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Lecture 11:

Energy demand in buildings, industry, and transport

Global Energy demand and CO_2 emissions

Buildings, **industry** and **transport** account for

- ~ 87% of global energy demand,
- 28.5 $GtCO_2$ (c.f. total fossil fuel emissions of 32 $GtCO_2$)

CO_2 emissions

- projected to increase by 50-150% on baseline scenarios by 2050
- To limit global warming to 2 °C requires 80% cut in CO_2 emissions by 2050

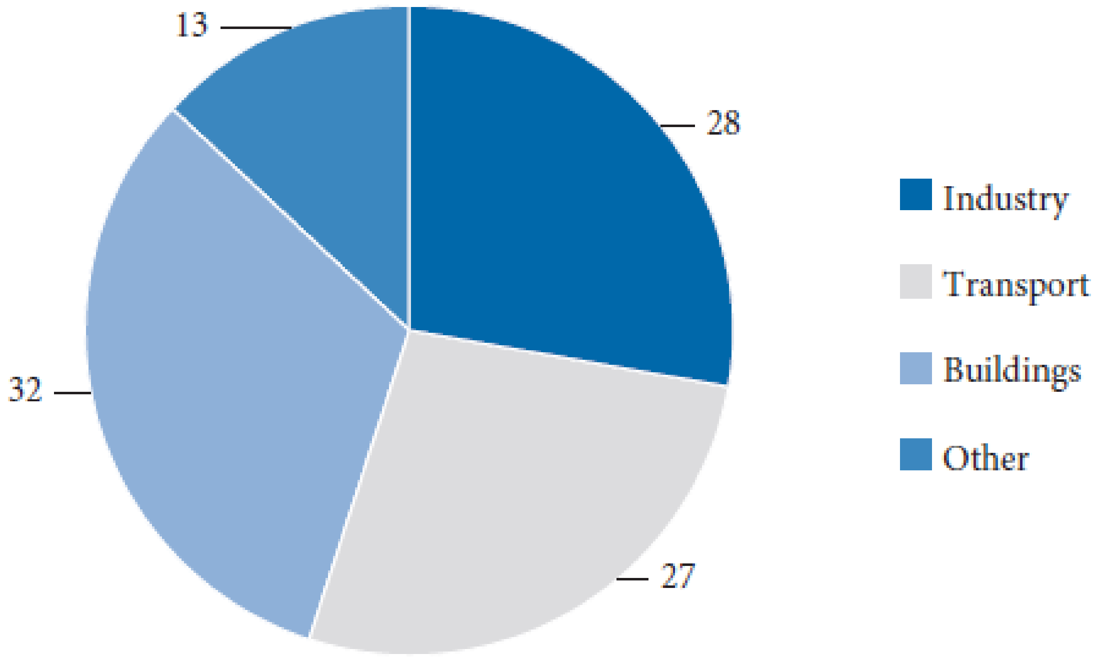

Fig. 11.1 Percentage of final energy demand by sector (adapted from IPCC-AR5).

Note: Decarbonizing heat is as important as decarbonizing electricity

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Areas for reducing energy consumption and CO_2 emissions

- Improve **energy efficiency**
- More **conservation**
- Change **lifestyle** (e.g. less reliance on cars)
- More **recycling**
- **Low-carbon buildings** (cement production is energy-intensive)
- **Retrofitting old buildings** (60% of existing homes will still be around in 2050)
- Imposing regulations on **fuel efficiency** of fossil-fuel powered vehicles
- **Decarbonizing transport** (electric vehicles)
- Generating **heat** from **renewable electricity**

How energy consumption in buildings and CO_2 emissions can be reduced

- **Restricting heating and lighting** to where and when it is needed; lowering indoor temperatures. Space heating and cooling, and water heating, accounts for 60% of global energy consumption in buildings.
- Using **renewable energy** resources e.g. solar thermal or geothermal energy for hot-water heating and using **heat pumps** driven by **renewable electricity**
- Improving **air-tightness** and **thermal insulation** (e.g. double-glazing, cavity insulation)
- Using **reflective services** in hot climates (= less air conditioning)
- Installing **efficient appliances** and **cook-stoves**
- Using **LEDs**

The IEA estimates that enhanced energy efficiency and electricity decarbonization could reduce CO2 emissions by ~ **75%**

Passive design houses can save up to 40% of the energy used in present designs.

Improved lighting and biomass cook-stoves

Comparison of light sources	luminosity lm W^{-1}	efficiency %
Tungsten incandescent lamp	15	2
Compact fluorescent tube	70	10
LED	210	30

Lighting accounts for ~ **20%** of electricity consumption in UK

Widespread adoption of LEDs could reduce UK electricity consumption by ~ 15%

If adopted globally, the reduction in CO_2 emissions would be ~ 2 $GtCO_2$ (c.f. total = 34.5 $GtCO_2$)

Biomass

3 billion people cook with wood. Most biomass stoves in use are **very inefficient** and **emit harmful smoke**. 4 million people die prematurely every year from smoke inhalation due to indoor cooking fires.

Switching to **improved biomass cook-stoves** would **save lives, energy and the environment**.

Thermal Mass

Thermal mass helps to keep buildings at a **comfortable temperature** in summer without wasting energy on air conditioning.

The essential idea is to use the **thermal capacity** of the building to keep the temperature inside between comfortable limits.

