel is used for panelling. Other applications including washing machine tubs (welded rolled steel strip), motors, expanders in fridge/freezers and cast parts for transmissions.

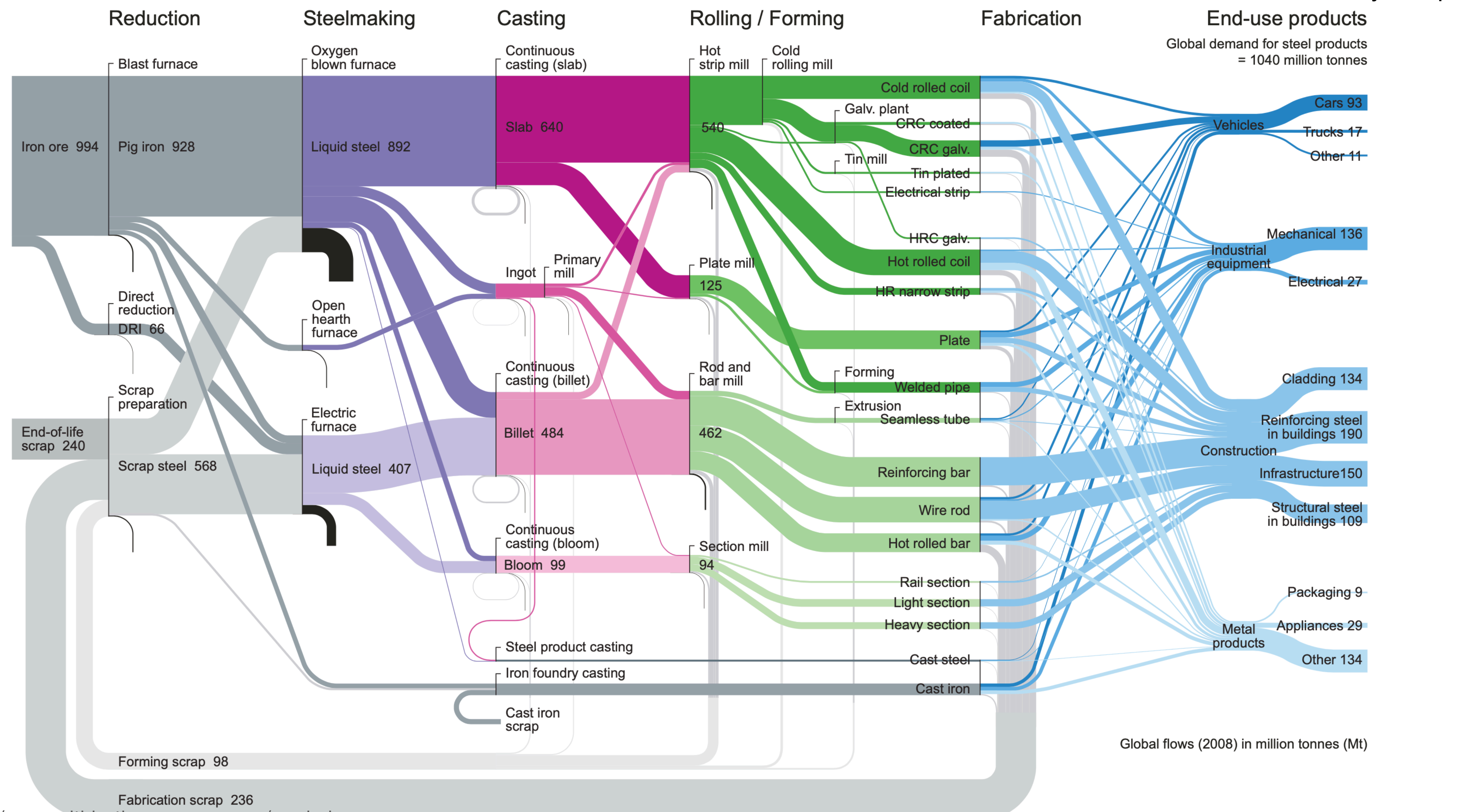
Figure 3.1—Steel product catalogue

We make over 1,000 Mt of steel products every year, equivalent to a 1 metre square band of steel wrapped around the equator more than three times. Global steel production is divided into 4 sectors and 9 categories of end-use products. The amount of steel in each category is given in millions of tonnes **Mt** and

the fraction of global steel as a percentage %, with the images sized to reflect this fraction. The end-use of steel is dominated by construction (56%). These numbers are derived from data for 2008.

Sankey steel flow

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Steelmaking uses 900 GW(t) plus 600 GW(e).

