Environmental Science Units 3 & 4

Chapter 13 — Managing the impacts of human energy use

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Chapter 13 Managing the impacts of human energy use — 13A Rehabilitating energy extraction sites: mechanical and biological processes

Theory

The dot point. The study design requires *"mechanical and biological processes involved in rehabilitating sites from which energy has been sourced"*. Three features of that wording set the whole subtopic. First, it names a **binary** — mechanical *and* biological — so an answer that describes earthworks and stops, or that describes planting and stops, has answered half the dot point. Second, it says **processes**, not activities: each item you name has to come with a mechanism (what physically or biologically happens) and a purpose (what problem it solves). "They put the topsoil back" is an activity; "respread topsoil is the only practical source of the seed bank and the soil microbial community, neither of which can be manufactured" is a process. Third, "**sites from which energy has been sourced**" is deliberately wider than "coal mines". It reaches open cuts, underground workings, oil and gas wells onshore and offshore, and the pads, roads, transmission easements and turbine foundations of renewable generation. A response built only around a coal pit is answering a narrower question than the one asked.

Boundaries. This subtopic owns the rehabilitation of *energy* sites, and the specific mechanical and biological work that follows *energy extraction*. It does not own the general ecology of repair. **7D** already teaches habitat restoration, erosion control and reintroduction of previously endemic species in the biodiversity context — natural versus assisted regeneration versus reconstruction, ecological vegetation classes, seed provenance, the forms of erosion and the soil-loss equation — and that material is assumed here, not repeated. What 13A adds is the part 7D cannot cover: a substrate that was never soil, a void 100 m deep, a hole drilled 3 km into rock, and a legal obligation attached to a licence. Energy sources themselves are **12A** and **12B**; combustion and the carbon cycle **12C**; efficiency and thermodynamics **12E** and **12F**; sustainability principles across the whole supply chain **12G**. Whether the remaining sources can carry base and peak load is **13B**; the four options for a sustainable energy future are **13C**; the stakeholder values, regulatory tensions and technology arguments that surround an energy decision are **13D**. The framework of principles and value systems is **3B** and **3C**; in-depth case-study method, risk analysis and cost–benefit analysis are Chapter **8**. Where this subtopic must touch one of those to make a process make sense, it does so in a sentence and points onward.

1 What "rehabilitated" has to mean, and the words that are not synonyms

Rehabilitation is the process of returning land disturbed by resource extraction to a **safe, stable and sustainable** condition that supports an agreed **post-extraction land use**. That three-part standard is the wording used in Victorian policy — the *Latrobe Valley Regional Rehabilitation Strategy* requires the three brown coal mines to become "safe, stable and sustainable" landforms, and operators commonly add a fourth word, **non-polluting**. Unpack the standard, because each limb drives different work.

Limb	What it requires	What fails it
Safe	No unacceptable risk to people, stock, machinery or neighbouring infrastructure — no collapse, no drowning hazard, no uncontrolled fire, no open shaft	An unfenced 100 m face; an exposed brown coal batter that can self-heat and ignite
Stable	The landform will not move under the design flood, rainfall and earthquake events, **and will still not move in a century** — geotechnically and hydrologically stable without ongoing engineering	A slope at its working angle; a spoil dump that gullies; groundwater rebound that liquefies a toe
Sustainable / non-polluting	The site functions **without continuing intervention** and does not export contamination to air, surface water or groundwater	A site that needs lime dosing forever; a pit lake that turns acid; a plantation that dies when watering stops

The third limb is the hard one, and it is the reason biology is not optional. Engineering can make a site safe and stable; only a functioning ecosystem makes it *self-sustaining*. A landform that requires a person with a machine every year has not been rehabilitated — it has been converted into a permanent liability.

Five words get used interchangeably in student answers and mean different things.

- **Decommissioning** — taking the operating plant out of service and removing or making safe the built infrastructure: draining and purging vessels, de-energising and demolishing, cutting and capping. It precedes rehabilitation and is not the same thing.
- **Remediation** — removing, containing or destroying a contaminant so the land meets a standard for its intended use. Chemical or biological, and site-specific.
- **Rehabilitation** — the whole job: landform, drainage, substrate, vegetation and ecosystem function, to an agreed end land use.
- **Restoration** — the more demanding target of returning the site to the composition, structure and function of the pre-disturbance ecosystem. Almost never achievable where the material that carried that ecosystem has been mined out; rehabilitation is the honest word for most energy sites.
- **Relinquishment** — the legal end point, when the regulator accepts the rehabilitation is complete and the licensee's obligation and financial security are released. Until relinquishment the operator still owns the problem.

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2 What each way of sourcing energy leaves behind

The rehabilitation task is set by the extraction method, not by the fuel. Learn the mapping, because a question can hand you any of these.

Site type	What extraction leaves	The rehabilitation problem that follows
Open-cut brown coal	A void tens of km² in area and 100 m+ deep; steep **batters**; **overburden** and **interburden** dumps; a drawn-down groundwater system; exposed coal	Slope stability at very large scale; fire risk from exposed coal; a void that must be filled, and the water to fill it; groundwater rebound
Underground coal	Voids and pillars at depth; shafts and adits; **subsidence** at the surface; spoil and reject dumps; mine water	Capping shafts; managing surface subsidence and altered drainage; long-term discharge of mine water
Onshore oil or gas well	A cased hole to depth, a wellhead, a pad, access tracks, pipeline easements, tank and separator areas	Permanently isolating the hole so nothing migrates up it; hydrocarbon and produced-water contamination of the pad; compacted pad and track soils
Offshore petroleum	Wells, subsea equipment, pipelines, platforms, floating facilities	Plugging wells beneath the seabed; removing or justifying leaving structures; the marine habitat that has grown on them
Uranium	A pit or in-situ leach field; **tailings** containing radionuclides and process chemicals	Containing tailings for a design life far longer than any company; radiological as well as chemical criteria
Biomass and biofuels	Land under harvest — plantation, crop or residue removal; sometimes cleared native vegetation	Soil nutrient and organic matter depletion from repeated biomass export; the land-clearing legacy itself
Hydro-electric	A dam, an impoundment, altered downstream flow, borrow pits and	Whether the structure is removed or retained; sediment trapped behind it;

Site type	What extraction leaves	The rehabilitation problem that follows
	access roads	restoring an environmental flow regime
Wind	Turbine foundations (large reinforced concrete blocks), hardstands, internal roads, an underground cable network, a substation	Removing or burying foundations; decompacting hardstand and road footprints; blade and turbine material recovery
Solar (utility scale)	Piled or ballasted mounting structures, panels, inverters, cabling, graded and often compacted ground	Decompaction and revegetation over a large footprint; recovery of panel and module materials

Two lessons come out of the table. The **footprint per unit of energy** and the **depth of disturbance** vary enormously — a wind facility disturbs a small fraction of its permit area and disturbs it shallowly; an open cut disturbs all of it, to 100 m. And the **duration of the obligation** varies just as much: a decompacted turbine hardstand can carry pasture within a season, while a brown coal void may take decades to fill and centuries to reach a stable ecosystem.

3 Mechanical processes, part 1 — building a landform that will not move

Mechanical processes are the physical works — earthmoving, demolition, drilling and construction — that reshape the site and set the physical and chemical conditions everything else must work inside. They come first, and they are conventionally sequenced as follows.

Decommissioning and demolition. Plant is de-energised, drained and purged; conveyors, dredgers, boilers and stacks are dismantled; concrete is broken out and, where clean, crushed and re-used as fill or road base. Hazardous materials — asbestos, transformer oils, refrigerants, residual fuels — are removed under their own controls before anything is knocked down. Hazelwood's eight chimneys were demolished in May 2020, three years after the station closed in March 2017; the demolition is the visible part of the job and much the smallest.

Void and slope reprofiling. Working faces are cut at the steepest angle machinery and short-term stability allow, because every degree of flattening costs volume moved. A rehabilitation slope must satisfy a different test: stability under design rainfall, flood and seismic loading with no maintenance, for the long term. So batters are **reprofiled** — cut back, flattened, benched, and their toes buttressed with fill. The stated scope of the Hazelwood Rehabilitation Project is exactly this: final decommissioning, earthworks to reprofile steep slopes, reinstatement of a watercourse to a more natural alignment, and creation of a pit lake. Indicative design slopes for rehabilitated spoil are of the order of 1 in 3 or flatter, with benches to break slope length, but the number always comes from a site-specific geotechnical assessment rather than a rule of thumb.

Spoil placement, selective handling and encapsulation. Overburden is not uniform. Some strata are **potentially acid-forming (PAF)** because they contain sulfide minerals, chiefly pyrite; others are saline, sodic or hostile to roots. **Selective handling** means identifying those materials during extraction and placing them deliberately — usually **encapsulated**, sealed within benign material and, where possible, kept below the water table so oxygen cannot reach them. Over the top goes a **cover system**: a compacted low-permeability layer to shed water, then a store-and-release layer thick enough to hold rainfall for plants to transpire before it can percolate into the waste. Getting this wrong is unrecoverable: PAF material placed near the surface will generate acid drainage for as long as sulfide and oxygen coexist, and no amount of later planting fixes it.

Drainage works. Contour drains, rock-lined chutes, sediment basins, armoured spillways and reinstated watercourses are built to convey design storms without concentrating flow on new, uncompacted ground. The erosion mechanisms these works defeat — sheet, rill, gully, tunnel — are taught at **7D**; the point here is that on a rehabilitated energy site the drainage network is *designed and constructed*, not inherited, and it has to work from the first storm after the machines leave.

Fire risk, which is specific to coal. Exposed brown coal oxidises and self-heats; a face left uncovered is an ignition risk that can be lit by embers from a bushfire kilometres away. The **Hazelwood mine fire** began on 9 February 2014 when embers spotted into the open cut and burned for **45 days**. Be careful how you state its consequences, because the Board of Inquiry was careful. On health, the Board found only that "it is likely that there was an increase in deaths in the Latrobe Valley between February and June 2014" and that "it is likely that the Hazelwood mine fire contributed to some of the increase" — it deliberately declined to put a number on it, and a specific death toll attributed to the Inquiry is wrong. On cost, the Board estimated that "the total cost borne by the Victorian Government, the local community and the operator of the Hazelwood mine, GDF Suez, exceeds **$100 million**" — a three-party total, not a response-cost figure. Covering coal faces with inert material is therefore a *safety* process, not a cosmetic one, and it is why the "safe" limb of the standard is listed first.

Underground workings. Shafts and adits are plugged with engineered concrete caps designed for the ground loads above them; subsidence areas are surveyed, regraded and re-drained, because subsidence changes surface gradients and can reverse the direction a paddock drains.

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4 Mechanical processes, part 2 — manufacturing a growing medium, and managing water

Once the landform is right, the mechanical work turns to the top two metres, and this is where mechanical and biological processes meet.

Topsoil handling. Topsoil — the A horizon — is stripped ahead of extraction and kept separate from subsoil and overburden, because it carries almost everything biologically valuable on the site: the **soil seed bank**, the microbial community, mycorrhizal fungal inoculum, organic matter, structure and nutrient store. It is respread over shaped ground at a design depth, typically in the range 100–300 mm, over placed subsoil.

The important discrimination is **direct return** versus **stockpiling**. Direct return moves topsoil straight from the strip face to a shaped rehabilitation area within the same season, and it is strongly preferred, because stockpiling degrades the very properties that make topsoil worth keeping: seed viability declines with storage time, the aerobic microbial and mycorrhizal populations collapse in the anaerobic interior of a deep stockpile, and organic matter is lost. A stockpile 14 years old still supplies texture and some nutrients; it no longer supplies a living community. Where stockpiling is unavoidable, piles are kept shallow, vegetated to hold them together and reduce weed invasion, and used oldest-last rather than oldest-first.

Relieving compaction. Every pass of a haul truck, dozer or spreader compacts what it drives on. High **bulk density** closes the pore network, so roots cannot penetrate, water cannot infiltrate and gas cannot exchange — the three things a plant needs from soil. **Deep ripping**, usually along the contour and often to 600–800 mm, fractures the compacted layer and reopens the profile. Sequence matters absolutely: rip *after* the last trafficking and *before* topsoil respread and seeding, or the work is undone.

Chemical amelioration. The substrate on an energy site is frequently outside the range plants tolerate, so it is corrected mechanically by incorporating amendments — **lime** to raise pH on acidic spoil, **gypsum** to displace sodium and stop **dispersive (sodic)** material slumping and sealing, and organic amendment or mulch to add carbon, hold water and moderate surface temperature. Fertiliser is used sparingly and deliberately: heavy nitrogen application on a bare substrate reliably favours fast exotic grasses over slower native shrubs and trees, so a mechanical decision made for speed can lock in a biological outcome nobody wanted.

Surface roughening. Leaving the final surface deliberately rough — furrowed, mounded, or scattered with rock and coarse woody debris — creates **microsites** that trap seed, shade it, hold water and shelter emerging seedlings. It is a mechanical process whose entire purpose is biological.

Water and the void. Where a void cannot be backfilled, the accepted end landform is a **pit lake**: a permanent water body engineered to be stable, of acceptable quality, and integrated with the surrounding groundwater and surface water systems. All three Latrobe Valley operators propose pit lakes. Filling is a water-balance problem with hard numbers attached. For Hazelwood, a full pit water body at +45 m AHD implies a surface area of about 1145 ha and a fill of about **637 GL**, with a target filling period of **10 to 20 years** and up to about 35 years in a worst case. Across all three voids, the *Latrobe Valley Regional Rehabilitation Strategy* puts the volume needed to fill to the crests at "up to **2,800 GL**", plus about **15 GL per year** thereafter simply to offset evaporation. Against that, mean annual surface water availability in the Latrobe system has fallen from a long-term average of about **800 GL per year** to about **600 GL per year** since 1997, and is projected to decline to about **467 GL per year** by 2050 under a dry climate scenario.

A rehabilitation strategy that needs decades of large water transfers is competing with environmental flows and consumptive users in a catchment with less water than it used to have — which is why water availability, not earthmoving, is the binding constraint on Latrobe Valley rehabilitation.

Water treatment during filling. Filling water and groundwater rebound bring the chemistry problems with them, and the mechanical response is dosing and mixing: neutralising agents to raise pH, aeration to oxidise and precipitate iron and manganese, and settling to drop the precipitate out. At the former **Anglesea** brown coal mine, closed on 31 August 2015, the site and its catchment contain naturally occurring **acid sulfate** materials, so pH management during filling is a designed part of closure: neutralising agents such as lime and sodium hydroxide are the standard means of raising the pH of pit spoil and recovering pit water. Anglesea also shows how the *rate* of filling is contested. Alcoa's preferred "fast fill" would have taken seven to ten years, supplementing natural inflow with groundwater; it applied to **Southern Rural Water** to draw **1500 ML per year for ten years** from the **Upper Eastern View Formation** aquifer, and after 167 public submissions, an independent technical review and a public hearing that application was **refused in July 2026**. The regulator found the extraction could reduce shallow groundwater levels and flows in the Anglesea River, could increase acid generation and no-flow days in the river and estuary, and that the benefit of filling fast was small against those risks given that the void will fill naturally in about **26 years**. No groundwater has been extracted for filling since the seven-month feasibility trial ended in December 2021, and the void is filling naturally. Dosing is mechanical, effective and expensive — and it cannot be the permanent answer, which brings in the biology at section 8.