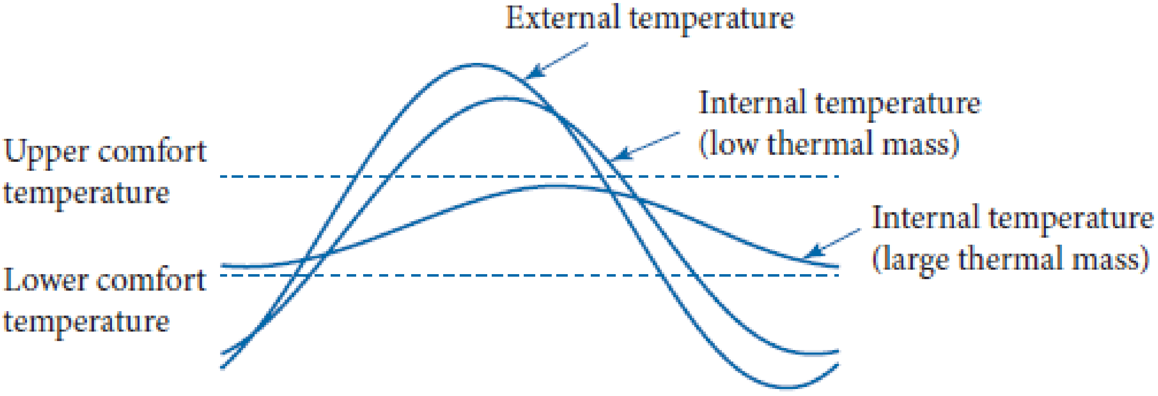

Fig. 11.2 Effect of thermal mass over a 24-hour period.

Thermal mass is useful in countries where there is a **large temperature difference** between day and night.

A thick concrete floor or outside wall can act as a **heat sink** during daytime and a **heat source** at night-time.

Buildings with low thermal mass **closely follow** the external temperature.

Buildings with high thermal mass are **less responsive** to the external temperature and the **peak temperature lags** behind that of the outside.

Quantifying heat losses and thermal insulation

Heat is lost from a building through the walls, windows, roof, doors and floor. Thermal insulation is required for all of them.

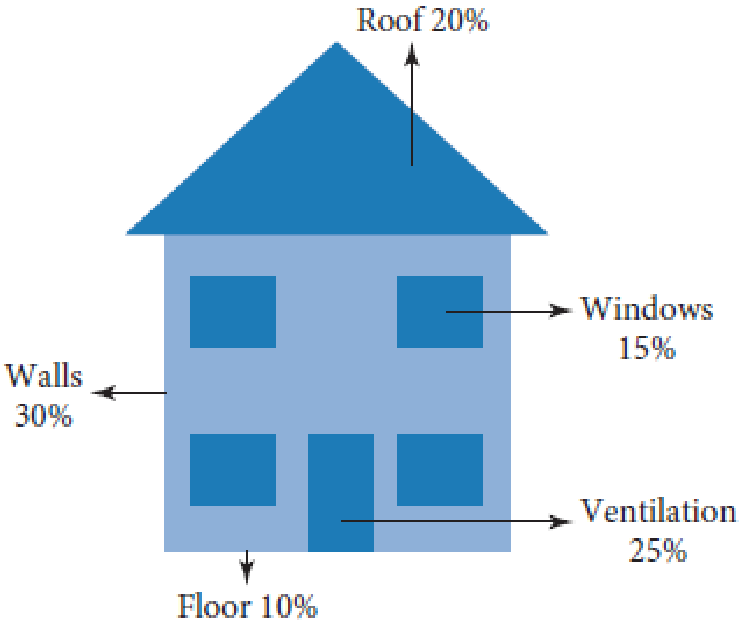

Fig. 11.3 Typical heat losses from an old domestic house.

To quantify thermal insulation, we define the rate of heat transfer through a material, *Q*, as

$$Q = UA\,\Delta T = \frac{1}{R} A\,\Delta T$$

A = *area*
U = thermal conductance or *U*-value (W $m^{-2}K^{-1}$)
ΔT = difference in temperature across material

Thermal image of Passive House

U and *R* are related to the thermal conductivity *k* and thickness *d* of the material by

$$U = \frac{1}{R} = \frac{k}{d}$$

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Comparison between old, new and passive house