Sustainable Materials
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Steel process map

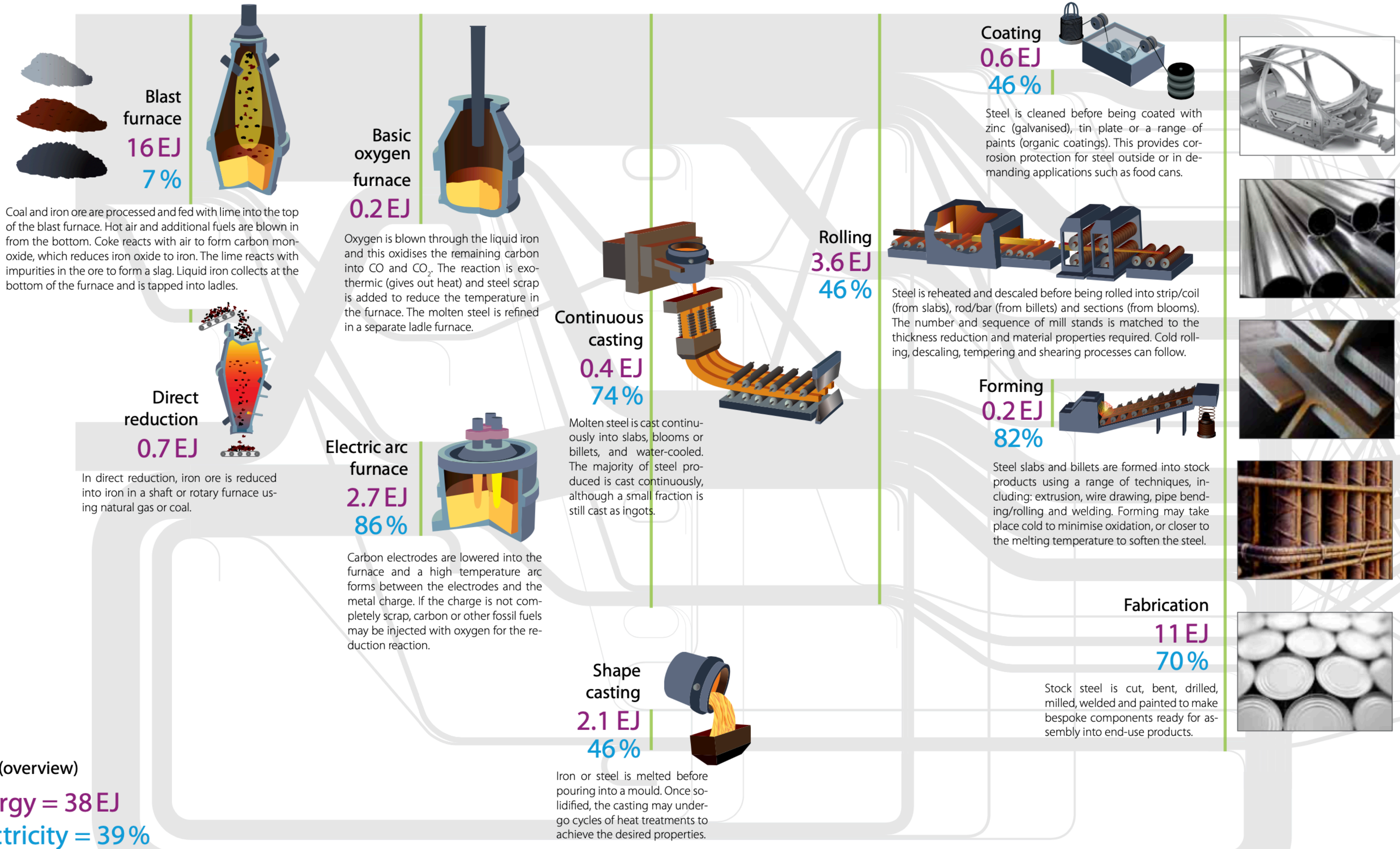