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5 Mechanical processes, part 3 — wells and offshore infrastructure

Wells are a distinct mechanical problem because the disturbance is a hole, and the risk is what travels up it.

Plugging and abandonment (P&A) permanently isolates every permeable zone the well penetrated, so hydrocarbons, saline formation water and gas cannot migrate to a shallow aquifer, to the surface or to the seabed. The sequence is mechanical throughout: kill the well and remove downhole equipment; set cement plugs across and above each zone to be isolated, verified by pressure testing and logging; where necessary perforate and squeeze cement into the annulus behind the casing so the cement–casing pathway is sealed too; cut the casing below ground level, or below the seabed offshore; remove the wellhead; then remediate the surface — demolish the pad, remove imported gravel, break up compacted layers, respread stored topsoil and reseed. Onshore in Victoria this sits under the *Petroleum Act 1998* (Vic).

Offshore, the default is complete removal. The national offshore regulator, **NOPSEMA**, treats complete removal of property and plugging and abandonment of all wells as the **base case** under the *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (Cth). A titleholder wanting to leave something in place must demonstrate that the alternative complies with all other requirements, that environmental impacts are acceptable and risks reduced to **as low as reasonably practicable (ALARP)**, and that the alternative delivers **equal or better** environmental, safety and well-integrity outcomes than full removal. Get the status of the timeframes right, because it is examinable in itself. The binding obligations are statutory — OPGGS Act **s 572** requires a titleholder to maintain property in use and remove property no longer in use, and **s 270** requires removal of property before a title can be surrendered — but the Act sets no deadlines. NOPSEMA's *Decommissioning Compliance Strategy 2024–2029* supplies those as **targets**, not requirements: non-producing wells suspended with downhole barriers within 12 months of losing real-time monitoring and permanently abandoned within 10 years of suspension; all wells plugged and abandoned within three years of **cessation of production**; floating infrastructure removed within 12 months; other property decommissioned to the approved end state within five years. The strategy itself states that the targets "cannot cover every case or variation" and do not supersede timelines or alternative end states accepted in a permissioning document — so NOPSEMA applies them when assessing plans and expects departures to be justified, rather than enforcing them as rules.

That framework exists because the alternative was tested and failed. Where an operator becomes insolvent, the works do not stop being necessary — they simply become the public's. Amendments to the OPGGS Act introducing broad **trailing liability** took effect on 2 March 2022 and apply retrospectively from 1 January 2021, allowing directions to be given to a wider range of entities than the current titleholder — former titleholders and related bodies — so that decommissioning costs stay with the industry rather than falling to government. Rehabilitation, on this framing, is a financial process as much as a physical one.

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6 Biological processes, part 1 — rebuilding a living soil

Mechanical work can deliver a stable landform with a respread, ripped, limed, fertilised surface, and that surface is still not soil. It is a graded mineral substrate. **Biological processes** are what convert it into a functioning soil, and they cannot be substituted by machinery because the things they build — living populations and their interactions — have to grow.

The soil seed bank. Respread topsoil is the cheapest and most complete source of local propagules available, holding seed of species that no nursery grows and that no seed collector could harvest at scale. This is the single strongest argument for direct return: it is not a soil-handling preference, it is the difference between seeding a site and inoculating it.

The soil microbial community. Bacteria and fungi drive decomposition, nutrient mineralisation and the aggregation that gives soil its structure. Raw overburden is close to sterile and, critically, contains almost no **nitrogen** — nitrogen has no mineral parent material, so it cannot be dug up and placed. It has to be **fixed** biologically or imported as fertiliser indefinitely.

Mycorrhizal fungi. Most Australian native plants form **mycorrhizal** associations, the fungus extending the effective root system by orders of magnitude and delivering phosphorus and water in exchange for photosynthate. On phosphorus-poor Australian substrates this is not a marginal benefit; seedlings planted into substrate without appropriate fungal inoculum are commonly stunted regardless of watering and fertiliser. Inoculum arrives with fresh topsoil, with litter transferred from an adjacent reference area, or on nursery-inoculated tubestock.

Nitrogen fixation. Rhizobia in the nodules of legumes — in southern Australia, chiefly *Acacia* species — reduce atmospheric N_2 to plant-available nitrogen. Establishing nitrogen-fixing species early is how a rehabilitated site builds a nitrogen capital it can live on, and it is the only route to a nitrogen budget that does not depend on a fertiliser truck.

Decomposers and soil fauna. Litter fall, then fungal and bacterial decomposition, then comminution and mixing by mites, collembola, termites, ants and earthworms, is the process that accumulates **soil organic carbon**, builds aggregate structure, restores infiltration and creates the water-holding capacity the site was stripped of. It is slow — organic carbon on rehabilitated spoil typically recovers over decades, not seasons — which is exactly why it is the standard monitoring proxy for whether a site is genuinely on a trajectory or merely green.

Biological soil crusts. On the bare inter-plant spaces, cyanobacteria, algae, lichens and mosses form a **biological soil crust** that binds surface particles, resists raindrop impact, fixes some nitrogen and improves the seedbed. Crust development is one of the earliest measurable signs that biological function has started.

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7 Biological processes, part 2 — vegetation, succession and fauna

Species selection under an unusual constraint. 7D’s provenance logic — collect seed locally, from the same vegetation community — is the right starting point and is assumed here. Energy sites add a complication 7D does not face: the growing medium is frequently not the soil the reference community evolved on. Where a cover system is more saline, more sodic, shallower or stonier than the surrounding soil, a strict reference species list will simply die, and the honest design uses species tolerant of the substrate that actually exists while keeping the reference community as the long-term target. Saying that plainly — that the plant list is set by the substrate the mechanical works produced, not only by the pre-mining vegetation — is what a good comparison answer contains.

Pioneers, framework species and a nurse crop. Establishment usually proceeds in stages. A fast, short-lived **nurse crop** (often a sterile or non-persistent cover) stabilises the surface and moderates the microclimate in the first season. **Pioneer** and **framework species** — hardy, fast, frequently nitrogen-fixing — then create shade, litter and root channels. Slower, longer-lived species are introduced under that shelter, either by later planting or by natural arrival. Direct seeding is used where species germinate readily and the area is large, because it is orders of magnitude cheaper per hectare than planting; **tubestock** is used for species that will not establish from broadcast seed, and for the structural species that matter most.

Succession is the mechanism, and the point. The aim is not a fixed planted assemblage. It is a **successional trajectory**: an initial community that modifies its own environment — adding nitrogen and carbon, closing the canopy, building structure — such that later species can establish without help. This is why the definitive test of rehabilitation is **natural recruitment**: a second generation of plants that germinated and survived *on the site*, from seed produced on the site or arriving from nearby. A stand with 95% survival of planted tubestock and no recruits is a garden; a stand with recruits is an ecosystem. Recruitment demonstrates simultaneously that plants reached reproductive maturity, that pollinators are present, that the seedbed is habitable and that the substrate supports germination — four separate functions in one indicator.

Fauna return, and what it depends on. Animals return in response to **structure and resources**, not to plant species lists, and they return in a sequence: invertebrates within a few years, then birds and small mammals as shrub and ground layers thicken, then hollow-dependent species only when there are hollows — which means a century or more unless structure is supplied artificially. Mechanical works help here in a way that looks trivial and is not: placing coarse woody debris, rock piles and logs during earthworks supplies shelter and invertebrate habitat that cannot otherwise exist on a new landform for decades. Reintroducing fauna deliberately is **7D** and **7B**'s territory; the point here is that a rehabilitated energy site is habitat, or it is not, according to whether it has structure.

Completion criteria and reference sites. Success is judged against quantified **completion criteria** agreed with the regulator and measured against a **reference (analogue) site** — an undisturbed area of the target community, sampled the same way. Typical indicators are species richness as a proportion of reference, perennial groundcover percentage, soil organic carbon, bulk density, and the density of natural recruits. Criteria are the mechanism by which "rehabilitated" stops being an opinion.

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8 Biological processes, part 3 — using organisms to fix chemistry and water

Some of the worst legacies of energy extraction are chemical, and the durable solutions are biological, because organisms keep working after the budget for dosing ends.

Acid and metalliferous drainage (AMD). Sulfide minerals exposed to oxygen and water oxidise:

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$$

The acid produced lowers pH, which mobilises aluminium, iron, manganese and heavy metals from the surrounding rock, so the discharge is both acidic and metal-laden — hence "acid *and metalliferous*". Two features make it the defining long-term risk. Iron- and sulfur-oxidising bacteria such as *Acidithiobacillus* catalyse the reaction and accelerate it enormously once pH falls, so the process is **self-accelerating**; and it continues for as long as sulfide, oxygen and water are all present, which can be centuries. Mechanical controls attack the reactants: encapsulate PAF material, keep it saturated to exclude oxygen, and cap it to exclude water. Chemical control neutralises the product with lime. Neither stops being needed.

The biological control works with the same microbiology, reversed. In an **anaerobic bioreactor** or a constructed **treatment wetland**, water is passed through a bed of organic material — compost, wood chip, straw — where oxygen is absent. **Sulfate-reducing bacteria** oxidise that organic carbon using sulfate as the electron acceptor, producing bicarbonate alkalinity (which raises pH) and sulfide (which precipitates dissolved metals as insoluble metal sulfides). One microbial process therefore fixes both halves of the problem at once, and continues to do so for as long as the organic substrate lasts. Its limits are real and examinable: it is slow, flow-rate limited, temperature-sensitive, and the organic bed has to be replaced eventually.

Phytoremediation. Plants can be used against contamination in three distinct modes, and the distinction earns marks. **Phytostabilisation** uses a vegetation cover to immobilise contaminants in place — roots bind the material, transpiration dries the profile so less water percolates, and canopy cover stops wind and water erosion carrying contaminated particles offsite. It does not remove the contaminant; it removes the pathway, and on a large tailings or spoil area that is usually the only affordable objective. **Phytoextraction** uses plants that accumulate a metal in harvestable shoots, which are then removed — genuinely reducing the contaminant load, but slowly, and it creates contaminated biomass that must itself be managed. **Rhizofiltration** uses roots in flowing water to take up dissolved contaminants. All three are cheap per hectare, solar-powered and self-repairing; all three are slow and depth-limited to the root zone.

Bioremediation of hydrocarbons. Around former wellheads, tank farms, workshops and fuel storages, the contaminant is petroleum hydrocarbon, and the treatment is microbial. **Landfarming** spreads contaminated soil in a thin lift and tills it periodically; **biopiles** heap it over an aeration network. Both do the same thing: supply oxygen, water and nutrients (usually nitrogen and phosphorus) so that indigenous hydrocarbon-degrading bacteria and fungi mineralise the hydrocarbons to CO_2, water and microbial biomass. **Bioaugmentation** adds cultured degrader organisms where the native population is inadequate. Compare it with the mechanical alternative — excavate and truck to landfill — and the case is easy to state: bioremediation destroys the contaminant rather than relocating it, avoids the emissions and road risk of long-haul cartage, and costs far less; but it is slower, it works poorly on heavy fractions, and it stalls when soil is cold, dry or anaerobic.

Pit lake biology. A pit lake that is only dosed is a permanent liability; a pit lake that is biologically functional maintains itself. The sequence shows the logic, and Anglesea — a filling void in acid sulfate country, with decades of natural fill ahead of it — is the kind of site it is designed for: neutralising agents such as lime and sodium hydroxide first, mechanically raising pH into a range organisms tolerate, then addition of **organic carbon and nutrients** to establish biological processes and stratification. Once running, primary production in the surface layer supplies organic carbon downwards; that carbon fuels microbial sulfate reduction in the anoxic bottom waters, which generates alkalinity and precipitates metals as sulfides in the sediment; and thermal **stratification** keeps the treated bottom water separated from the oxygenated surface. The chemistry is then being held by a biological process rather than by a dosing budget — which is precisely the difference between "stable" and "sustainable" in section 1's table.

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9 Why the sequence matters, and how rehabilitation actually fails

The relationship between the two families of process is one-directional and worth stating as a formula: **mechanical work sets the physical and chemical envelope, and biological processes are the only things that deliver self-sustaining function — but they can only run inside the envelope the mechanical work built.** Mechanical processes are therefore necessary and never sufficient; biological processes are the source of function and are never possible on their own. Almost every documented rehabilitation failure is a sequencing or envelope error, not a planting error.