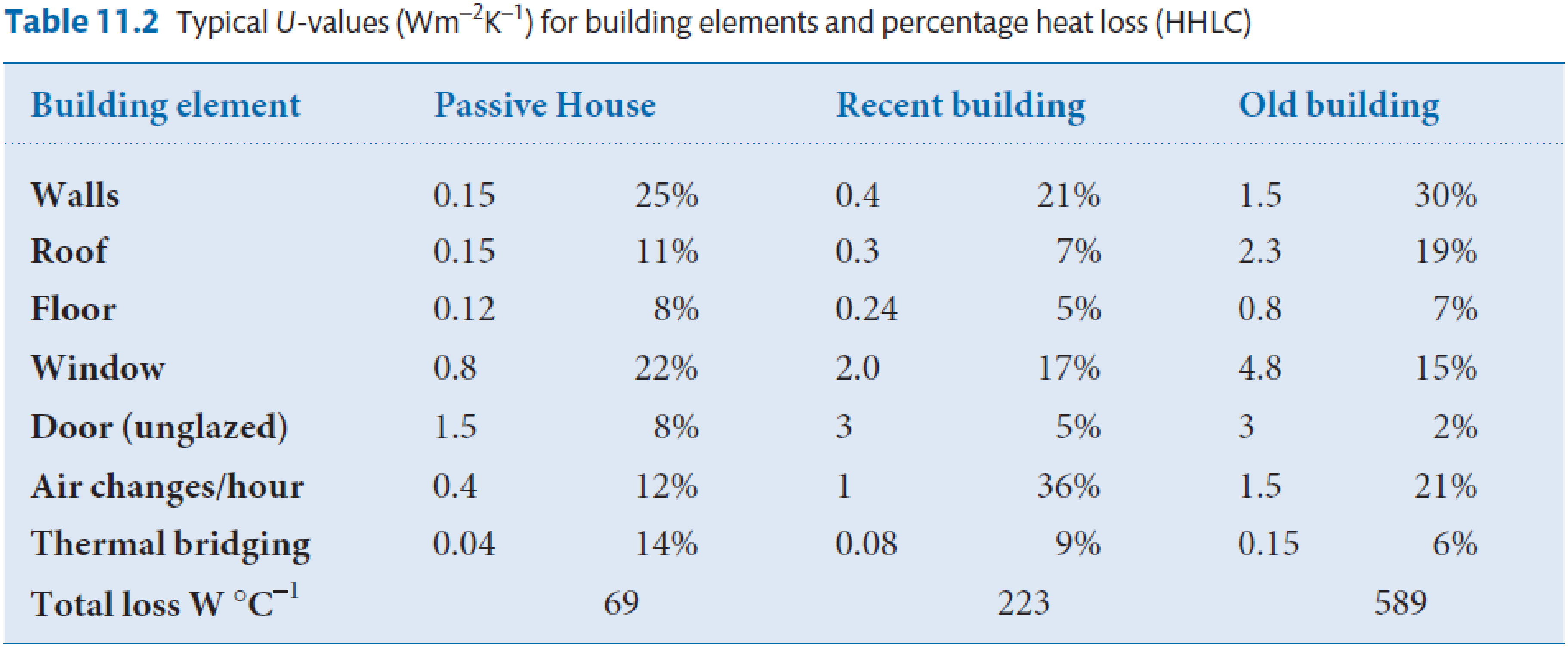


Table 11.2 Typical *U*-values ($Wm^{-2}K^{-1}$) for building elements and percentage heat loss (HHLC)

Building element	Passive House		Recent building		Old building	
Walls	0.15	25%	0.4	21%	1.5	30%
Roof	0.15	11%	0.3	7%	2.3	19%
Floor	0.12	8%	0.24	5%	0.8	7%
Window	0.8	22%	2.0	17%	4.8	15%
Door (unglazed)	1.5	8%	3	5%	3	2%
Air changes/hour	0.4	12%	1	36%	1.5	21%
Thermal bridging	0.04	14%	0.08	9%	0.15	6%
Total loss $W\,°C^{-1}$	69		223		589	

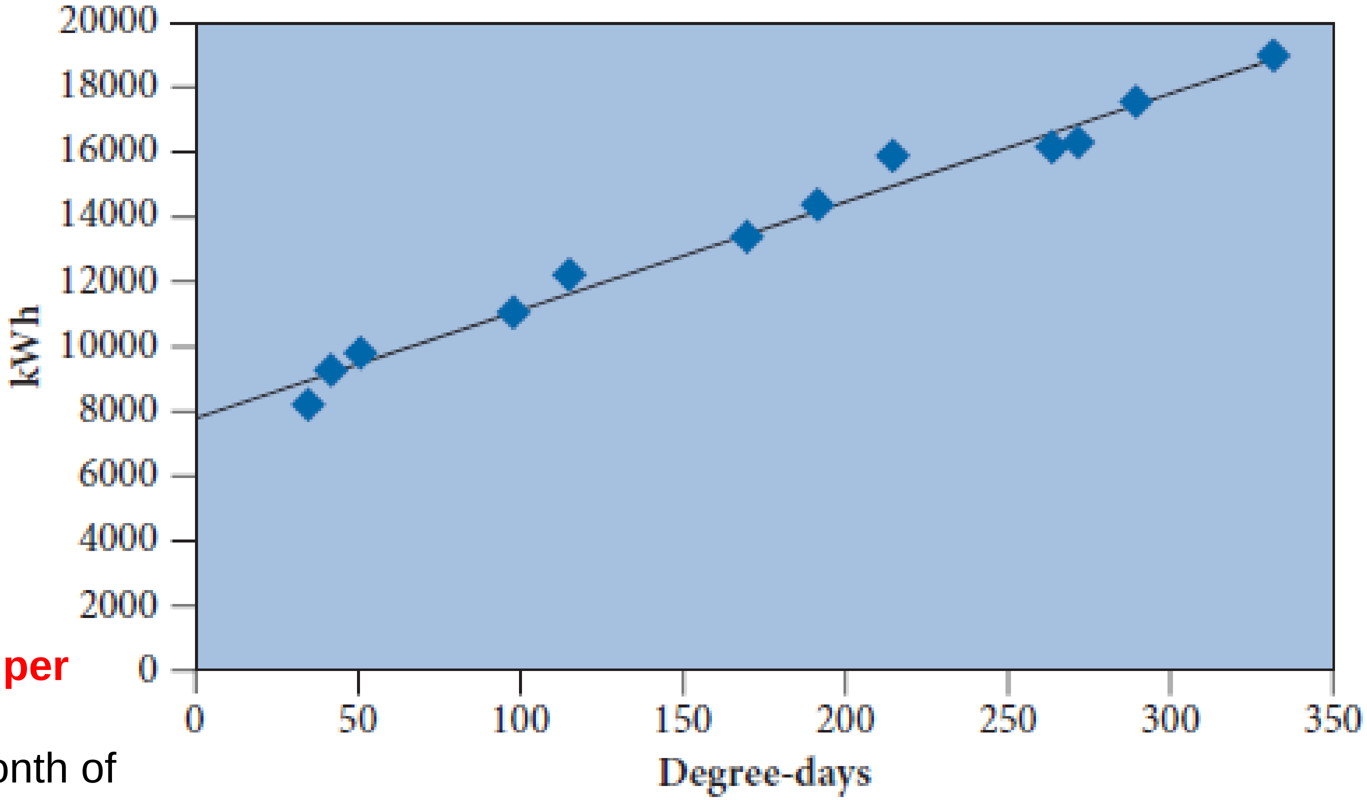
All houses are detached, have the same footprint of 7m x 7m and ceiling heights of 2.5 m.