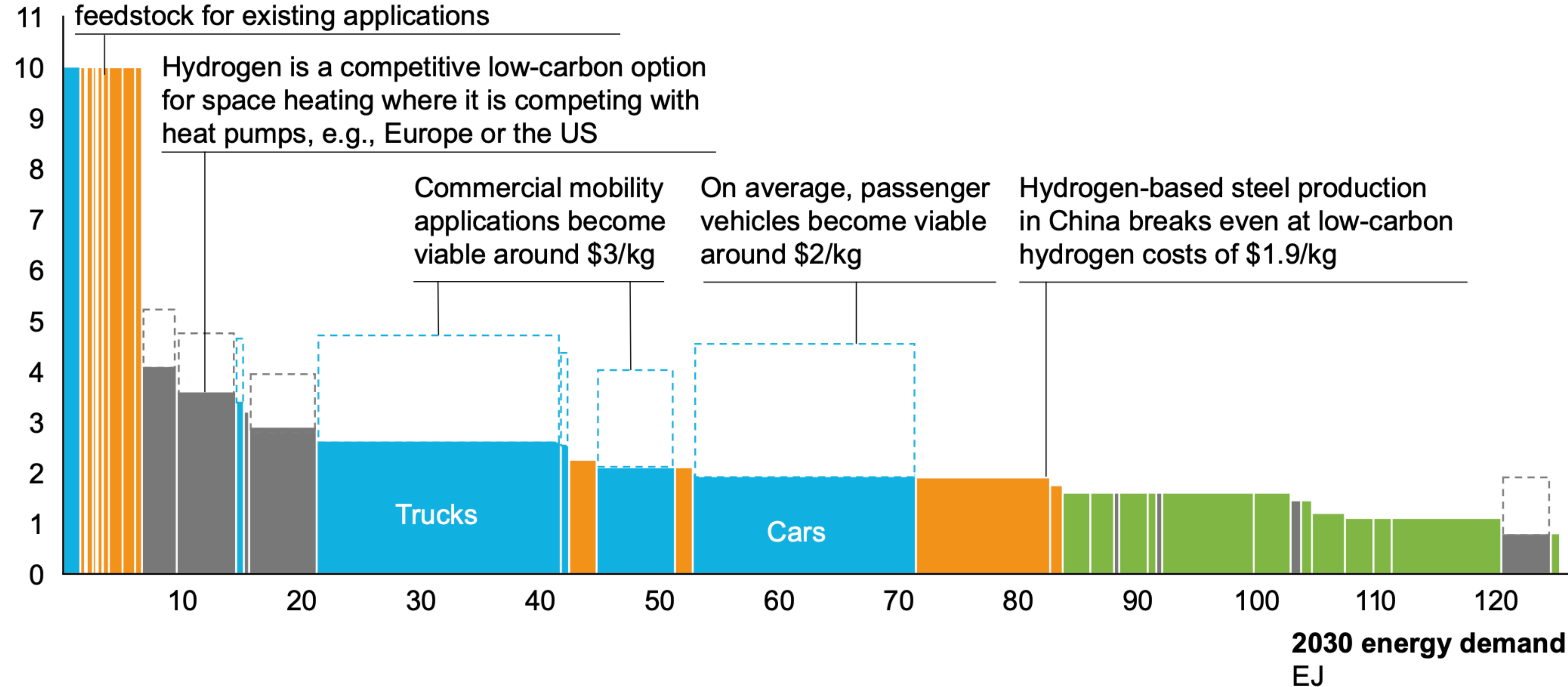
Figure 5.1—Steel process map⁹

Hydrogen based steel production may be viable at \$1.9/kg-H2.