Error	What was skipped	What happens
Planting before ripping	Compaction relief	Roots cannot penetrate the compacted layer; plants survive one wet season on stored moisture and die in the first dry one
Respreading topsoil directly over PAF spoil	Selective handling and encapsulation	Acid generated below moves upward; pH falls; the vegetation cover dies from the roots down and cannot be replaced
Using deep, long-stored stockpiled topsoil	Direct return	Seed viability and microbial and mycorrhizal populations are largely gone; the site must be seeded and inoculated at full cost
Heavy nitrogen fertilising a bare substrate	Restraint	Exotic grasses capture the nitrogen and outcompete native shrub and tree seedlings; the community locks at grassland
Planting canopy species only	Multi-strata design	No shrub or ground layer, so no fauna habitat, no litter diversity, and no recruitment pathway
Filling a void with no water balance	Hydrological assessment	Filling takes far longer than planned; batters stay unsupported and unvegetated; a partly filled lake concentrates salts
Declaring success on 12-month survival	Recruitment criterion	The site passes on a metric that measures planting quality, not ecosystem function, and fails a decade later with the bond already

Error	What was skipped	What happens returned

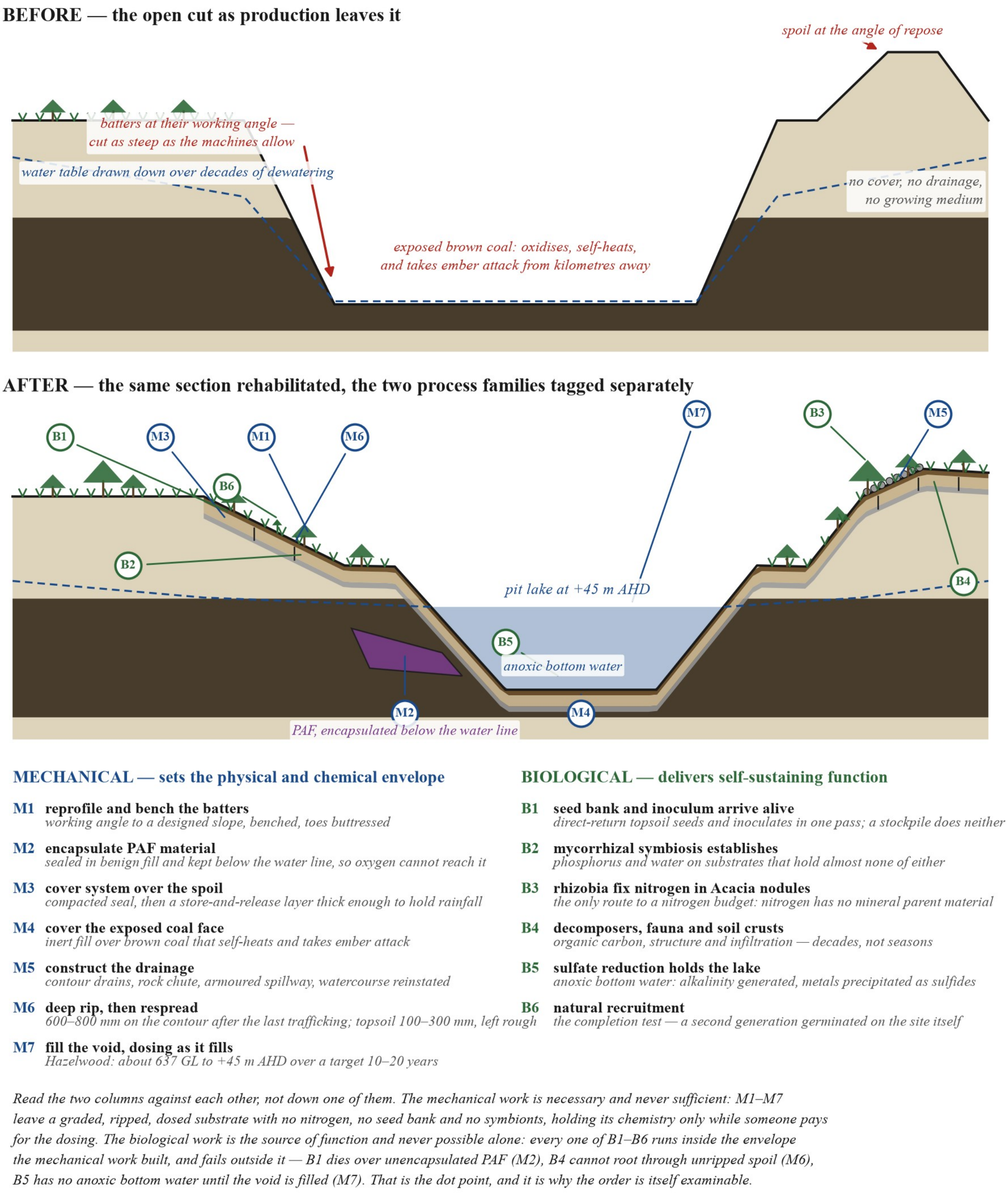

Figure 13A.1 *One section through a Latrobe Valley open cut, before and after, drawn on the published end landform for the Hazelwood Rehabilitation Project — batters reprofiled and benched, a watercourse reinstated, and a full pit water body at +45 m AHD. The two process families are tagged in separate series on purpose, because that separation is the dot point:* ***M1–M7*** *mechanical,* ***B1–B6*** *biological. Read the two keys against each other rather than down one of them. Every biological item sits inside the envelope a mechanical item built — B1 dies over unencapsulated PAF, B4 cannot root through unripped spoil, B5 has no anoxic bottom water until the void is filled — which is the necessary-but-not-sufficient relationship stated above, drawn.*

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10 The Victorian and Commonwealth framework, and who pays

Rehabilitation is not voluntary, and the regulatory design is examinable in its own right because it determines whether the work actually happens.

Victorian mining and extractives. The *Mineral Resources (Sustainable Development) Act 1990* (Vic) is the primary instrument. A licensee must have an approved **rehabilitation plan** before work begins and must lodge a **rehabilitation bond** — a financial security sized to the assessed cost of the outstanding rehabilitation — which is released only when the Minister is satisfied that the rehabilitation has been carried out in accordance with the plan **and is likely to be successful**. That second half matters: the test is forward-looking, not a tick that the works were done. The Act also carries a **declared mine** framework for mines the Minister determines pose a significant risk to public safety, the environment or infrastructure; the three Latrobe Valley brown coal mines are declared mines and must produce a **declared mine rehabilitation plan**. EnergyAustralia submitted Yallourn's on 30 September 2025, ahead of the mine and station's closure in mid-2028; AGL's Loy Yang A is scheduled to close by 2035.

The Mine Land Rehabilitation Authority (MLRA), established under the same Act, superseded the Latrobe Valley Mine Rehabilitation Commissioner on 30 June 2020. It oversees implementation of the **Latrobe Valley Regional Rehabilitation Strategy**, advises the Minister on that strategy and on post-closure maintenance of declared mine land, engages the community, and can investigate at the Minister's request. Note what its existence concedes: someone has to hold the obligation after the company's licence ends.

Environmental and planning instruments. The *Environment Protection Act 2017* (Vic), in force from 1 July 2021, imposes a **general environmental duty** and specific duties for contaminated land, administered by EPA Victoria — these apply to a rehabilitating site regardless of its mining licence. Major rehabilitation projects can be assessed under the *Environment Effects Act 1978* (Vic): the Minister for Planning determined in February 2022 that an **Environment Effects Statement** is required for the Hazelwood Rehabilitation Project. The *Environment Protection and Biodiversity Conservation Act 1999* (Cth) carries a **water trigger**, but note its reach precisely: it catches a **large coal mining development** — a defined term, not any coal mining action — and, since December 2023, unconventional gas development, where the action is likely to have a significant impact on a water resource (ss 24D and 24E). Where it applies, the **Independent Expert Scientific Committee** provides advice — it advised on the Hazelwood Rehabilitation Project on 10 December 2025.

Petroleum. Onshore Victorian petroleum operates under the *Petroleum Act 1998* (Vic). Hydraulic fracturing and coal seam gas exploration and mining are prohibited in Victoria, and the *Constitution Amendment (Fracking Ban) Act 2021* (Vic) entrenched those prohibitions in the *Constitution Act 1975* (Vic), so altering them now requires a three-fifths special majority in both Houses; the separate moratorium on onshore *conventional* gas exploration was lifted on 1 July 2021. Offshore in Commonwealth waters, the *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (Cth), NOPSEMA and the trailing liability regime apply as set out in section 5.

Renewables, and a real asymmetry. Wind and solar facilities in Victoria are consented by **planning permit** under the *Planning and Environment Act 1987* (Vic), typically with conditions requiring decommissioning and rehabilitation at end of life. They are not mining licences, so the MRSD Act's bond regime does not apply to them — the security, if any, is whatever the permit condition and the responsible authority require. Given the number of facilities now approaching a first repowering or retirement, that is a live regulatory question rather than a settled one, and it is a fair thing to identify in an evaluation answer.

Whether the money is actually there. The Victorian Auditor-General's *Rehabilitating Mines* audit, tabled on 5 August 2020, examined this directly. As at December 2019 the regulator held **$813 million** in rehabilitation bonds across the state, of which **$591 million — about 73% — was for the three Latrobe Valley coal mines**, leaving roughly $222 million spread across some 1391 other mines and quarries. The audit found bonds fell at least **$361 million** short of the estimated cost of rehabilitating Victoria's existing mines and quarries, and described that as a low estimate based on desktop analysis; 578 mining **and quarry** sites had no rehabilitation bond at all, and within that group the audit was able to identify 24 sites that are actively operating — a floor discovered within acknowledged data problems, not a count. A bond shortfall is not an accounting curiosity. It is the mechanism by which the **user pays principle** fails: if the security is less than the cost, and the operator does not or cannot complete the work, the difference is met by the public, and the intergenerational transfer the bond was designed to prevent happens anyway. How that argument runs against the other sustainability principles is **12G** and **13D**.

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11 Exam technique for this dot point

- **Answer the binary.** If the question says "mechanical and biological", structure the response in two labelled parts. Marks are commonly allocated as some-for-each, so a brilliant answer on earthworks alone caps low.

- **Give a mechanism, then a purpose.** "Deep ripping to 600–800 mm fractures the compacted layer so roots can penetrate and water can infiltrate" earns; "they rip the ground" does not.
- **Get the sequence right and say why.** Landform → drainage → subsoil → rip → topsoil → seed and plant → monitor. The commonest structural error is putting a biological step before the mechanical step that makes it possible.
- **Do not confuse the words.** Decommissioning, remediation, rehabilitation, restoration and relinquishment are five different things.
- **Use the three-part standard** — safe, stable, sustainable (and non-polluting) — and tie each process you name to the limb it serves.
- **Quote numbers with units and sources.** 637 GL for a Hazelwood pit lake; up to 2800 GL to fill all three voids; 15 GL per year for evaporation; $813 million in bonds against a $361 million shortfall; 45 days of mine fire.
- **Name the instrument correctly.** *Mineral Resources (Sustainable Development) Act 1990* (Vic) for Victorian mines; *Petroleum Act 1998* (Vic) onshore; *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (Cth) with NOPSEMA offshore; *Planning and Environment Act 1987* (Vic) for wind and solar. Do not attribute a wind farm to a mining Act.
- **The success test is recruitment, not survival.** Say so whenever a question offers you a 12-month survival figure.
- **Remember the sites that are not coal.** A question about a well, a turbine foundation or a solar hardstand is still this dot point.
- **Do not import 7D wholesale.** Erosion forms and provenance rules are assumed knowledge; the marks here are for what is specific to a site energy was taken from.

Worked examples

The companies, councils and fieldwork datasets in the scenarios below are fictional, and are invented for this workbook. Every Act, agency, site, quantity and dated event named is real and is stated as at July 2026.

Example 1 — scaffolded

Corravale Energy Pty Ltd is rehabilitating a shaped overburden dump of area 42 ha at a closed open-cut coal mine. The approved plan specifies topsoil respread to a design depth of 250 mm. Site stockpiles hold 78 000 m³ of recovered topsoil.

a. Calculate the volume of topsoil required to meet the design depth over the whole area. Show working. *(2 marks)*

Scaffold: convert hectares to square metres first — 1 ha = 10 000 m² — then multiply by the depth in metres.

> Area = 42 × 10 000 = 420 000 m² **(1)** Volume = 420 000 × 0.250 = **105 000 m³ (1)**

b. Calculate the shortfall, and express it as a percentage of the requirement. *(2 marks)*

> Shortfall = 105 000 − 78 000 = 27 000 m³ **(1)** 27 000 ÷ 105 000 × 100 = **25.7% (1)**

c. Corravale proposes instead to spread all available topsoil evenly across the full 42 ha. Calculate the depth achieved, and state one biological consequence. *(2 marks)*

Scaffold: depth = volume ÷ area. Then ask what topsoil supplies, and what less of it means.

> Depth = 78 000 ÷ 420 000 = 0.186 m = **186 mm (1)** A thinner layer carries proportionally less seed bank, less mycorrhizal and microbial inoculum and less organic matter per unit area, and holds less plant-available water, so germination, establishment and later natural recruitment are all reduced. Treating a smaller area to the design depth, and staging the remainder, would give better ecological return from the same volume. **(1)**

Example 2 — scaffolded

Published assessments for rehabilitation of the Latrobe Valley brown coal mines give the following.

Quantity	Published value
Water to fill all three mine voids to their crests	up to about 2800 GL
Water needed each year thereafter to offset evaporation	about 15 GL per year
Latrobe system mean annual surface water availability, long-term average	about 800 GL per year
Latrobe system mean annual surface water availability, since 1997	about 600 GL per year
Projected mean annual availability by 2050, dry climate scenario	about 467 GL per year

a. Calculate the percentage change in mean annual surface water availability between the long-term average and the post-1997 figure. Show working. *(2 marks)*

> Percentage change = (600 − 800) ÷ 800 × 100 **(1)** = −200 ÷ 800 × 100 = **−25% (1)**

b. Explain why a pit lake is proposed as the final landform for these voids rather than backfilling them. *(3 marks)*

Scaffold: three separate reasons — material, stability, and end use. Do not just say "it is cheaper".

> The material to backfill a void 100 m deep and kilometres across no longer exists on site: the coal was removed and sold, and the overburden volume is far smaller than the void it came out of, so there is nothing to put back. **(1)** A permanent water body is also a stabilising engineering choice — water in the void provides lateral support to the batter toes and resists the groundwater pressures that develop as the depressed water table rebounds, and it covers exposed coal, removing the self-heating and fire risk. **(1)** A lake additionally provides an agreed post-extraction land use with recreational, amenity and habitat value, which the "sustainable" limb of the rehabilitation standard requires the final landform to have. **(1)**

c. Explain what the 15 GL per year figure implies for whether these landforms meet the "sustainable" requirement. *(2 marks)*

Scaffold: the marks are for identifying the obligation as permanent, and for connecting that to the definition.