To calculate the **total heat loss over a month**, we need to know the average temperature difference between the inside and the outside of the house for the month.

This is given by the **number of degree-days per month**.

Degree-Days

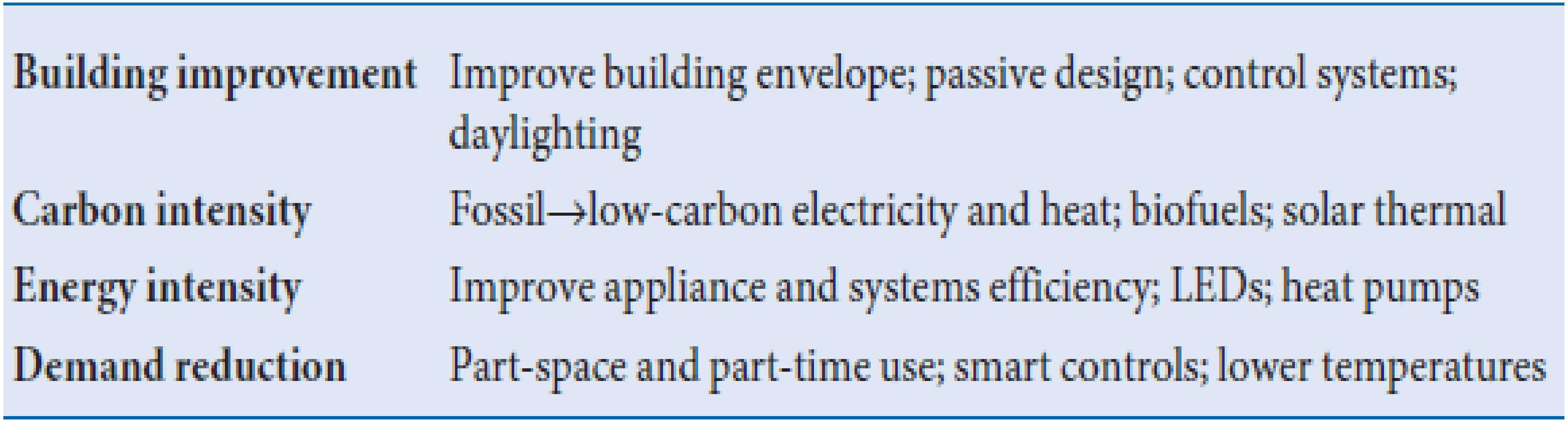
To calculate the **number of degree-days**, we assume that buildings are heated only when the **ambient temperature is less than a nominal base temperature.**



number of degree-days per month can be defined as
= Sum for each day of month of (base temperature – average ambient temperature)
{N.B. No. of degree-days = 0 if average ambient temperature exceeds base temperature}

For the house illustrated, the non-space heating requirement is 8000 kWh per month and for a month with 150 degree days then the heating needed is 5000 kWh. The line shown is called the **performance line**

Mitigation measures for buidlings



Building improvement	Improve building envelope; passive design; control systems; daylighting
Carbon intensity	Fossil→low-carbon electricity and heat; biofuels; solar thermal
Energy intensity	Improve appliance and systems efficiency; LEDs; heat pumps
Demand reduction	Part-space and part-time use; smart controls; lower temperatures

Space heating and cooling accounts for **~ 60%** of global energy consumption in buildings. so

- **Electrical resistance heating** and **incandescent light bulbs** need to be phased out.
- New buildings should have **low energy demand** and use **passive heating and cooling**.
- Existing buildings should be **retrofitted with energy-saving technology**.

Direct emissions of CO_2 from Industry

Globally, the industry accounts for 28% of final energy use, with about **70% from fossil fuels**.

Production of cement, pulp and paper, aluminium, chemicals, iron and steel, account for ~ **75% of direct emissions of CO_2** from industry (=13.1 Gt in 2010).