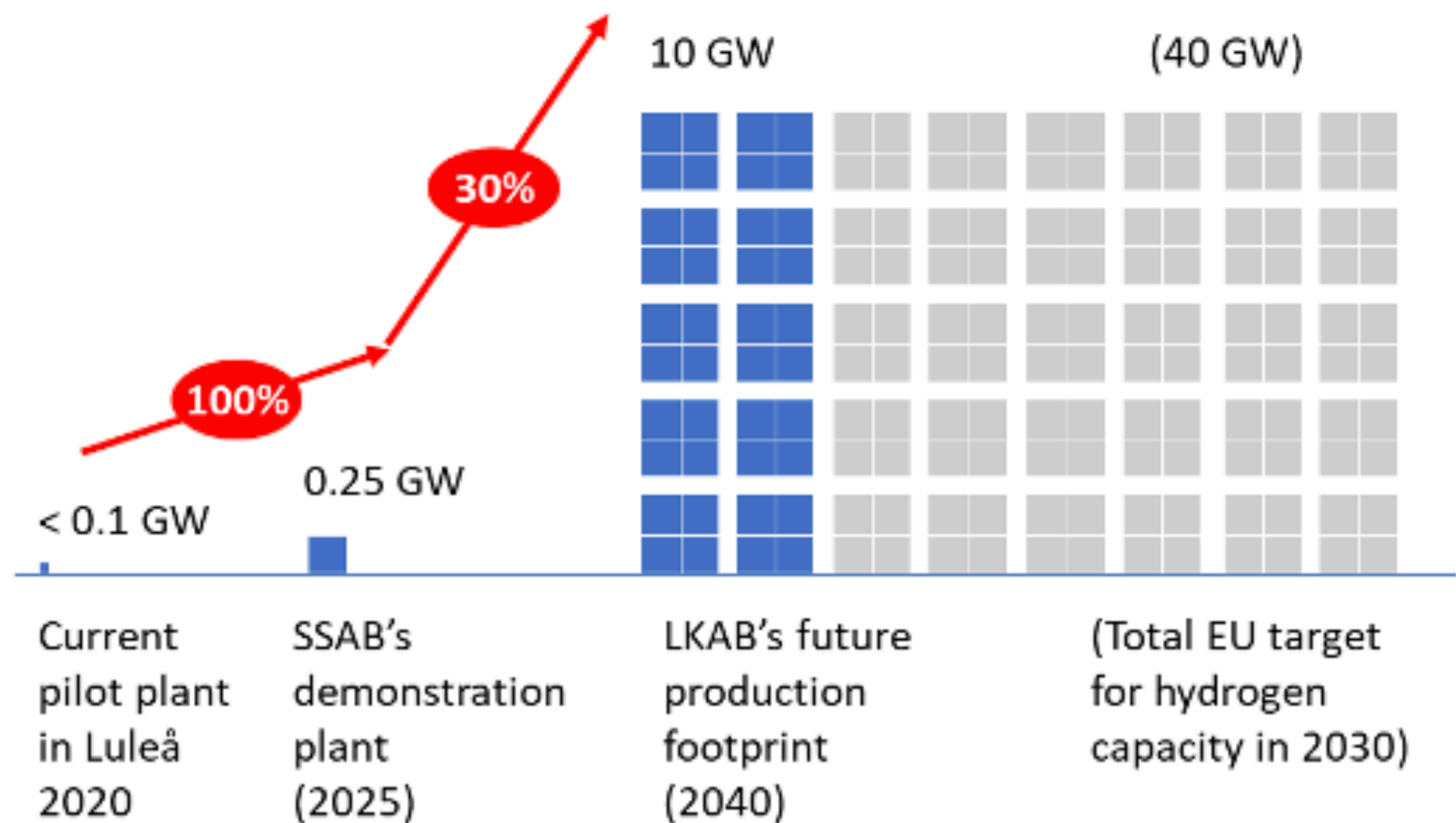
(Hydrogen Council)

H2

\$/kg Hydrogen is the only alternative for industry feedstock for existing applications