> Evaporation from a large lake surface exceeds direct rainfall onto it, so about 15 GL per year must be supplied indefinitely just to hold the water level — an ongoing obligation with no end date, in a catchment where availability has already fallen 25% and is projected to fall further. **(1)** A landform that requires permanent external input and permanent management is stable but not self-sustaining, so on the definition in section 1 the "sustainable" limb is the one genuinely in question, and it turns on a water-balance argument rather than on the earthworks. **(1)**

Example 3 — unscaffolded

Explain why respreading recovered topsoil recovers ecological function on a rehabilitated energy site faster than importing clean subsoil, naming the biological processes involved. *(4 marks)*

> Recovered topsoil contains the site's **soil seed bank** — viable seed of local species, including many that are not commercially available and could not be collected at scale — so respreading it seeds and inoculates the site simultaneously, whereas imported subsoil must be seeded entirely from purchased or collected stock. **(1)** It also carries the living **soil microbial community** and **mycorrhizal fungal** inoculum; most Australian native plants depend on mycorrhizal associations to obtain phosphorus and water from these characteristically phosphorus-poor substrates, and seedlings planted into material without appropriate inoculum are commonly stunted regardless of watering and fertiliser. **(1)** It supplies **organic matter** and an established decomposer and soil-fauna community, so nutrient mineralisation, aggregate formation and infiltration begin immediately rather than having to develop from nothing over decades. **(1)** Subsoil, by contrast, has negligible organic carbon and essentially no nitrogen, and nitrogen has no mineral parent material, so it cannot be placed mechanically — it must be fixed biologically by rhizobia in legume nodules or imported as fertiliser indefinitely. Topsoil therefore delivers, at once, the propagules, the symbionts and the nutrient-cycling machinery that would otherwise have to be rebuilt from zero. **(1)**

Example 4 — unscaffolded

"Once the coal has run out, the cheapest thing to do is fill the hole with water and let nature take over." Evaluate this claim. *(4 marks)*

> The claim contains something correct: a pit lake is in fact the accepted end landform for large voids that cannot be backfilled, and all three Latrobe Valley operators propose one, because the backfill material no longer exists and water provides lateral support to batter toes and covers exposed coal. **(1)** But "fill the hole" understates the mechanical work that must precede filling. Batters have to be reprofiled from their working angle to a slope stable under design flood and seismic loading without maintenance; potentially acid-forming material must be selectively placed and encapsulated below the future water line; drainage and spillways must be constructed; and filling requires a quantified water balance — for Hazelwood alone about 637 GL over a target 10 to 20 years, drawn from a catchment whose mean annual availability has fallen from about 800 to about 600 GL per year since 1997. Filling without that assessment risks a partly filled, salt-concentrating lake with unsupported batters left exposed for decades. **(1)** "Let nature take over" also misdescribes the biology. Raw spoil is compacted, frequently acidic or sodic, and contains essentially no nitrogen and no seed bank, so unassisted colonisation is dominated by weeds and takes centuries; the biological processes that deliver function — mycorrhizal establishment, nitrogen fixation, organic carbon accumulation, natural recruitment — must be deliberately initiated by ripping, topsoil return, amelioration and multi-strata seeding, and a pit lake typically needs pH correction and then organic carbon and nutrient addition before sulfate reduction and stratification will hold its chemistry. **(1)** Finally, "cheapest" is only true if the cost is measured over the operator's remaining life rather than the landform's. Cheap rehabilitation shifts cost forward: the Victorian Auditor-General found in 2020 that bonds held were at least $361 million short of estimated rehabilitation costs, which means the shortfall falls to the public — a failure of both the user pays principle and intergenerational equity. The claim is therefore partly right about the *landform* and wrong about the *process*, the *water* and the *cost*. **(1)**

Practice questions

Scaffolded

Q1. Define *rehabilitation* as it applies to a site from which energy has been sourced. **(1 mark)**

Q2. State the three-part standard that a rehabilitated Victorian coal mine landform must meet, and explain why "sustainable" is a separate requirement from "stable". **(2 marks)**

Q3. For each process, state whether it is a **mechanical** process or a **biological** process in site rehabilitation. **(4 marks)**

	Process	Mechanical or biological
a.	Reprofiling a batter from its working angle to a flatter designed slope	
b.	Inoculating tubestock with mycorrhizal fungi before planting	
c.	Deep ripping a respread surface along the contour to 700 mm	
d.	Passing mine water through a compost bed so sulfate-reducing bacteria generate alkalinity	

Q4. Topsoil handling.

a. Explain why topsoil is stripped and stockpiled separately from overburden. **(2 marks) b.** Explain why **direct return** of topsoil is preferred to stockpiling it for several years. **(2 marks) c.** Name **two** components of topsoil that cannot be manufactured mechanically, and state what each contributes. **(2 marks)**

Q5. Landform and substrate works.

a. State what a **batter** is, and explain why batters are reprofiled during rehabilitation. **(2 marks) b.** Explain what **selective handling and encapsulation** of potentially acid-forming material involves, and why it cannot be corrected later. **(2 marks) c.** Explain why compaction must be relieved by deep ripping **before** topsoil is respread and seed is sown. **(2 marks)**

Q6. The Hazelwood Rehabilitation Project proposes a full pit water body at +45 m AHD requiring about 637 GL of water, with a target filling period of 10 to 20 years. Mean annual surface water availability in the Latrobe system has been about 800 GL per year over the long term and about 600 GL per year since 1997, and is projected to fall to about 467 GL per year by 2050 under a dry climate scenario.

a. Calculate the mean annual rate of water supply needed to fill the void in 15 years. Show working. **(2 marks) b.** Calculate the percentage change in mean annual availability between the long-term average and the projected 2050 dry-scenario figure. Show working. **(2 marks) c.** Using both answers, explain one risk this creates for the rehabilitation strategy. **(2 marks)**

Q7. Wells.

a. Describe **two** mechanical steps in the plugging and abandonment of a petroleum well. **(2 marks) b.** State the purpose of plugging and abandonment. **(1 mark) c.** State the timeframe that NOPSEMA's *Decommissioning Compliance Strategy 2024–2029* sets as its **target** for all wells to be plugged and abandoned after cessation of production. **(1 mark)**

Q8. Distinguish between **decommissioning**, **rehabilitation** and **relinquishment**. **(3 marks)**

Q9. Acid and metalliferous drainage.

a. Explain how acid and metalliferous drainage forms at a mine site, and why it is described as self-accelerating. **(2 marks) b.** Name **one** mechanical and **one** biological control for acid and metalliferous drainage, explain the mechanism of each, and state one limitation of the biological control. **(4 marks)**

Q10. A rehabilitation contractor respreads topsoil and plants tubestock on shaped spoil. Explain why this alone does not deliver a rehabilitated site, naming **three** biological processes that must establish. **(3 marks)**

Q11. A student writes: *"Rehabilitating a mine site means planting trees on it once the mining has finished."* Identify **two** errors in this statement and correct each one. **(4 marks)**

Unscaffolded

Q12. State **two** reasons a rehabilitation bond is required before extraction begins, and explain what a bond shortfall means for the public. **(3 marks)**

Q13. Explain, using one specific example, why a particular mechanical process must be completed before a particular biological process can succeed. **(3 marks)**

Q14. Compare the rehabilitation task at a decommissioned wind energy facility with that at a closed open-cut brown coal mine. Refer to the disturbance, the mechanical work, the biological work and the regulatory instrument in each case. **(4 marks)**

Q15. A former well pad carries soil contaminated with petroleum hydrocarbons. Explain why the operator may treat it by landfarming rather than by excavating it and sending it to landfill, and state one limitation of landfarming. **(3 marks)**

Q16. During the filling of a former brown coal void, lime is spread on the pit spoil and sodium hydroxide is dosed into the recovering water, and organic carbon and nutrients are then added. Explain the purpose of each stage, and explain why the second stage is what makes the water quality outcome sustainable. **(4 marks)**

Q17. *The data below were generated by a Year 12 student conducting fieldwork at a rehabilitated overburden dump at a closed open-cut coal mine and at a nearby unmined reference site of the target vegetation community. Ten 5 m × 5 m quadrats were sampled at each site and the means are reported.*

Indicator	Rehabilitated area	Reference site	Completion criterion
Native species richness per quadrat	11.4	18.2	≥ 60% of reference
Perennial groundcover (%)	71	84	≥ 70%
Soil organic carbon, 0–100 mm (%)	0.9	3.4	≥ 50% of reference
Natural recruits per quadrat	0.2	6.8	≥ 1.0
Soil bulk density (g cm^{-3})	1.62	1.28	≤ 1.40

a. Calculate native species richness in the rehabilitated area as a percentage of the reference site, and state whether the criterion is met. Show working. **(2 marks)** **b.** Identify the criteria that are **not** met, and identify the single mechanical failure that best explains two of them. **(2 marks)** **c.** Explain why the density of natural recruits is a better indicator of rehabilitation success than survival of planted tubestock at 12 months. **(3 marks)**

Q18. Describe the mechanical and biological processes involved in rehabilitating a closed open-cut coal mine, and explain why neither family of processes is sufficient on its own. **(10 marks)**

Q19. Corravale Energy Pty Ltd has submitted the following draft rehabilitation plan for its closed open cut to the regulator, with a copy to **Ardencote Shire Council**.

1. Demolish the power station and remove all above-ground infrastructure.
2. Leave the batters at their current working angle and fence the void.
3. Respread topsoil from stockpiles created 14 years ago, at 100 mm depth, directly onto the shaped spoil.
4. Sow a single fast-growing exotic pasture grass across the whole area and apply nitrogen fertiliser at a high rate.
5. Allow the void to fill from rainfall and groundwater, with no water balance assessment, and treat water quality if problems arise.
6. Seek return of the rehabilitation bond 12 months after sowing, on the basis of 90% plant survival.

Evaluate the plan. Identify **four** elements that are inadequate; for each, explain the mechanical or biological process it omits or misapplies and state what should be done instead. Then state whether the bond should be returned, and justify your answer. **(10 marks)**

Answers

Q1. Returning land disturbed by energy extraction to a safe, stable and sustainable (non-polluting) condition that supports an agreed post-extraction land use.

Q2. Safe, stable and sustainable. "Stable" means the landform will not move under design events; "sustainable" means it functions without continuing intervention and does not export contamination — a site needing permanent dosing or watering is stable but not sustainable.

Q3. a. Mechanical. b. Biological. c. Mechanical. d. Biological.

Q4. a. It carries the seed bank, microbes, mycorrhizal inoculum, organic matter and nutrients; mixing it with overburden dilutes and destroys all of that. b. Seed viability and the aerobic microbial and mycorrhizal populations decline with storage, so aged topsoil supplies texture but not a living community. c. Any two of: soil seed bank (local propagules, including species not commercially available); microbial and mycorrhizal community (nutrient cycling, phosphorus and water uptake); organic matter and soil fauna (structure, water holding, mineralisation).

Q5. a. The engineered slope of an excavated face or spoil dump; reprofiled from the steep working angle to a flatter designed slope that is stable under design flood and seismic loading with no maintenance. b. Identifying sulfide-bearing (potentially acid-forming) strata during extraction and placing them sealed inside benign material, ideally below the water table so oxygen is excluded; once such material is near the surface, acid generation continues for as long as sulfide, oxygen and water coexist and cannot be undone by later planting. c. Machinery traffic raises bulk density and closes the pore network, so roots cannot penetrate, water cannot infiltrate and gases cannot exchange; ripping must follow the last trafficking and precede respread and sowing or the work is undone.

Q6. a. 637 ÷ 15 = **42.5 GL per year**. b. (467 − 800) ÷ 800 × 100 = **−41.6%**. c. 42.5 GL per year is about 9% of the projected 467 GL per year and competes with environmental flows and consumptive users; if availability falls, filling extends (published worst case up to about 35 years) and batters remain unsupported, unvegetated and exposed for decades.

Q7. a. Any two of: kill the well and remove downhole equipment; set and verify cement plugs across each permeable zone; squeeze cement behind the casing; cut the casing below ground or seabed level; remove the wellhead; remediate the pad. b. Permanently isolating the permeable zones the well penetrated so hydrocarbons, gas and saline formation water cannot migrate to aquifers, the surface or the seabed. c. A target of within **three years** of cessation of production.

Q8. Decommissioning: taking plant out of service and removing or making safe built infrastructure. Rehabilitation: the whole job of landform, drainage, substrate, vegetation and ecosystem function to an agreed end land use. Relinquishment: the legal end point at which the regulator accepts rehabilitation is complete and releases the obligation and the financial security.

Q9. a. Sulfide minerals (chiefly pyrite) exposed to oxygen and water oxidise, producing acid; the low pH mobilises aluminium, iron, manganese and heavy metals. It is self-accelerating because iron- and sulfur-oxidising bacteria catalyse the reaction and multiply as pH falls. b. Mechanical: encapsulation of PAF material below a cover system and, where possible, below the water table, which excludes oxygen and water, the reactants. Biological: an anaerobic bioreactor or treatment wetland in which sulfate-reducing bacteria oxidise organic carbon using sulfate, generating bicarbonate alkalinity that raises pH and sulfide that precipitates metals as insoluble metal sulfides. Limitation: slow and flow-limited, temperature-sensitive, and the organic bed must eventually be replaced.

Q10. Respread topsoil and planted seedlings give a landform with plants on it, not a functioning ecosystem; the site must develop (any three of) mycorrhizal associations; biological nitrogen fixation by rhizobia in legume nodules; decomposition and soil organic carbon accumulation by decomposers and soil fauna; biological soil crust formation; and natural recruitment of a second generation.

Q11. Error 1: rehabilitation is far more than planting — the mechanical work (reprofiling slopes, encapsulating acid-forming material, constructing drainage, ripping, respreading topsoil, plugging wells, managing water) sets the physical and chemical envelope, and planting into an unprepared substrate fails. Error 2: trees alone are not the target and "once mining has finished" is wrong — a multi-strata, self-sustaining community is required, judged on natural recruitment against completion criteria, and rehabilitation is planned before extraction begins and progressed during operations, not started at closure.

Q12. Any two of: it secures the cost of rehabilitation against operator default or insolvency; it applies the user pays principle by putting the cost on the beneficiary of extraction rather than on future taxpayers; it gives the regulator leverage, since the bond is released only on satisfactory completion. A shortfall means the security held is less than the cost of the work, so if the operator does not complete it the difference is met by the public — the Victorian Auditor-General found bonds at least $361 million short in 2020, against $813 million held.

Q13. Any correctly paired example, with its mechanism and the consequence of reversing the order. For example: potentially acid-forming material must be selectively placed and encapsulated before revegetation, because pyrite oxidises wherever sulfide, oxygen and water coexist and the acid moves upward through the profile; a cover established over near-surface PAF spoil dies from the roots down as pH falls in the rooting zone, and cannot be replaced without re-excavating the material. Other acceptable pairs: correcting pit-lake pH before adding organic carbon and nutrients; respreading topsoil before expecting seed-bank germination; deep ripping before planting (worked at Q5c).

Q14. Wind: a small, shallow footprint (foundations, hardstands, roads, cables, substation); mechanical work is removing or burying foundations, taking out cable and hardstand material and decompacting the footprint; biological work is limited to revegetating a modest area, often back to pasture or grassland, with topsoil largely intact; consented and controlled by planning permit conditions under the *Planning and Environment Act 1987* (Vic). Coal: the whole permit area disturbed to 100 m; mechanical work is batter reprofiling, spoil placement and encapsulation, drainage construction, void filling and water treatment; biological work is building a soil biota and a successional community from a sterile substrate over decades; controlled by the *Mineral Resources (Sustainable Development) Act 1990* (Vic) with an approved rehabilitation plan and a rehabilitation bond, and a declared mine rehabilitation plan where the mine is declared.

Q15. Landfarming spreads the soil thinly and tills it to supply oxygen, water and nutrients so indigenous hydrocarbon-degrading microbes mineralise the hydrocarbons to CO_2, water and biomass; it destroys the contaminant rather than relocating it, and avoids the cost, emissions and road risk of long-haul cartage to landfill. Limitation (any one): slow; ineffective on heavy hydrocarbon fractions; stalls when soil is cold, dry or anaerobic; needs a large area.