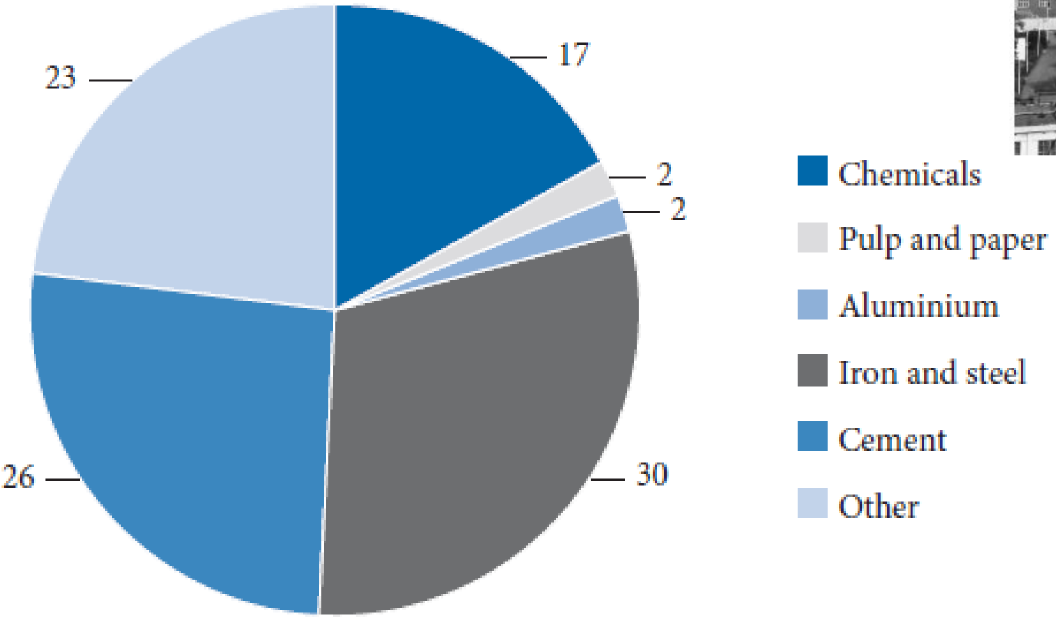


Fig. 11.7 Direct emissions of CO_2 from industry in 2007 (GICC2012).

Industrial plant ©zhaojiankang/istock

Decarbonizing industry is difficult:

- Investment timescales for replacing equipment are 20-40 years
- Many processes are energy-intensive and involve heat from fossil-fuel combustion
- Reluctance to lose competitiveness

Breakdown of GHG emissions for industrial processes

For any given industry, the greenhouse gas (GHG) emissions per year, *G*, can be usefully expressed as a product

$$G = \frac{G}{E} \times \frac{E}{M} \times \frac{M}{P} \times P$$

where $\frac{G}{E}$ = carbon intensity

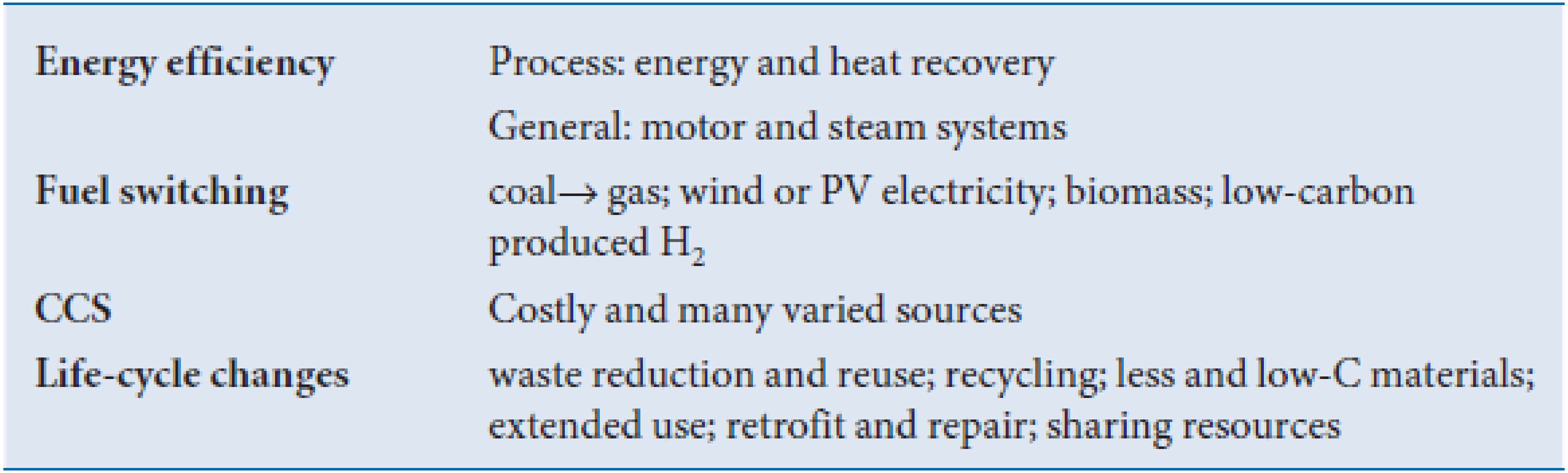
$\frac{E}{M}$ = energy intensity

$\frac{M}{P}$ = mass material per product (product efficiency)

P = number of products

Hence, reducing the ratios $\frac{G}{E}, \frac{E}{M}, \frac{M}{P}$ reduces the emissions of GHGs.

Mitigation measures for industrial emissions



Energy efficiency	Process: energy and heat recovery
	General: motor and steam systems
Fuel switching	coal→ gas; wind or PV electricity; biomass; low-carbon produced H_2
CCS	Costly and many varied sources
Life-cycle changes	waste reduction and reuse; recycling; less and low-C materials; extended use; retrofit and repair; sharing resources

Power-to-gas process: Use surplus renewable energy to produce gaseous fuels (e.g. hydrogen, methane, ammonia).

Electro-thermal processes: Develop specific electrical heating processes for low (< 100°C), medium (100-400°C), high (400-2000°C) industrial applications, e.g. electric furnaces, induction heating, microwave, laser, electron beam, plasma heating.