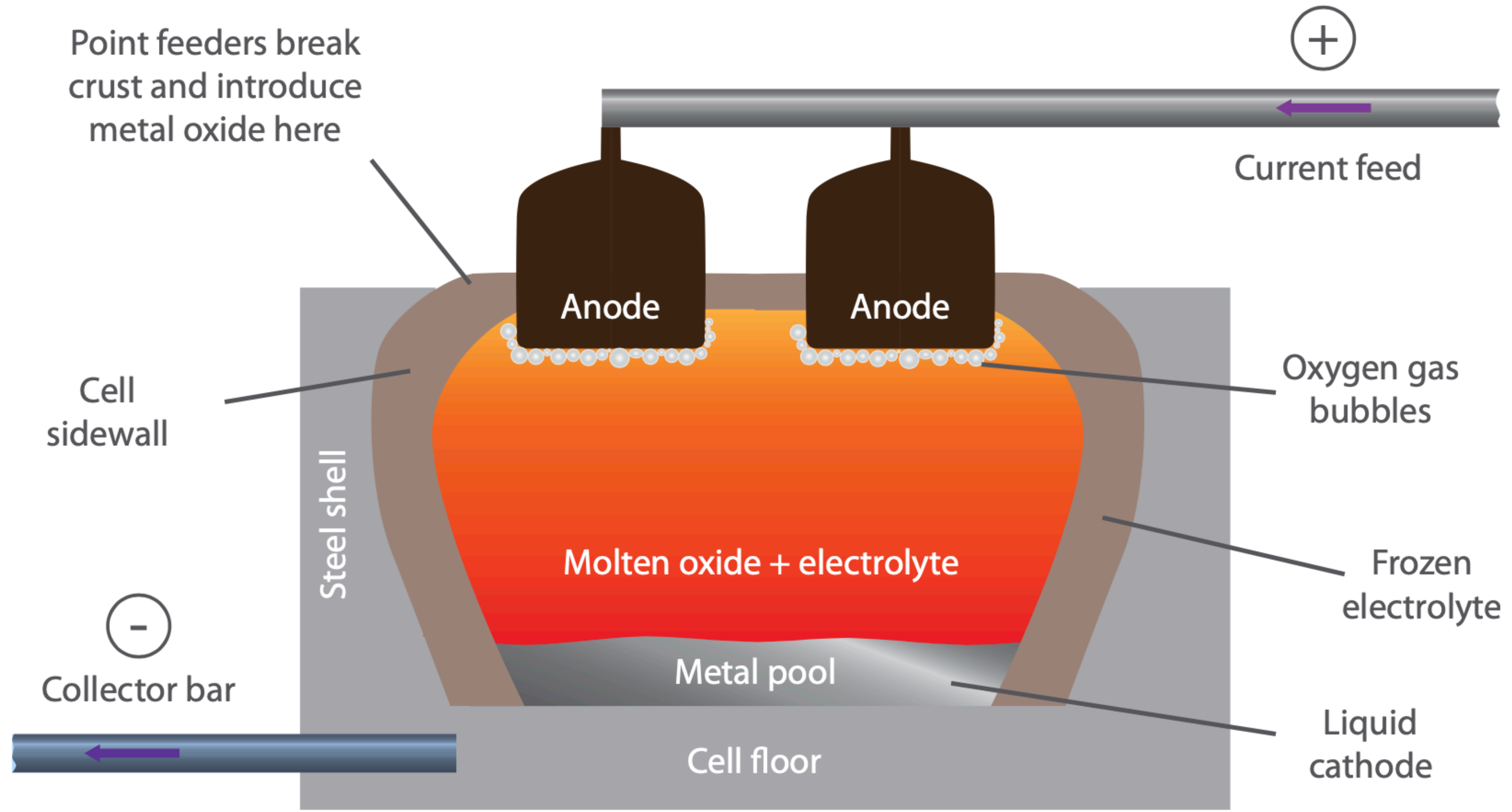


RMI estimates 10 GW of H2 use for LKAB project to remove oxygen from iron oxide using H2 reduction.



Iron may be freed from oxide ore by electrolysis.

Sustainable Materials
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45 Mt of aluminum are used each year.

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Aluminium product catalogue

Transport

Cars

8 Mt
18 %



An average car contains 120 kg of aluminium. 35 % is in the cast engine, requiring high strength and wear resistance. 15 % is in the cast transmission casing, providing stiffness for gear teeth alignment and thermal conductivity for dissipation of frictional heat. 15 % is in the cast wheels, giving

ing a lightweight aesthetic design. The remaining aluminium is mainly in the heat exchanger (requiring high thermal conductivity) and forgings in the chassis and suspension. Aluminium is increasingly used in car engines and bodies to save weight.

Trucks

3 Mt
7 %



Many of the basic aluminium components described for the car also apply to trucks, with the exception that aluminium cast engines are rare. Aluminium is used in trucks for corrosion resistance and weight saving. Applications include the cab structure and outer skin, chassis and suspension parts, tipping bodies and sliding side doors.



Other
1 Mt
2 %

Aluminium, used extensively in the aerospace industry for its high specific strength, fracture toughness and good formability, typically makes up 80 % of the airframe. Common alloys are AA2024 and 7xxx. Rail carriages are made from aluminium welded extrusion frames (AA5083/6061) and sheet sidewalls (5xxx/AA6061), giving light, non-corroding vehicles.

Industrial equipment

Electrical equipment

2 Mt
4 %



Electrical equipment includes conduits (often AA6063) and sheathing (Alclad 5056) to strengthen and protect electrical wiring. Other applications include wide strip aluminium in bus bars (1xxx) to conduct electricity around switchboards.



Electrical cable
4 Mt
9 %

Cables are made from concentrically stranded aluminium wire (typically AA1350-H19) wound in multiple layers around a steel core. The aluminium has conductivity around 60 % that of copper, but is cheaper and lighter.

Mechanical equipment

3 Mt
7 %



Mechanical equipment includes products such as heating and ventilation systems. Aluminium is widely used in heat exchangers for its high thermal conductivity, good corrosion resistance and low cost. Drawn or extruded tubes are either brazed or mechanically fastened to sheet (both 1xxx or 3xxx alloy).

Packaging

6 Mt
13 %



Aluminium is used in packaging, and provides an attractive outer package and inert inner surface. Half of this aluminium is used in light-weight drinks cans (14 grams each), where rolled (AA3104) aluminium strip is drawn to form the can body, the lid attached (AA5182) and inside sprayed with an epoxy-based lacquer. The other half is thin aluminium foil used in household foil, food and drink pouches and semi-rigid containers to provide an inert and flexible package.