Q16. Lime and sodium hydroxide neutralise acidity and raise pH mechanically/chemically into a range organisms can tolerate. Adding organic carbon and nutrients then establishes biological processes and stratification: primary production in the surface layer supplies carbon downward, fuelling microbial sulfate reduction in anoxic bottom waters that generates alkalinity and precipitates metals as sulfides, while stratification keeps treated bottom water separate. The second stage is what makes the outcome sustainable because the chemistry is then held by a self-maintaining biological process rather than by permanent dosing.

Q17. a. $11.4 \div 18.2 \times 100 =$ **62.6%**, which is $\geq 60\%$, so the criterion is **met**. b. Not met: soil organic carbon ($0.9 \div 3.4 = 26.5\%$, below 50%), natural recruits (0.2, below 1.0) and bulk density (1.62, above 1.40). The mechanical failure is inadequate relief of compaction — the high bulk density directly fails its own criterion and explains the near-absence of recruitment. c. Recruitment shows the site is self-sustaining: plants have reached reproductive maturity, pollinators are present, seed is being produced or arriving, and the substrate permits germination and seedling survival. Twelve-month survival measures planting and watering quality over a single season and can be high on a site that will fail later.

Q18. Model response — see solutions. Must cover both families with mechanisms, in sequence, and argue the necessary-but-not-sufficient relationship in both directions.

Q19. Model response — see solutions. Defective elements: batters left at working angle (safety and stability); 14-year-old stockpiled topsoil at 100 mm respread with no ripping and no PAF assessment; single exotic grass with high nitrogen (locks the community at exotic grassland, no strata, no recruitment); no water balance for filling; bond release on 12-month survival rather than completion criteria including recruitment. Bond should not be returned.

Fully-worked solutions

Q1. *(1 mark)* One mark for a definition that names both the standard and the end use: returning land disturbed by energy extraction to a **safe, stable and sustainable** (non-polluting) condition supporting an **agreed post-extraction land use**. “Fixing up the site afterwards” earns nothing; “making it look like it did before” describes *restoration*, which is a different and usually unattainable target once the material carrying the original ecosystem has been removed.

Q2. *(2 marks)* **Safe, stable and sustainable** — the wording used in the *Latrobe Valley Regional Rehabilitation Strategy*, to which operators commonly add *non-polluting* **(1)**. “Stable” is a geotechnical and hydrological test: the landform will not move under the design flood, rainfall and seismic events, and will still not move in a century. “Sustainable” is a functional test: the site operates **without continuing intervention** and does not export contamination. They are separate because a landform can pass one and fail the other — a lake held at level by permanent pumping, or spoil kept neutral by permanent lime dosing, is stable and not sustainable, and a site that needs a person with a machine every year has been converted into a liability rather than rehabilitated **(1)**.

Q3. *(4 marks)* One mark each. **a. Mechanical** — earthmoving to a designed slope. **b. Biological** — establishing a fungal symbiosis that delivers phosphorus and water to the plant. **c. Mechanical** — physical fracturing of a compacted layer. **d. Biological** — microbial sulfate reduction generating alkalinity and precipitating metal sulfides. Items c and d are deliberately paired with a and b: the classification follows whether the *process doing the work* is physical or the activity of living organisms, not whether machinery was used to set it up. A bioreactor is built with machinery and is a biological process.

Q4. *(6 marks)* **a.** *(2)* Topsoil is the A horizon and carries almost all of the site’s biological value — the soil seed bank, the microbial and mycorrhizal community, organic matter, soil structure and the nutrient store **(1)**. Mixing it into overburden dilutes those components to uselessness and buries them where there is no oxygen, so it is stripped ahead of extraction and kept as a separate, identified resource **(1)**. **b.** *(2)* Direct return moves topsoil straight from the strip face onto shaped ground within the same season, so the living components arrive alive **(1)**. In storage, seed viability declines with time and the aerobic microbial and mycorrhizal populations collapse in the anaerobic interior of a deep stockpile, while organic matter is lost — so aged topsoil still supplies texture and some nutrients but no longer supplies a living community, and the site must be seeded and inoculated at full cost **(1)**. **c.** *(2)* One mark each for any two, each with its contribution: the **soil seed bank** — viable local propagules, including species not commercially available and not collectable at scale; the **microbial and mycorrhizal community** — nutrient mineralisation, and phosphorus and water uptake on phosphorus-poor substrates; **organic matter with its decomposer and soil fauna community** — aggregate structure, water-holding capacity and continuing nutrient cycling. Naming a component without stating what it contributes earns half the point and is marked as not earning it.

Q5. *(6 marks)* **a.** *(2)* A **batter** is the engineered slope of an excavated face or a spoil dump **(1)**. Working batters are cut as steep as short-term stability and machinery allow, because flattening costs volume moved; a rehabilitation batter must instead be stable under design rainfall, flood and seismic loading **with no maintenance for the long term**, so it is cut back, flattened, benched to break slope length, and buttressed at the toe **(1)**. **b.** *(2)* Some overburden strata are **potentially acid-forming** because they contain sulfide minerals, chiefly pyrite. Selective handling identifies those strata during extraction and places them deliberately — encapsulated within benign material, under a cover system, and where possible below the water table so oxygen is excluded **(1)**. It cannot be corrected later because acid generation continues for as long as sulfide, oxygen and water coexist, and the acid moves upward through the profile; a vegetation cover established over near-surface PAF material dies from the roots down, and the only remedy is to re-excavate and re-place the material — which is why this is treated as an unrecoverable error **(1)**. **c.** *(2)* Every machinery pass raises **bulk density** and closes the soil pore network, so roots cannot penetrate, water cannot infiltrate and gases cannot exchange — the three functions plants need from soil **(1)**. Ripping (typically along the contour, to 600–800 mm) fractures the compacted layer, and it must follow the **last** trafficking and precede respread and sowing; ripping first and then driving over the surface, or planting into an unripped surface, produces plants that survive one wet season on stored moisture and die in the first dry one **(1)**.

Q6. *(6 marks)* **a.** *(2)* Rate = volume ÷ time = 637 ÷ 15 **(1)** = **42.5 GL per year** (42.47 GL y^{-1}) **(1)**. The unit is required. **b.** *(2)* Percentage change = (467 − 800) ÷ 800 × 100 **(1)** = −333 ÷ 800 × 100 = **−41.6%** **(1)**. Dividing by the final value instead of the initial value is the standard error and caps the answer at 1 mark; the negative sign carries the meaning and must be given. **c.** *(2)* The required fill rate of 42.5 GL per year is about 9% of the projected 2050 availability of 467 GL per year, and it has to be found in a catchment whose mean annual availability has already fallen 25% since

1997 and is projected to fall about 42% below the long-term average **(1)**. That volume competes directly with environmental flows and consumptive users, so the water may not be available at the assumed rate; filling then extends well beyond the 10–20 year target — the published worst case is about 35 years — and while the void is only partly filled the batters remain without the lateral support the lake was to provide, coal faces remain exposed to fire risk, and salts concentrate in a shallower water body **(1)**. *Award the second mark for any one consequence developed, not merely named.*

Q7. *(4 marks)* **a.** *(2)* One mark each for any two mechanical steps, described: killing the well and pulling downhole equipment; setting cement plugs across and above each permeable zone and verifying them by pressure testing and logging; perforating and squeezing cement into the annulus so the pathway behind the casing is also sealed; cutting the casing below ground level (below the seabed offshore); removing the wellhead; demolishing the pad, removing imported gravel, breaking up compacted layers and respreading stored topsoil. **b.** *(1)* To isolate permanently every permeable zone the well penetrated, so that hydrocarbons, gas and saline formation water cannot migrate up the hole or up the annulus to a shallow aquifer, the surface or the seabed. **c.** *(1)* Within **three years** of cessation of production. Accept the bare timeframe; the word *target* is not required for the mark, but a response that calls it a legal deadline has misread the instrument. (For context, the other targets are: non-producing wells suspended with downhole barriers within 12 months of losing real-time monitoring and permanently abandoned within 10 years of suspension; floating infrastructure removed within 12 months of cessation of production; other property decommissioned to the approved end state within five years. All four are targets set by a compliance strategy, not statutory time limits — the binding duties are OPGGS Act s 572, to maintain property in use and remove property no longer in use, and s 270, to remove property before surrendering a title, neither of which fixes a deadline.)

Q8. *(3 marks)* One mark each. **Decommissioning** is taking the operating plant out of service and removing or making safe the built infrastructure — draining and purging, de-energising, demolishing, cutting and capping. It precedes rehabilitation and is not the same thing. **Rehabilitation** is the whole job of returning the disturbed land to a safe, stable and sustainable condition supporting an agreed end land use: landform, drainage, substrate, vegetation and ecosystem function. **Relinquishment** is the legal end point at which the regulator accepts that rehabilitation is complete and releases the licensee's obligation and financial security — until then the operator still owns the problem. *A response that treats decommissioning as a synonym for rehabilitation loses the first and second marks together.*

Q9. *(6 marks)* **a.** *(2)* Sulfide minerals exposed to oxygen and water by excavation oxidise — for pyrite, $2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$ — producing acidity, and the resulting low pH mobilises aluminium, iron, manganese and heavy metals from the surrounding rock, so the discharge is both acidic and metal-laden **(1)**. It is self-accelerating because iron- and sulfur-oxidising bacteria such as *Acidithiobacillus* catalyse the oxidation and become more active as pH falls, so the reaction speeds itself up, and it continues for as long as sulfide, oxygen and water are all present — potentially centuries **(1)**. **b.** *(4)* **Mechanical control (2):** selective handling and **encapsulation** — the PAF material is placed sealed within benign material beneath an engineered cover system and, where possible, below the water table **(1)**. The mechanism is exclusion of reactants: the compacted low-permeability layer sheds water, the store-and-release layer holds infiltration for plants to transpire, and saturation excludes oxygen, so the oxidation cannot proceed **(1)**. **Biological control (2):** an anaerobic bioreactor or constructed treatment wetland — water passes through a bed of compost, wood chip or straw in the absence of oxygen, where **sulfate-reducing bacteria** oxidise the organic carbon using sulfate as the electron acceptor **(1)**. This produces bicarbonate alkalinity, raising pH, and sulfide, which precipitates the dissolved metals as insoluble metal sulfides — one process treating both halves of the problem. Limitation (any one, required for the final mark): it is slow and flow-rate limited; it is temperature-sensitive; and the organic substrate is consumed and must eventually be replaced, so it is low-maintenance rather than no-maintenance **(1)**.

Q10. *(3 marks)* Respread topsoil and planted tubestock give a stable landform with plants growing on it; they do not give the self-sustaining function the "sustainable" limb of the standard requires, because that function is delivered by living populations that have to establish and grow. One mark each for any three, with the contribution stated: **mycorrhizal associations**, without which seedlings on phosphorus-poor substrates are stunted regardless of watering and fertiliser; **biological nitrogen fixation** by rhizobia in legume nodules, which is the only route to a nitrogen budget that does not depend on permanent fertiliser, because nitrogen has no mineral parent material; **decomposition and soil organic carbon accumulation** by decomposers and soil fauna, which builds aggregate structure, infiltration and water-holding capacity over decades; **biological soil crust** formation, which binds the surface between plants and resists raindrop impact; and **natural recruitment** of a second generation, which is the definitive evidence that the community can continue without intervention.

Q11. *(4 marks)* Two errors, each identified and corrected — 1 mark for the identification and 1 for the correction, twice.

- **Error 1: the scope is wrong — planting is a small part of the job.** Rehabilitation requires the mechanical works that set the physical and chemical envelope first **(1)**: reprofiling batters to a slope stable without maintenance, selectively placing and encapsulating potentially acid-forming material, constructing drainage, relieving compaction by deep ripping, respreading topsoil, plugging any wells, and resolving the water balance for a void. Planting into an unprepared substrate fails — compacted spoil with no nitrogen and no inoculum kills seedlings whatever their quality **(1)**.
- **Error 2: the target and the timing are wrong.** The target is not trees but a **multi-strata, self-sustaining community** measured against quantified completion criteria and a reference site, with **natural recruitment** as the definitive test; a canopy with no shrub or ground layer supports no fauna, produces no litter diversity and has no recruitment pathway **(1)**. And rehabilitation is not something that begins at closure: the plan must be approved and the bond lodged before extraction starts, topsoil is stripped and preferably directly returned during operations, and progressive rehabilitation of worked-out areas runs alongside production — which is also what makes direct return possible at all **(1)**.

Q12. *(3 marks)* One mark each for any two reasons, stated with the reasoning attached: it **secures the cost against default** — rehabilitation obligations survive a company's insolvency, and the bond is the only asset the regulator holds that does not disappear with the operator; it applies the **user pays principle**, placing the cost on the party that benefited from the extraction rather than on future taxpayers, which is also how **intergenerational equity** is protected in this context; and it gives the regulator **leverage over completion**, because the bond is released only when the Minister is satisfied the rehabilitation is complete, so the operator has a financial reason to meet the criteria rather than walk away. Third mark: a **shortfall** means the security held is less than the assessed cost of the outstanding work, so if the operator does not complete it the difference falls to the public — the Victorian Auditor-General's *Rehabilitating Mines* audit, tabled 5 August 2020, found that against $813 million held as at December 2019 (of which $591 million, about 73%, related to the three Latrobe Valley coal mines) bonds were at least $361 million short of estimated costs, and described that as a low estimate; 578 mining and quarry sites had no rehabilitation bond at all, and the audit identified 24 sites within that group that are actively operating **(1)**.

Q13. *(3 marks)* One mark for naming a correctly paired mechanical and biological process, one for the mechanism, one for the consequence of reversing the order. For example: **selective handling and encapsulation of potentially acid-forming material must precede revegetation (1)**. PAF strata contain sulfide minerals, chiefly pyrite, which oxidise wherever sulfide, oxygen and water coexist; encapsulating that material within benign fill beneath a cover system, and where possible below the water table, excludes the reactants, whereas leaving it near the surface lets the acid it generates move upward through the profile **(1)**. If revegetation happens first, the established cover dies from the roots down as pH falls in the rooting zone; because generation continues for as long as the reactants coexist there is no biological remedy, and the only fix is to re-excavate and re-place the material — so the whole revegetation cost is lost **(1)**. *Other acceptable pairs, each earning full marks on the same three-part structure: deep ripping before planting and sowing (worked at Q5c, so prefer one of the others here); correcting pit-lake pH with lime and sodium hydroxide before adding organic carbon and nutrients; respreading topsoil before expecting seed-bank germination.*

Q14. *(4 marks)* One mark per point of comparison, each requiring both sides.