Reducing CO_2 emissions by industry

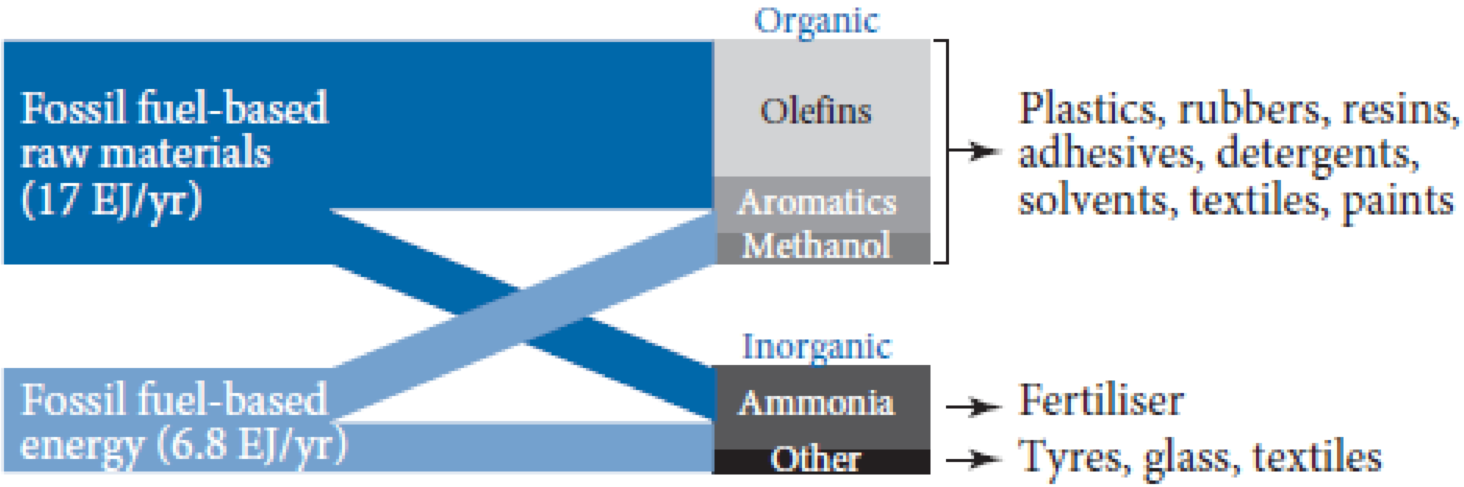
Carbon capture in industrial processes: Large steel plants could provide better economies of scale for CCS than for power plants. Ammonia plants produce almost pure stream of CO_2, which only needs compressing.

Steel industry: In blast furnaces, ~ 80% of CO_2 emissions in steel production come from reducing iron using coke. Alternatives to coke are hydrogen (requires heat), electrolysis (electrowinning), biochar.

Cement industry: produces ~6% of global CO_2 emissions, 60% from converting limestone ($CaCO_3$) to lime (CaO), 40% from burning fossil fuels for heat. Using biomass/oxy-fired process with CCS could produce negative CO_2 emissions. Alternatives to $CaCO_3$ cement exist but not competitive.

Electrification of heat: the large-scale electrification of energy-intensive industries could become viable if and when renewable electricity becomes cheaper than fossil fuels.

Reducing CO_2 emissions by industry (continued)



Chemical industry: very diverse compared with cement and steel industries, but some large scale opportunities exist for fossil fuel-based materials and energy (see Table below). Also opportunities for improving heat and energy recovery.

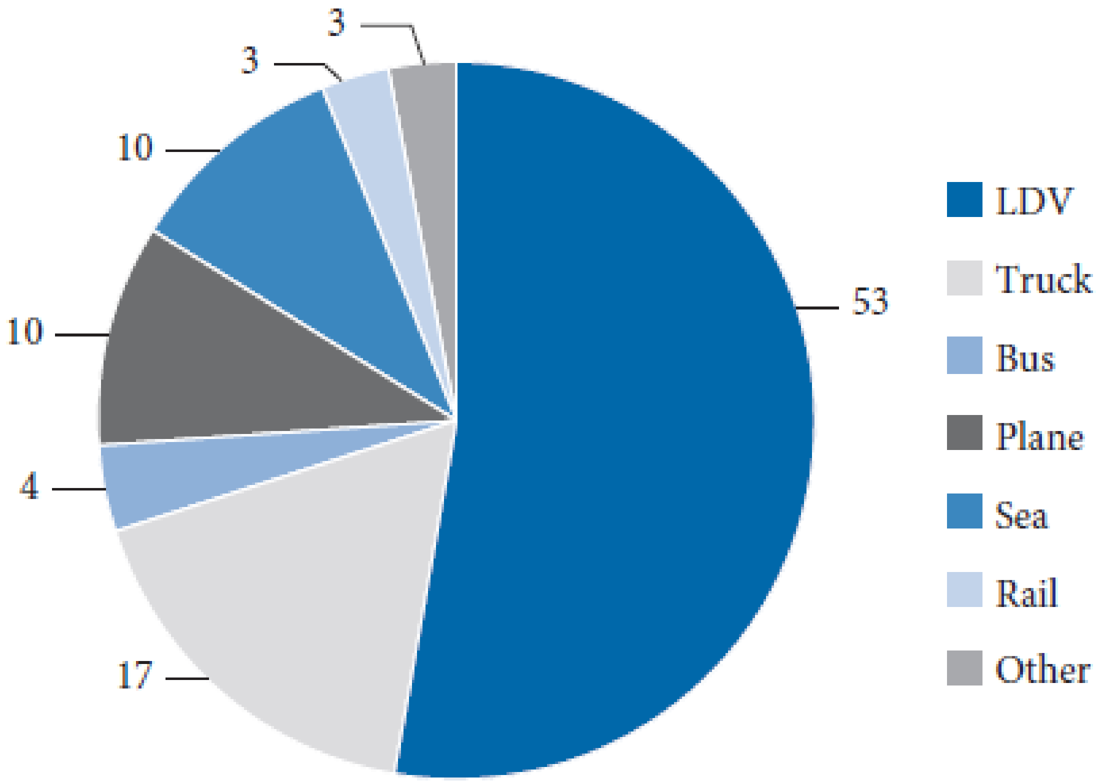
Summary of industrial emissions reduction:

- Substantial investment needed to make significant impact.
- CCS could be more economic if renewable energy becomes cheaper than fossil fuels and if there are economies of scale.
- 80% reduction in emissions by 2050 looks very difficult to achieve.