Metal products

Other
4 Mt
9 %



Approximately half of this is powdered aluminium used in powder metallurgy, paints and pigments. Other applications are the deoxidation of steel: aluminium has a high affinity for oxygen, so is used to reduce formation of gas bubbles in steel casting. Lithographic plate (1xxx and 3xxx series) is another significant use, for which aluminium is chosen because of the criteria for flatness and high surface quality.

Construction

Buildings
11 Mt
24 %

Most aluminium in construction is made from extrusions or sheet. 45 % of it is used for extruded frames in windows, doors and curtain walls (projected, non-load bearing façades on commercial buildings). Another 40 % is used in corrosion resistant roofing and cladding, for which aluminium strip is cold formed to a profile.



Appliances

3 Mt
7 %



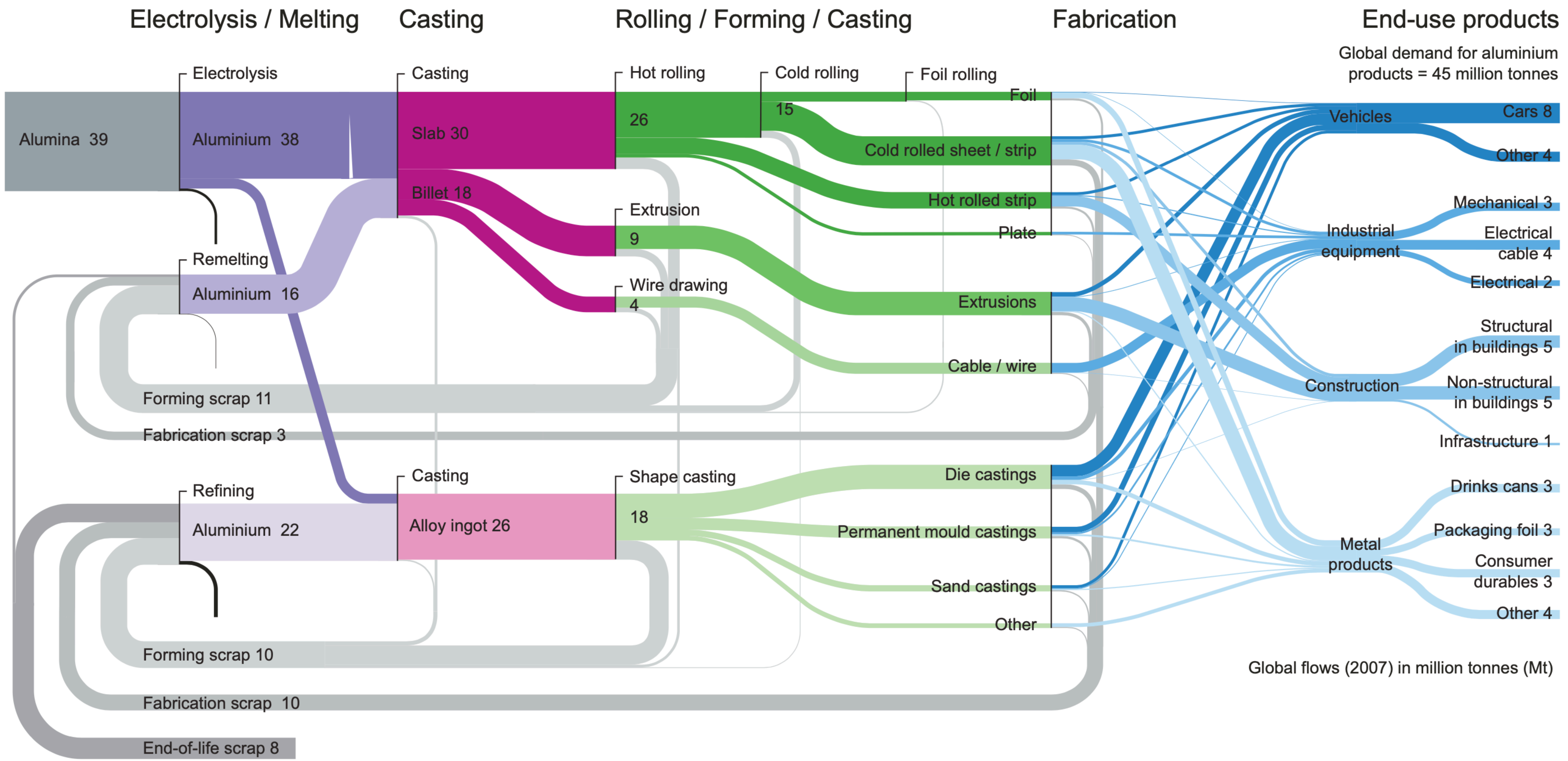
The main use of aluminium in consumer durables is in household white goods. Most aluminium in white goods is in fridges/freezers and washing machines. AA5754 is a common sheet alloy of medium strength used for appliance bodywork, and AA3003 and AA3103 are common sheet materials used as fridge/freezer linings. Fridge/freezers also require heat exchangers where the fins, and sometimes tubes, are aluminium.