- **Disturbance.** A wind facility disturbs a small fraction of its permit area and disturbs it shallowly — turbine foundations, hardstands, internal roads, buried cable and a substation — with surrounding soil and often the surrounding land use intact. An open-cut brown coal mine disturbs the whole area to 100 m or more, removing the coal entirely and leaving a void, batters and spoil dumps, with the groundwater system drawn down **(1)**.
- **Mechanical work.** Wind: remove or bury foundations, remove cable, break out or rip hardstand and road pavements, respread stored topsoil. Coal: reprofile batters to a stable designed slope, place and encapsulate potentially acid-forming spoil under a cover system, construct drainage and spillways, reinstate a watercourse, cover exposed coal against self-heating, and fill the void with a quantified water balance **(1)**.
- **Biological work.** Wind: revegetate a modest, shallow footprint, frequently back to the surrounding pasture or grassland, with intact adjacent seed sources and largely intact topsoil — a task of seasons. Coal: build a soil biota from a near-sterile substrate — seed bank, mycorrhizal inoculum, nitrogen fixation, organic carbon

accumulation — and establish a multi-strata successional community whose success is judged on natural recruitment; a task of decades, with pit lake chemistry to be held biologically as well **(1)**.

- **Regulatory instrument.** Wind and solar are consented by planning permit under the *Planning and Environment Act 1987* (Vic), with decommissioning and rehabilitation conditions but no mining-style bond regime. Coal operates under the *Mineral Resources (Sustainable Development) Act 1990* (Vic), with an approved rehabilitation plan, a rehabilitation bond, and — where the mine is declared, as the three Latrobe Valley mines are — a declared mine rehabilitation plan and oversight by the Mine Land Rehabilitation Authority **(1)**.

Q15. *(3 marks)* **Landfarming** spreads the contaminated soil in a thin lift and tills it periodically, supplying oxygen, water and nutrients so that indigenous hydrocarbon-degrading bacteria and fungi mineralise the hydrocarbons to CO_2, water and microbial biomass **(1)**. It is preferred to excavate-and-dispose because it **destroys** the contaminant rather than relocating the problem to a landfill where it remains a liability, and it avoids the cost, the fuel use and emissions, and the road risk of long-haul cartage of large soil volumes; per tonne it is far cheaper **(1)**. Limitation, any one: it is slow, taking months to years against days for cartage; it works poorly on heavy hydrocarbon fractions, which are not readily bioavailable; it stalls when the soil is cold, dry or anaerobic; and it needs a large, contained, managed area with its own runoff controls **(1)**.

Q16. *(4 marks)* **Stage 1 — lime and sodium hydroxide (1).** These neutralise acidity in the pit spoil and the recovering water, raising pH out of the range at which metals stay dissolved and into a range organisms can tolerate. It is a chemical dosing process delivered mechanically, it acts quickly, and it is what makes the water habitable at all **(1)**. **Stage 2 — organic carbon and nutrients (1).** These establish biological processes and thermal stratification in the filling lake: primary production in the surface layer supplies organic carbon downward; that carbon fuels microbial sulfate reduction in the anoxic bottom waters, generating bicarbonate alkalinity and precipitating dissolved metals as insoluble sulfides into the sediment; and stratification keeps the treated bottom water separated from the oxygenated surface layer. This is the stage that makes the outcome **sustainable**, because the water chemistry is thereafter held by a self-maintaining biological process rather than by a dosing program that must be funded and staffed indefinitely — the difference between "stable" and "sustainable" **(1)**. *This is the standard treatment sequence for an acidic pit lake, and the former Anglesea brown coal mine — closed on 31 August 2015, in country containing naturally occurring acid sulfate materials, and now filling naturally over an estimated 26 years after Southern Rural Water refused the groundwater "fast fill" licence in July 2026 — is the kind of long-filling site for which the biological stage matters most.*

Q17. *(7 marks)* **a.** *(2)* 11.4 ÷ 18.2 × 100 **(1)** = **62.6%**, which exceeds the 60% criterion, so the criterion is **met (1)**. The stated conclusion is required for the second mark; a bare percentage earns one. **b.** *(2)* **Not met:** soil organic carbon — 0.9 ÷ 3.4 × 100 = 26.5%, well below the 50% criterion; **natural recruits** — 0.2 per quadrat against a criterion of 1.0; and **bulk density** — 1.62 g cm^{-3} against a criterion of ≤ 1.40. (Groundcover at 71% just meets its 70% criterion, and richness is met from part a.) **(1)** The single mechanical failure that best explains two of them is **inadequate relief of compaction**: bulk density fails its own criterion directly, and a closed pore network prevents root penetration, infiltration and gas exchange, which is the most parsimonious explanation for near-zero recruitment. Thin or long-stockpiled topsoil is a plausible additional contributor to the low organic carbon **(1)**. **c.** *(3)* **Natural recruits** are individuals that germinated and survived on the site itself, from seed produced on site or arriving from nearby **(1)**. Their presence demonstrates four separate ecosystem functions simultaneously: planted individuals have reached reproductive maturity and are setting viable seed; pollinators and dispersers are present; the seedbed is physically and chemically habitable enough for germination; and seedlings can survive their first summer on the substrate as built. That is the definition of a self-sustaining trajectory, which is what the "sustainable" limb of the standard requires **(1)**. **Twelve-month survival of planted tubestock** measures something much narrower — the quality of the nursery stock, the planting technique and the establishment watering over a single season — and can be high on a site that will fail later, because tubestock can live on stored moisture in a shallow respread layer for one wet season before compaction and the absence of nitrogen and mycorrhizal inoculum take effect. A stand with 95% survival and no recruits is a garden, not an ecosystem, and releasing a bond on that figure transfers a predictable future failure to the public **(1)**.

Q18. *Model response (10 marks).*

The task and the standard. Rehabilitating a closed open-cut coal mine means returning the disturbed land to a **safe, stable and sustainable** (non-polluting) condition supporting an agreed post-extraction land use. The site presents a void tens of square kilometres in area and 100 m or more deep, steep **batters** cut at their working angle, overburden and interburden dumps, exposed coal, and a groundwater system drawn down over decades. The study design's binary — **mechanical** and **biological** processes — maps onto a division of labour: the mechanical work sets the physical and chemical envelope, and the biological processes are the only things that deliver self-sustaining function.

Mechanical processes, in sequence. *Decommissioning* comes first: plant is drained, purged and de-energised, and conveyors, boilers and stacks are demolished, with hazardous materials removed under their own controls before demolition. *Landform* is next. Batters are **reprofiled** — cut back, flattened to a designed slope (indicatively of the order of 1 in 3 or flatter, always from a site-specific geotechnical assessment), benched to break slope length, and buttressed at the toe — so the landform is stable under design flood, rainfall and seismic loading with no maintenance. Spoil placement is not indiscriminate: **potentially acid-forming (PAF)** strata are identified by **selective handling** and **encapsulated** within benign material beneath a cover system, ideally below the water table so oxygen is excluded, because acid generation once established continues for as long as sulfide, oxygen and water coexist and cannot be undone by later planting. Drainage — contour drains, rock chutes, sediment basins, armoured spillways, and in the Hazelwood project a watercourse reinstated to a more natural alignment — is constructed to convey design storms without concentrating flow on new ground. Exposed coal is covered, because brown coal self-heats: the Hazelwood mine fire began on 9 February 2014 from embers spotting into the open cut and burned for 45 days, and the Board of Inquiry found it likely both that deaths in the Latrobe Valley increased between February and June 2014 and that the fire contributed to some of that increase, estimating the total cost borne by the State, the community and the operator at more than $100 million.

Then the top two metres. Compaction from haulage and spreading is relieved by **deep ripping** along the contour, typically to 600–800 mm, after the last trafficking; without it, high bulk density prevents root penetration, infiltration and gas exchange. **Topsoil** stripped ahead of mining is respread at a design depth, typically 100–300 mm, over placed subsoil — and **direct return** within the same season is strongly preferred to stockpiling, because seed viability and the aerobic microbial and mycorrhizal populations decline in storage. Amendments are incorporated where the substrate is outside plant tolerance: lime for acidity, gypsum to stop **dispersive (sodic)** material slumping and sealing, organic amendment for carbon and water holding — with nitrogen fertiliser used sparingly, because heavy application reliably favours exotic grasses over native shrubs and trees. The surface is left deliberately rough to create **microsites** that trap seed and water. *Finally, water.* Where backfill material no longer exists, the accepted end landform is a **pit lake**: for Hazelwood, about **637 GL** to a full water body at +45 m AHD over a target 10–20 years; across all three Latrobe Valley voids up to about **2800 GL** to the crests plus about **15 GL per year** thereafter to offset evaporation — against a catchment whose mean annual availability has fallen from about 800 to about 600 GL per year since 1997 and is projected to reach about 467 GL per year by 2050 under a dry scenario. Filling water is dosed, aerated and settled to correct pH and precipitate iron and manganese.

Biological processes. What the mechanical work produces is a graded, ripped, limed mineral substrate — not soil. Respread topsoil supplies the **soil seed bank**, which is the cheapest and most complete source of local propagules and includes species no nursery grows; it also supplies the **soil microbial community** and **mycorrhizal fungal** inoculum, on which most Australian natives depend for phosphorus and water uptake on characteristically phosphorus-poor substrates. **Biological nitrogen fixation** by rhizobia in the nodules of legumes, chiefly *Acacia* species, is indispensable, because raw overburden contains essentially no nitrogen and nitrogen has no mineral parent material — it cannot be placed by machine, only fixed or imported indefinitely. **Decomposers and soil fauna** then accumulate **soil organic carbon**, rebuilding aggregate structure, infiltration and water-holding capacity over decades, and **biological soil crusts** of cyanobacteria, algae, lichens and mosses bind the surface between plants. Vegetation is established in stages: a short-lived **nurse crop** to stabilise the surface, then fast **pioneer and framework species** (frequently nitrogen-fixing) to create shade, litter and root channels, then slower long-lived species under that shelter — direct seeding at scale, tubestock for species that will not establish from broadcast seed. The aim is a **successional trajectory**, and the definitive test is **natural recruitment**, because a second generation germinating on site demonstrates reproductive maturity, pollinator presence, a habitable seedbed and seedling survival at once. Fauna return in response to structure, which is why coarse woody debris and rock are placed during earthworks. Biology also holds the chemistry: **sulfate-reducing bacteria** in anaerobic bioreactors or treatment wetlands oxidise organic carbon using sulfate, generating alkalinity and precipitating metals as sulfides; **phytostabilisation** immobilises contaminants and removes the erosion and infiltration pathways; and in a pit lake, once pH is corrected, added organic carbon and nutrients establish primary production, stratification and microbial sulfate reduction, so water quality is maintained biologically rather than by permanent dosing.

Why neither is sufficient alone. The mechanical processes are **necessary and never sufficient**. They can produce a safe and stable landform, but not a functioning one: a graded, ripped surface has no nitrogen, no seed bank, no symbionts and no organic carbon, so it supports no self-maintaining community, and every chemical outcome it achieves — neutral pH, acceptable metals — is achieved by dosing that must be funded forever. That fails the "sustainable" limb by definition. The biological processes are the **source of function and never possible alone**, because they can only run inside the envelope the mechanical work built: seed sown on a compacted surface cannot root; topsoil respread over near-surface PAF material dies from the roots down as acid moves upward; a lake filled without a water balance concentrates salts and leaves batters unsupported; and a slope at its working angle will erode or fail regardless of what is planted on it. The relationship is one-directional and it is the answer to the question: **mechanical processes set the physical and chemical envelope; biological processes are the only things that deliver self-sustaining function; and they can only operate inside that envelope.** Almost every documented rehabilitation failure is a sequencing or envelope error rather than a planting error — which is why the order (landform → drainage → subsoil → rip → topsoil → seed and plant → monitor against completion criteria) is itself examinable content.

Marking guide: up to 4 marks for mechanical processes, requiring at least four distinct processes each with a mechanism and a purpose, in a defensible sequence; up to 4 marks for biological processes, requiring at least four distinct processes with mechanisms, including one that is not simply "planting"; up to 2 marks for the necessary-but-not-sufficient argument run in ***both*** *directions with a concrete example of each failure. A response that describes only earthworks, or only revegetation, cannot exceed 5 marks. A response that lists activities without mechanisms cannot exceed 6.*

Q19. *Model response (10 marks).*

Assessment of the draft rehabilitation plan — Corravale Energy Pty Ltd. Element 1 is sound: decommissioning and removal of above-ground infrastructure is the correct first step, and clean concrete can be crushed and re-used as fill or road base. Four of the remaining five elements are inadequate, and the bond request cannot be supported.

Element 2 — batters left at their working angle, with a fence. Inadequate. Working batters are cut as steep as short-term stability and machinery permit; a rehabilitation batter must be stable under design flood, rainfall and seismic loading **with no maintenance, in the long term**. A fence controls access; it does nothing about slope failure, and it does not address the self-heating and fire risk of exposed brown coal — the process failure that produced the 45-day Hazelwood mine fire in February 2014. The plan omits **reprofiling**. Corravale should cut the batters back to a designed slope from a site-specific geotechnical assessment, bench them to break slope length, buttress the toes, and cover exposed coal with inert material.

Element 3 — 14-year-old stockpiled topsoil, 100 mm, straight onto shaped spoil. Inadequate on three counts. First, the plan omits **deep ripping**: haulage and spreading have raised bulk density so roots cannot penetrate and water cannot infiltrate, and ripping must follow the last trafficking and precede respread. Second, 14-year-old stockpiled topsoil has lost most of what makes topsoil valuable — seed viability declines with storage and the aerobic microbial and mycorrhizal populations collapse in the anaerobic interior of a deep pile — so it supplies texture but not a living community, and the site must be separately seeded and inoculated. Third, there is no statement that **potentially acid-forming material** has been identified and encapsulated; respreading topsoil over near-surface PAF spoil produces a cover that dies from the roots down as acid moves upward, and that error is not recoverable without re-excavation. Corravale should test and selectively place PAF material below a cover system, rip to 600–800 mm on the contour, respread to the approved design depth over placed subsoil, and supplement the aged stockpile with fresh topsoil or litter transfer as inoculum.

Element 4 — one exotic pasture grass plus high-rate nitrogen. Inadequate. This is a biological error with a mechanical cause. Heavy nitrogen on a bare substrate reliably favours fast exotic grasses over slower native shrubs and trees, so the community locks at exotic grassland: a single stratum, no shrub or ground-layer diversity, no fauna habitat, no litter diversity and no recruitment pathway. It also does nothing to build a nitrogen budget the site can live on, since applied nitrogen is a recurring input, whereas **biological nitrogen fixation** by rhizobia in *Acacia* nodules is a permanent one. Corravale should use a short-lived nurse crop for first-season surface stability, establish nitrogen-fixing pioneer and framework species, seed and plant all strata using local-provenance material appropriate to the substrate as built, and restrict fertiliser to a starter rate.