Transport sector overview

Mitigation options

- Increasing use of public transport, more walking and cycling
- Increasing local manufacturing
- Avoiding unnecessary journeys
- More internet shopping



- Transport sector accounted for **~23% of energy-related CO_2** emissions in 2010
- Transport emissions projected to increase from **6.7 $GtCO_2$ in 2010** to **12 $GtCO_2$ in 2050**
- No. of **LDVs** (light duty vehicles) expected to increase from **1 million to 2 million** over next few decades.

Carbon emissions by mode of transport

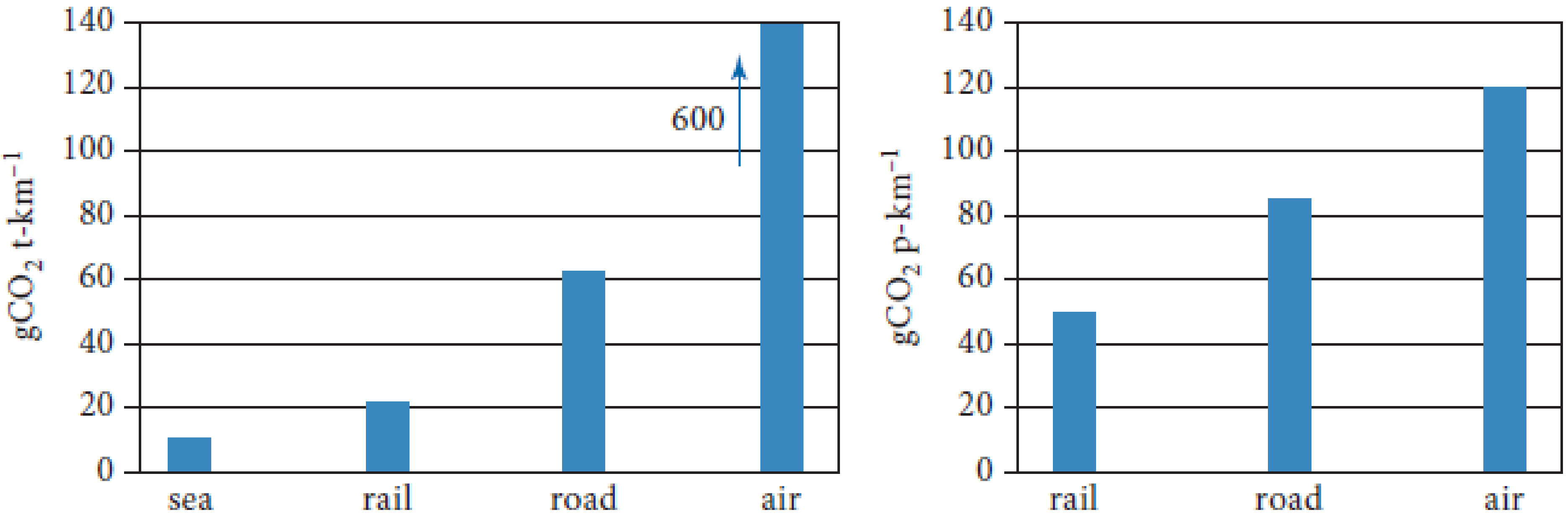


Fig. 11.12 Carbon emissions per tonne-kilometre and per passenger-kilometre.

- **Policy changes** could encourage the use for freight of high-speed rail and shipping rather than trucks and aircraft.
- Efficiency improvements and an increased number of occupants can reduce the **energy intensity**

Freiburg: Germany’s green city

Philosophy: to make energy, transport & building as clean and efficient as possible

- Excellent public transport
- Renewable energy (especially solar PV)
- New buildings = low-carbon
- District heating via CHP
- Car sharing promoted
- Maximum speed = 20 mph or less

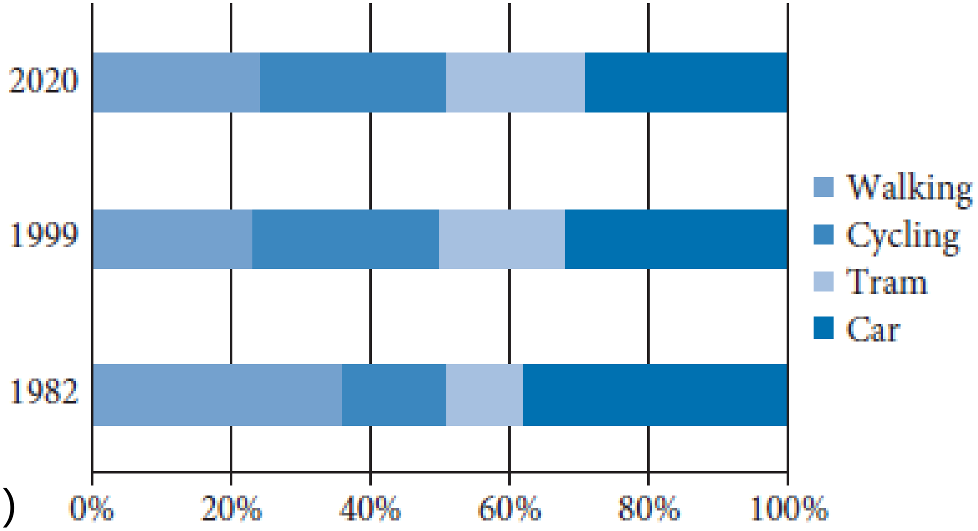


Fig. 11.13 Freiburg mode of travel (2020 estimate).