Figure 3.2—Aluminium product catalogue

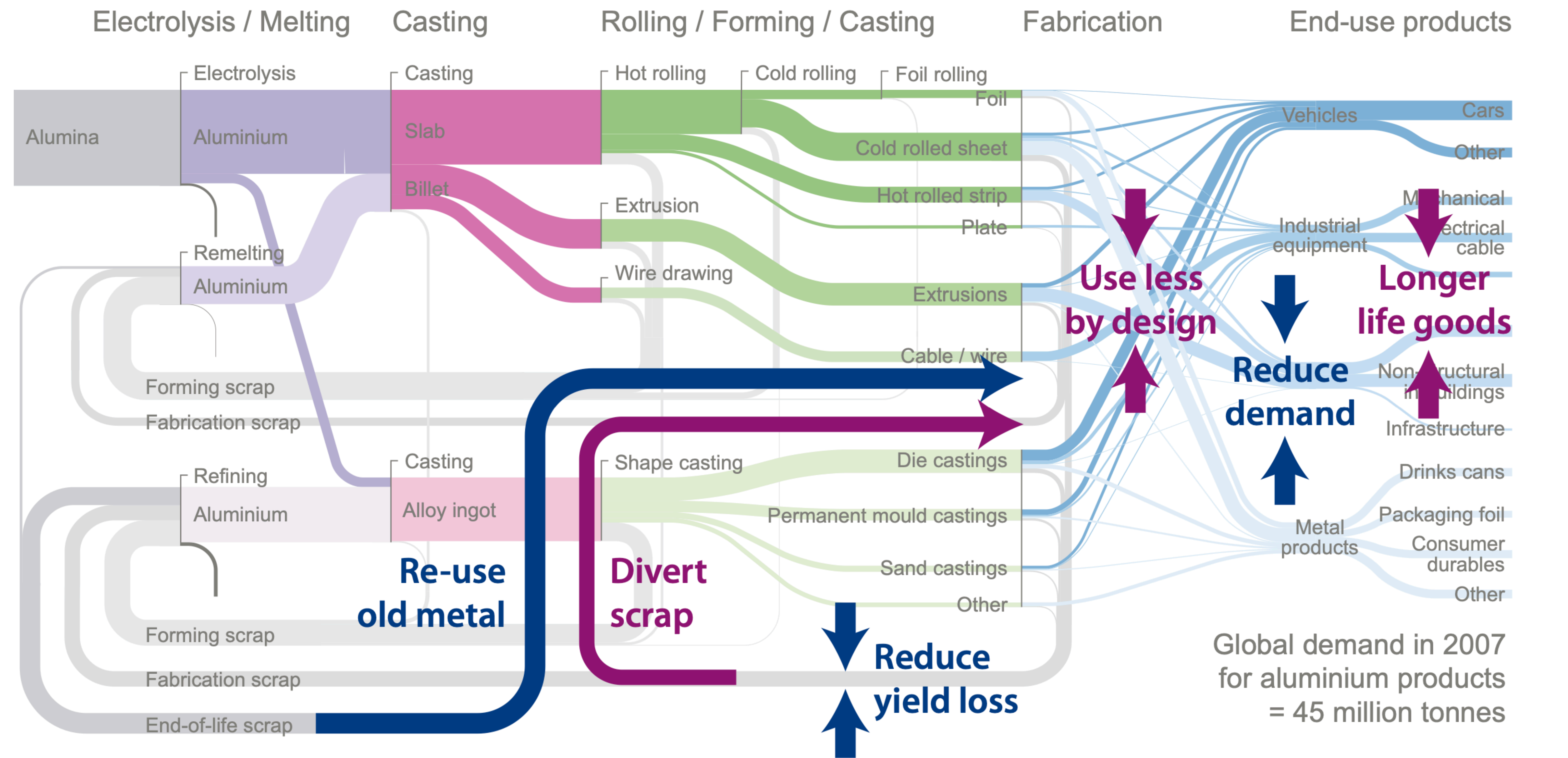
We make approximately 45 Mt of aluminium products every year. We have shown the uses of global aluminium production divided into 4 sectors and 10 categories of end-use products. The amount of aluminium in each category is given in millions of tonnes **Mt** and the fraction of global aluminium as

a percentage **%**, with the images sized to reflect this fraction. The end-use of aluminium is more evenly spread across the 4 sectors than for steel. These numbers are derived from data from 2008. (Aluminium alloy codes, e.g. 1xxx are described at the end of this chapter).