Element 5 — fill from rainfall and groundwater with no water balance, and treat "if problems arise". Inadequate. Void filling is a quantified hydrological problem: the comparable Hazelwood full pit water body needs about 637 GL over a target 10 to 20 years, and up to about 35 years in a worst case, in a catchment where mean annual availability has fallen from about 800 to about 600 GL per year since 1997 and is projected to fall to about 467 GL per year by 2050 under a dry scenario. Without a water balance, filling may take decades longer than assumed, during which batters remain without the lateral support the lake was to supply, coal stays exposed and salts concentrate in a shallow water body. Reactive treatment is also the wrong model for acid and metalliferous drainage, which is self-accelerating once bacterial catalysis takes hold. Corravale should complete a water balance identifying sources, rates and evaporation losses, plan pH correction and metals removal during filling, and then add organic carbon and nutrients to establish primary production, stratification and microbial sulfate reduction — so that water quality is held biologically instead of by permanent dosing.

Element 6 and the bond — should the bond be returned? No. Two things are wrong. Twelve-month survival of planted stock measures nursery quality, planting technique and establishment watering over one season; it does not measure ecosystem function, and tubestock can live a single wet season on stored moisture in a shallow respread layer before compaction and the absence of nitrogen and mycorrhizal inoculum take effect. The correct test is performance against quantified **completion criteria** measured against a **reference site** — species richness as a proportion of reference, perennial groundcover, soil organic carbon, bulk density and, decisively, the density of **natural recruits**, because a second generation germinating on site demonstrates reproductive maturity, pollinator presence, a habitable seedbed and seedling survival together. On this plan the landform is not stable, the fire risk is unresolved, the acid-forming material is unaddressed, the substrate is compacted and the community is a single exotic stratum, so the rehabilitation is not complete on any limb of the safe–stable–sustainable standard and **relinquishment** is not available. Releasing the bond would remove the only security the regulator holds that survives the company, and the Victorian Auditor-General's 2020 audit shows the consequence at scale: bonds at least $361 million short of estimated costs, which is the mechanism by which the **user pays principle** fails and the cost transfers to the public and to future generations. The bond should be retained, the plan resubmitted, and release considered only against completion criteria including recruitment.

Marking guide: up to 8 marks for four inadequate elements, 2 marks each — 1 for identifying the omitted or misapplied process with its mechanism, 1 for a specific and correct remedy. Up to 2 marks for the bond conclusion: 1 for rejecting 12-month survival in favour of completion criteria including natural recruitment, 1 for justifying retention against the safe–stable–sustainable standard or the consequence of a shortfall. A response that criticises elements without naming the underlying mechanical or biological process cannot exceed 5 marks; a response that returns the bond cannot exceed 7.

Chapter 13 Managing the impacts of human energy use — 13B Base load and peak load: matching supply to demand

Theory

What this dot point asks, and what it does not. The study design wants *the extent to which different energy sources can supply current and projected base and peak load energy needs, and how these can be met at individual and societal levels*. Read it as three tasks, because it is marked as three. The first is a **comparison across sources** — not a description of how each source works, which is 12A and 12B's territory and is assumed here, but a judgement about what each one can and cannot be relied on to do at a particular moment of the day. The second is the word **projected**: the answer for 2026 is not the answer for 2040, because demand is growing and changing shape while the generating fleet is being replaced. The third is the phrase **at individual and societal levels**, which is the limb students most often drop entirely. It asks what a household can do about the shape of demand, and what a state or a market can do, and it expects both. Nothing in this subtopic is about *reducing* total energy use or total emissions — that is 13C — and nothing in it is about whose values should prevail, which is 13D. This subtopic is about **timing**: getting supply and demand to match, instant by instant, because electricity is generated and consumed at the same moment.

Load, demand, and why electricity is a special case. Load is the electrical power being drawn by consumers at an instant, measured in megawatts (MW); **demand** is used interchangeably. Energy delivered over a period is power multiplied by time, in megawatt hours (MWh), gigawatt hours (GWh) or terawatt hours (TWh). The awkward fact that generates this entire dot point is that the electricity grid stores almost nothing. Coal can sit in a stockpile and gas in a pipeline, but once electricity is on the wires it must be consumed within a fraction of a second of being generated, and supply must therefore be matched to demand continuously, not on average. If the match fails, system frequency moves away from 50 Hz and equipment disconnects to protect itself. "We generated enough energy over the year" is not a defence, and that is why a source's **average** output is a poor measure of its usefulness.

Base load, peak load and the load curve. Plot demand against time over a day and the resulting **load curve** has a floor and a ceiling.

- **Base load** is the minimum level of demand that persists continuously across the period — the floor of the curve. It never goes away: refrigeration, water and sewage pumping, hospitals, street and security lighting, telecommunications, data centres and continuous industrial processes draw power at 3 am on a Sunday just as they do at 6 pm on a Tuesday.
- **Peak load** is the maximum demand reached in the period — the ceiling. It typically lasts tens of minutes to a few hours, and in Victoria it occurs on the summer evening of a heatwave, when air conditioning is running hard and rooftop solar output has fallen away.
- **Intermediate** or **shoulder load** is everything in between, and it is where most of the day sits.

Two ratios describe the shape, and both are examinable. The **peak-to-base ratio** is peak demand divided by base demand, and it measures how "peaky" the system is. The **load factor** is average demand divided by peak demand, usually as a percentage; a low load factor means expensive capacity sits idle most of the time.

The single most-corrected error in this topic. *Base load is a property of demand, not a type of power station.* The phrase "base load power station" is a shorthand for a station whose technical and economic characteristics suit running near-continuously at high output — and that is a statement about the station's minimum stable output, its ramp rate and its fuel cost, not a category of electricity. Electricity from a wind farm and electricity from a coal unit are identical on the wire. So the sentence "wind cannot provide base load power" is a category error as written: what is true is that wind cannot be *relied upon* to be generating at any nominated instant, which is a statement about **dispatchability**. Say that instead, and the mark is earned rather than lost.

Victoria's load curve, in real numbers. These four figures do more work than any amount of description, and they are worth learning as a set.

What it measures	Value	When	Source
All-time **maximum** operational demand, Victoria	**10,736 MW**	27 January 2026, extreme heat (exceeding the previous	AEMO, *Quarterly Energy Dynamics* Q1 2026

What it measures	Value	When	Source
		record set in January 2009)	
All-time **minimum** operational demand, Victoria	**1,287 MW**	27 December 2025, half-hour ending 1300 hrs — the middle of the day	AEMO, *Quarterly Energy Dynamics* Q4 2025
Winter maximum operational demand record, Victoria	**8,818 MW**	25 June 2025, cold and windy	AEMO, *Quarterly Energy Dynamics* Q2 2025
Previous all-time minimum, Victoria	1,504 MW	1 January 2025, a mild (22 °C) public holiday with high distributed PV output	AEMO, *Quarterly Energy Dynamics* Q1 2025

Figure 13B.1 plots the shape those four numbers describe, and sets the records themselves on one bar axis so the span between them is a length on the page. Panel (a) is a shape, not a dated record: its floor and ceiling are scaled to the two real Victorian extremes, and everything read off it — the peak-to-base ratio, the load factor, the hour at which each occurs — is computed from the plotted series.

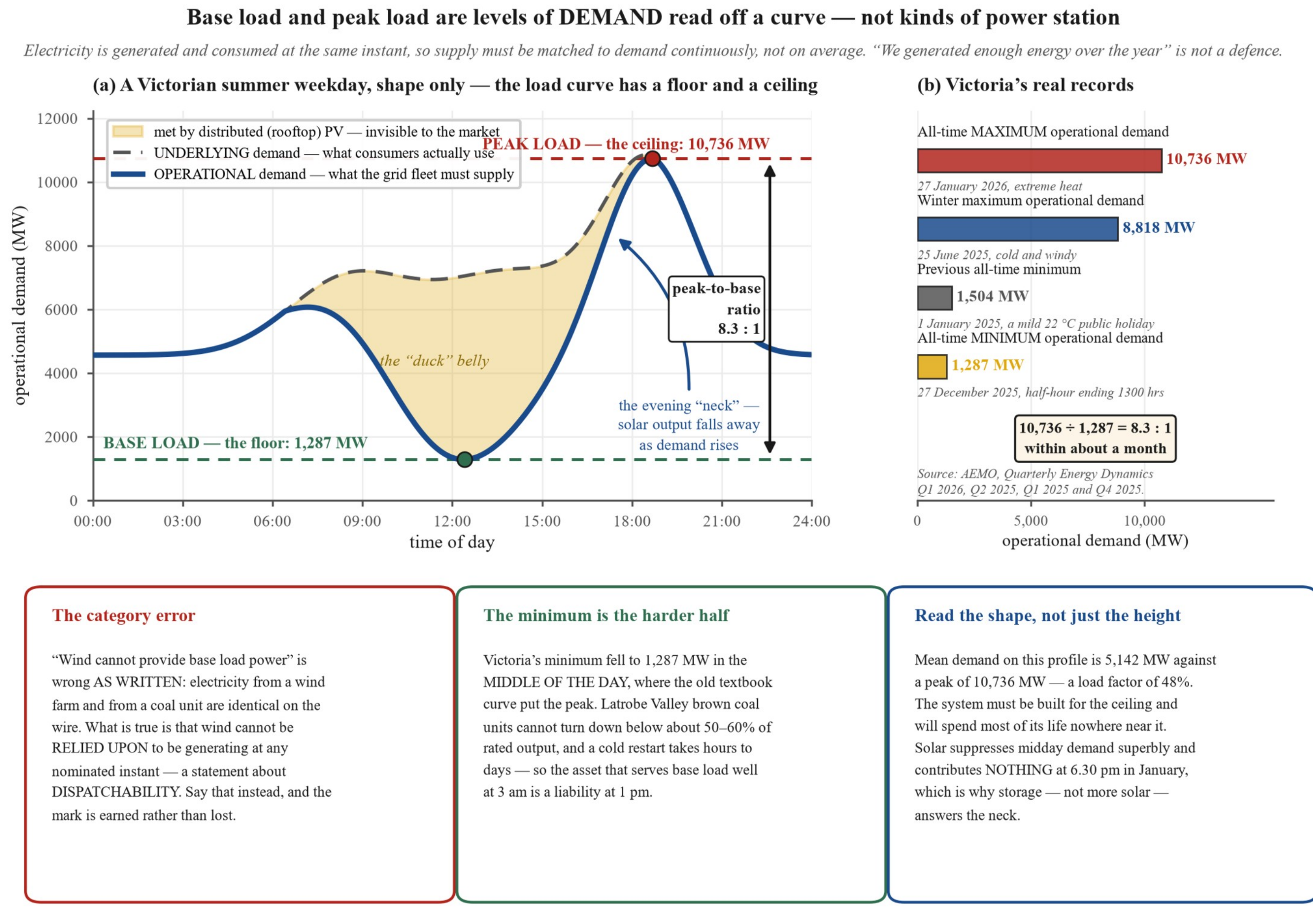

Figure 13B.1 (a) Base load is the **floor** of the operational-demand curve and peak load its **ceiling**; the shaded wedge between operational and underlying demand is the part met by rooftop PV behind the meter, which hollows the middle of the day into the duck's belly and leaves the steep evening neck. (b) Victoria's four real operational-demand records, to scale.

Set the first two beside each other. Within about a month, the Victorian grid had to serve 1,287 MW and then 10,736 MW — a ratio of roughly **8.3 to 1**. The system must be built for the ceiling, will spend most of its life nowhere near it, and must now also cope with a floor that is falling year on year. The fourth row shows how fast: the record the 1,287 MW replaced had itself been set less than twelve months earlier. Note as well that the minimum occurred *in the middle of the day in summer*, which is where the old textbook load curve put the peak.

Operational versus underlying demand — and the duck curve. The distinction explains the whole of the paragraph above. **Underlying demand** is what consumers actually use. **Operational demand** is the part of it that the grid-connected generating fleet has to supply — that is, underlying demand minus the output of **distributed photovoltaics (PV)**, the rooftop solar that sits behind the meter and is invisible to the market as generation. As rooftop PV has grown, midday operational demand has collapsed while underlying demand has not, hollowing out the middle of the curve into the shape known as the **duck curve**: a midday belly, then a steep evening neck as the sun sets and demand rises together.

This makes **minimum demand** a genuine engineering problem, not merely an economic one, and it is the modern half of this dot point.

- Large thermal units cannot turn down indefinitely. Each has a **minimum stable generation** level — for Latrobe Valley brown coal units, of the order of 50–60% of rated output — below which combustion and steam conditions cannot be held and the unit must be shut down entirely. A shutdown is not a small decision: a cold start on brown coal takes many hours to a couple of days.
- Very low operational demand means very little **synchronous** generation online, and synchronous machines are what supply the grid's **inertia** and system strength. Without them, frequency and voltage move faster after a disturbance and are harder to control.
- Voltage tends to rise on distribution feeders exporting large amounts of solar, and distributed PV is neither centrally visible nor, historically, centrally controllable — which is why AEMO and the distribution businesses have acquired emergency "backstop" powers to curtail distributed PV as a last resort in Victoria and elsewhere.

So the asset that serves base load well at 3 am is a liability at 1 pm. That tension is the heart of the transition, and it is examinable in exactly those terms.

What a source needs in order to serve base load, and what it needs to serve peak load. Six characteristics do all the work. Learn them as a checklist and any source can be assessed on the spot. The first two are 12B's — it classifies every source as **variable** or **dispatchable** and defines the **capacity factor** as energy generated ÷ (nameplate capacity × hours in the period); 12E separates capacity factor from *efficiency*, which is a different quantity again. They are carried here because this subtopic does the thing 12B hands over: matching those properties against a real day's demand.

Characteristic	What it means	Why it decides base or peak suitability
Dispatchability (12B)	Whether output can be raised or lowered on instruction, to a level the operator chooses	The single most important property. A **dispatchable** source can be committed in advance; a **variable** source such as wind or solar can be curtailed downwards but cannot be turned *up* on demand
Capacity factor (12B, 12E)	Energy actually generated over a period ÷ energy if the plant ran at rated power for the whole period	High capacity factor suits base load, because base load must be served every hour. A peaking plant may have a capacity factor of 1–5% by design
Ramp rate	How fast output can change, in MW per minute	Peak service needs fast ramping. Brown coal units manage of the order of 1–3 MW per minute per unit; hydro can go from standstill to full output in about 90 seconds; a grid battery responds in under a second
Minimum stable generation	The lowest output a unit can hold without shutting down	Decides whether a plant can stay online through a midday minimum, or must shut down and face a long

Characteristic	What it means	Why it decides base or peak suitability
		restart
Start-up time	Cold start to useful output	Brown coal: many hours to about two days. Combined-cycle gas: about one to three hours. Open-cycle gas: roughly 5–15 minutes. Hydro and batteries: seconds or less
Short-run marginal cost	Fuel plus variable operating cost per MWh	Sets the **merit order** — the market dispatches cheapest-to-run first. Low marginal cost plant runs continuously; expensive plant runs only when prices are high, i.e. at the peak

Two further terms complete the vocabulary. **Firming** — 12B's term for pairing a variable source with storage, a dispatchable plant or demand management so the combination can be relied on — is what the second half of this subtopic is about, since firming is only meaningful against a stated hour of demand. **Storage duration** is the term this subtopic adds: a store's energy capacity divided by its power rating, in hours, and the single number that decides whether a battery can cover an evening peak or merely the first part of it.