Vauban (suburb 3 km from centre of Freiburg)

- Restricted number of through roads
- Extensive cycle paths
- Parking only on edge of district
- 70% of households have no car (57% of these gave up car on moving to Vauban)

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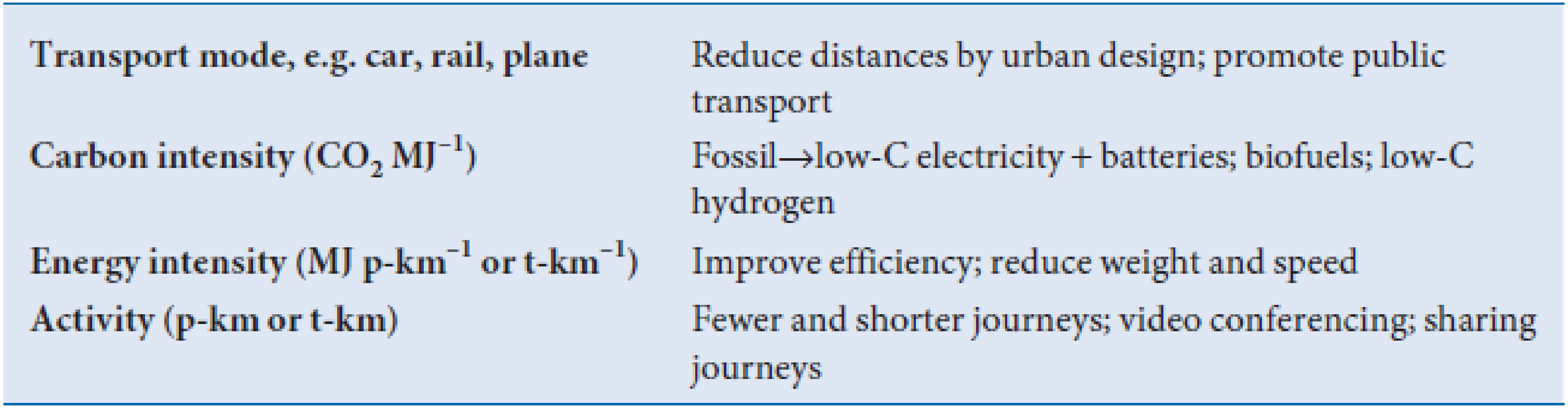
Mitigation measures for transport



Transport mode, e.g. car, rail, plane	Reduce distances by urban design; promote public transport
Carbon intensity (CO_2 MJ^{-1})	Fossil→low-C electricity + batteries; biofuels; low-C hydrogen
Energy intensity (MJ p-km^{-1} or t-km^{-1})	Improve efficiency; reduce weight and speed
Activity (p-km or t-km)	Fewer and shorter journeys; video conferencing; sharing journeys

There are developments in

- **communications and controls** of cars, with improvements in sensors and as a result in safety
- the testing of **self-driving cars**, and the increasing use of **ride-sharing** arrangements using smartphones.

- An benefit of electric vehicles (**EVs**) is that the batteries can be used to provide **energy storage**, which will become increasingly important as the percentage of renewable power increases.

Hybrid and electric vehicles

Hybrid electric vehicles (HEVs):

- combine internal combustion engine with electric motor and battery
- Use regenerative braking (braking energy stored in battery)

Up to 35% reduction in CO_2 emissions compared with conventional vehicles.

Plug-in hybrid electric vehicles (PHEVs) = bridge to pure EVs, based on statistics in Europe and USA that

Europe:	50% < 10 km, 80% < 25 km
USA:	60% < 50 km, 80% < 100 km

Electric vehicles (EVs): between 2016 and 2021

- Battery costs expected to fall by 60%
- Driving range expected to increase by 70%, comparable with conventional cars

16% of cars in Norway are EVs

Electric Vehicles

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Charging of EVs:

- Near workplace when PV electricity is available
- At small distributed PV farms

Global penetration:

Possibly 22% by 2025

Wholesale shift from fossil-fuel cars to electric cars depends on

- Future oil prices, and regulations and policies on carbon emissions
- Development of long-range (200 km) rechargeable batteries.
- Falling costs of batteries through ‘learning’

Key Points

- Buildings, industry & transport account for ~ **87% of final energy demand**
- Business-As-Usual scenario: emissions to increase by **50-150% by 2050**
- Limiting global warming to 2^{o}C requires **80% cut in GHG emissions**
- Need to improve **heat insulation** of buildings, efficiency of machines and processes, urban design, and **reuse and recycle**
- Opportunities exist for reducing emissions in industry, notably in the **cement and steel industries**
- **CCS with hydrogen production** may be an important source of decarbonised heat
- Switching to **electric vehicles**, using renewable energy for recharging, and deploying more **heat pumps** would make a significant difference
- Will require development of **heat and electricity storage** and **effective policies**
- Essential to significantly **reduce and shift energy demand**, and to **decarbonize electricity and heat**

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