Sankey aluminum flow



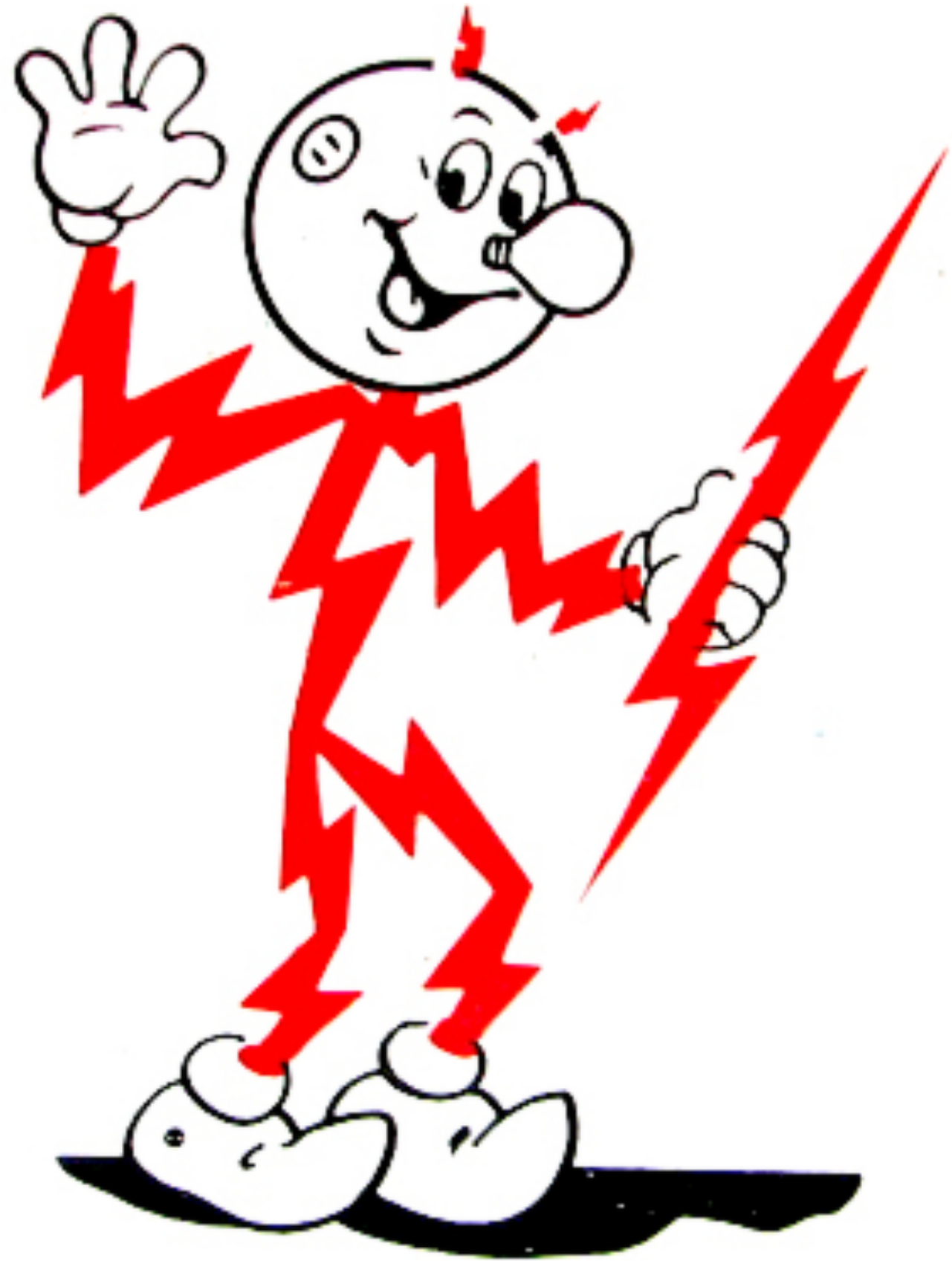
What else? Re-engineer the materials processes.



Shipbuilding technology for whole new factories.
Shell's natural gas liquifaction plant larger than 5 aircraft carriers.



13 Industry



3200 GWt power today

Cement

Plasma arc temperatures

Iron reduction, electrolysis

Aluminum, solid electricity

Shipyard building factories

Fission is in Fashion