Source by source: the extent to which each can supply base and peak load. This table is the core of the dot point. It covers every source the study design names in 12A and 12B, judged in the Australian context.

Source	Dispatchable?	Typical capacity factor	Base load	Peak load	Judgement in the Australian context
Coal (black and Latrobe Valley brown)	Yes, but slowly and within a narrow band	60–80% historically, falling	**Well suited**	**Poorly suited**	Low fuel cost and high availability made it the base load fleet. Slow ramping, high minimum stable generation and long restarts make it useless for peaks and increasingly awkward at midday minimum demand
Natural gas — combined cycle (CCGT)	Yes	30–60%	Suited	Partly suited	Efficient and flexible enough for intermediate load; start-up of one to three hours is too slow for a sudden peak
Natural gas — open cycle (OCGT)	Yes, very fast	1–10% by design	Poorly suited	**Very well suited**	The classic **peaking plant**: starts in minutes, high fuel cost per MWh, deliberately idle most of the year.

Source	Dispatchable?	Typical capacity factor	Base load	Peak load	Judgement in the Australian context
					Bought for its capacity, not its energy
Coal seam gas	As for natural gas	—	As for gas	As for gas	A *fuel source*, not a plant type. Once in the pipeline it behaves exactly as natural gas; suitability is set by the turbine, not the gas field
Oil (distillate)	Yes, very fast	<1%	Not used	Emergency and remote peaking	Fuel cost is prohibitive. Retained for reciprocating engines and some remote or emergency duty
Nuclear	Yes, but slowly and uneconomically	80–90%	**Very well suited**	Poorly suited	Technically the strongest base load performer of all. In Australia it is **prohibited by law** (see below), and the lead time to build would place first output well beyond the closure dates of the existing coal fleet
Hydro-electric (storage)	Yes, fastest of the conventional plant	10–30% in the NEM	Possible but not how it is used	**Very well suited**	Standstill to full output in about 90 seconds. Australian hydro is **energy-limited** by rainfall and storage volume, so it is deployed as a peaking and firming resource rather than run flat out
Hydro-electric (run-of-river)	Barely	Varies with flow	Weakly suited	Poorly suited	Output follows the river, not the operator
Wind	No — curtailable downwards only	30–40% onshore; 45–55% offshore	Contributes **energy**, cannot be committed	Not reliably	Cheap energy with no fuel cost, so it sits at the bottom of the merit order and

Source	Dispatchable?	Typical capacity factor	Base load	Peak load	Judgement in the Australian context
					displaces coal energy. Requires firming to serve a nominated hour. Geographic spread and offshore siting raise reliability, and Victorian offshore wind blows more strongly in winter, when solar is weakest
Solar PV	No — curtailable downwards only	15–25% utility-scale in Victoria	No	**No — output is zero at the evening peak**	The decisive fact of this dot point. Solar suppresses *midday* demand superbly and contributes nothing at 6.30 pm in January. Without storage it moves the problem rather than solving it
Solar thermal with molten-salt storage	Yes, within its storage duration	30–50%	Partly suited	Suited	Dispatchable for a stated number of hours after sunset. No commercial plant operates in Australia
Biomass and biofuels	Yes	40–80% where fuel is secure	Suited at small scale	Suited at small scale	Landfill gas, bagasse and wood residue behave like small thermal plant. Limited by fuel supply, land and transport, so the contribution is real but modest
Geothermal	Yes	70–90% internationally	**Technically well suited**	Partly suited	Overseas, an excellent base load source. Australia's resource is hot dry rock, deep and far from load centres; there is no commercial

Source	Dispatchable?	Typical capacity factor	Base load	Peak load	Judgement in the Australian context
					geothermal generation here, so its practical contribution is currently nil
Tidal	No, but highly **predictable**	20–35%	No	Only when the tide coincides	Predictability is not dispatchability. The tidal cycle advances about 50 minutes a day, so peak output drifts out of step with the evening demand peak. No commercial generation in Australia; the resource is concentrated in the Kimberley

Storage is not a source, and this is where marks are won. Batteries and pumped hydro generate no energy; they move it in time. That makes them the direct answer to a "matching supply to demand" question, and it makes the distinction between **power** (MW) and **energy** (MWh) the most important arithmetic in the subtopic. A store rated 300 MW / 450 MWh can deliver 300 MW for 1.5 hours and then it is empty. Sizing storage for a peak therefore requires the **area** under the peak in MWh, not just its **height** in MW. Round-trip losses must also be paid: at, say, 88% round-trip efficiency, delivering 1,000 MWh requires about 1,136 MWh to be charged in.

Store	Power	Energy	Duration	Role
Typical grid-scale lithium battery	50–500 MW	—	**1–4 hours**	Evening peak, frequency control, fast response; grid-forming inverters can also supply synthetic inertia
Snowy 2.0 pumped hydro (under construction)	**2,200 MW**	**350,000 MWh**	about **159 hours**	Multi-day and seasonal shifting — the class of duration batteries cannot reach
Household battery	5 kW	10 kWh	2 hours	Shifts the household's own midday solar into its own evening peak

Pumped hydro is the same physics as hydro-electricity run backwards: surplus electricity pumps water uphill, and it is released through turbines when demand is high. Snowy 2.0 — 2,200 MW and 350,000 MWh, revised cost about $12 billion, targeting commercial operation of all units in December 2028 — is under construction in New South Wales and matters to Victoria because the interconnected market shares it.

Current and projected needs: the numbers that make "projected" answerable. AEMO publishes the **Integrated System Plan (ISP)** every two years as the least-cost roadmap for the **National Electricity Market (NEM)** to 2050. The final **2026 ISP** was published on **25 June 2026**, and its headline figures are the ones to quote.

Projection to 2050 (AEMO, *2026 Integrated System Plan*, 25 June 2026)	Figure
NEM underlying electricity consumption, 2026 → 2050	**205 TWh → 390 TWh** (close to double)
Grid-scale wind and solar required	about **120 GW**
Shallow and medium grid-scale storage required (batteries the primary source)	**35 GW**
Deep storage required, delivered by new pumped hydro	**5 GW**, on top of the existing **7 GW** of hydro
Grid-scale storage and hydro, all types together	nearly **50 GW**
Flexible gas required	**17 GW**
Rooftop and other small-scale solar expected	**87 GW**
Household and small business batteries expected	**35 GW**
National renewable share	**82% by 2030**, **98% by 2050**
Coal	two-thirds of the remaining fleet could retire by **2035**; all withdrawn by **2049**

Three features of that table answer "projected" precisely. First, demand is **growing**, driven by electrification of transport, industry shifting off gas, and data centre construction. Second, demand is **changing shape** — electric vehicles and electrified heating add load at different hours than the loads they replace, and in Victoria the winter record of 8,818 MW in June 2025 shows a winter peak that will grow as homes leave gas. Since 1 January 2024, Victorian planning provisions have required new homes needing a planning permit to be all-electric, which moves a winter gas peak onto the electricity system over time. Third, note the size of the two consumer rows: 87 GW of rooftop solar and 35 GW of home batteries are *larger* than much of the grid-scale fleet. Individual decisions are not a footnote to this dot point; they are a substantial part of the projected answer. Two cautions when quoting the table: the 35 GW of household and small business batteries is a separate quantity from the 35 GW of grid-scale shallow and medium storage — the two figures coincide by accident — and the 5 GW of deep storage is *new* pumped hydro, additional to the 7 GW of hydro the NEM already has.

For Victoria specifically, the legislated framework sets the pace.

- The *Renewable Energy (Jobs and Investment) Act 2017* (Vic) carries the **Victorian Renewable Energy Target**: **65% by 2030** and **95% by 2035**.
- The *Climate Change and Energy Legislation Amendment (Renewable Energy and Storage Targets) Act 2024* (Vic), which received Royal Assent on 26 March 2024, inserted **energy storage targets of at least 2.6 GW by 2030 and 6.3 GW by 2035**, and **offshore wind targets of at least 2 GW by 2032, 4 GW by 2035 and 9 GW by 2040**.
- The *Climate Action Act 2017* (Vic) — renamed from the *Climate Change Act 2017* by that same 2024 amending Act, so older sources cite the former name — sets net zero emissions by **2045**, with interim targets of 45–50% below 2005 levels by 2030 and 75–80% by 2035.
- Victoria's remaining coal capacity is closing inside that window. **Yallourn W** is to retire by **mid-2028**, ahead of its licence to 2032, with EnergyAustralia building a 350 MW four-hour (1,400 MWh) battery as part of the arrangement. AGL announced in 2022 that **Loy Yang A** would close in **2035**. Alinta's **Loy Yang B** has a stated closure in the 2040s, but a 95% renewable target for 2035 implies all three exit by then.

How the match is enforced, and by whom. Reliability is not left to goodwill. The **National Electricity Rules**, made by the Australian Energy Market Commission under the National Electricity Law and applied in this State by the *National Electricity (Victoria) Act 2005* (Vic), set a **reliability standard** of a maximum of **0.002% expected unserved energy** in a region in a financial year — that is, 99.998% of forecast demand met, equivalent to roughly ten and a half minutes of supply interruption per customer per year. **AEMO** operates the market and the power system against that standard; the **Australian Energy Regulator** enforces the rules. Commonwealth policy adds the **Capacity Investment Scheme**, which underwrites revenue for new capacity and was expanded on 29 July 2025 to target **40**

GW by 2030 — 26 GW of renewable generation and **14 GW of dispatchable capacity**, up from 23 GW and 9 GW as originally announced. The dispatchable limb of that scheme exists precisely because energy alone does not keep the lights on at 6 pm.

Nuclear: technically apt, legally unavailable. Because nuclear is the strongest base load performer on the checklist, students reasonably propose it, and the answer must be legally correct rather than merely sceptical. Nuclear power generation is prohibited in Australia by three separate instruments, and naming them earns marks:

- the *Australian Radiation Protection and Nuclear Safety Act 1998* (Cth), **s 10**, which prevents the regulator from licensing a nuclear power plant, an enrichment plant, a fuel fabrication plant or a reprocessing facility;
- the *Environment Protection and Biodiversity Conservation Act 1999* (Cth), **s 140A**, which prohibits the Commonwealth Environment Minister from approving such an action; and
- in this State, the *Nuclear Activities (Prohibitions) Act 1983* (Vic), **s 8**.

A complete answer therefore separates the technical claim from the legal one: nuclear *would* serve base load well; it *cannot presently be built* in Victoria without repeal of Commonwealth and State legislation, and the construction lead time would in any case place first generation well after Yallourn W and Loy Yang A have closed.

Meeting the need at the individual level. The study design asks for this explicitly, and it rewards quantified, concrete measures rather than "people should use less power" — which belongs to 13C in any case. Each measure below changes the *shape* of the load curve.

Individual measure	What it does to the curve	Scale
Rooftop PV	Cuts daytime operational demand; deepens the midday minimum; does nothing for the evening peak	A 6.6 kW system in Melbourne yields about 24 kWh a day averaged over the year
Home battery	Stores the midday surplus and discharges it into the household's evening peak — **shifts** rather than reduces	A 10 kWh / 5 kW unit covers about two hours of evening load; AEMO projects 35 GW of these nationally by 2050
Smart electric-vehicle charging	An EV charging at 7 kW at 6 pm is among the largest single additions to the peak; the same charge overnight or at midday fills a trough	A 60 kWh EV battery holds roughly six days of an average household's electricity
Vehicle-to-grid (V2G)	Turns the parked car into a household or grid battery during the peak	Bidirectional chargers are now being connected under revised Australian standards
Controlled load (off-peak electric hot water)	The original demand-shifting technology: a thermal store filled in the overnight trough, and increasingly retimed to the solar middle of the day	Typically 1–3 kW for several hours per household
Time-of-use and demand tariffs	Price signals that make shifting worthwhile. Victoria's mandated smart meter rollout (2009–2013) is near-universal, so time-based tariffs are genuinely available here	Peak rates can be several times off-peak rates
Efficiency and building fabric	Insulation, draught sealing and shading cut the peak as well as the total; a thermostat at 24–25 °C instead of 20 °C markedly reduces peak draw on a 40 °C day	Reduces both MW and MWh
Aggregation into a virtual power plant (VPP)	Thousands of household batteries and controlled loads orchestrated as one dispatchable fleet — the bridge	Individually trivial, collectively gigawatt-scale

Individual measure	What it does to the curve	Scale
	from the individual to the societal level	

Meeting the need at the societal level. These are the measures a state, a market or a network business takes, and the strongest answers pair each with the characteristic from the checklist that it supplies.

- **Grid-scale batteries** — fast, precise, ideal for the evening neck of the duck curve, and with grid-forming inverters able to supply synthetic inertia. Duration is the limit: today's fleet is mostly one to four hours, and the 2026 ISP's 35 GW of shallow and medium storage extends that only as far as twelve. Victoria's legislated storage targets of 2.6 GW by 2030 and 6.3 GW by 2035 are the largest in Australia.
- **Pumped hydro** — the only technology at scale that shifts energy across days rather than hours. The ISP calls for 5 GW of new deep storage from pumped hydro on top of the NEM's existing 7 GW of hydro; Snowy 2.0's 350,000 MWh is roughly 159 hours at full output.
- **Flexible gas** — 17 GW of it in the 2026 ISP by 2050, running few hours a year. It is bought as **insurance**: high capacity value, low energy share, and therefore a small emissions contribution despite a large capacity number. This distinction between energy and capacity is exactly what a good answer shows.
- **Transmission, interconnection and renewable energy zones** — geographic spread smooths wind output, because weather is correlated over hundreds of kilometres but not thousands, and interconnectors let one region's surplus serve another's peak. Building wires is a supply-matching measure.
- **Demand response** — reducing demand is operationally equivalent to increasing supply. The **Wholesale Demand Response Mechanism**, in force under the National Electricity Rules since 24 October 2021, lets large consumers bid demand reductions into the market as if they were generators; AEMO's **Reliability and Emergency Reserve Trader (RERT)** contracts emergency reserves as a last resort; and heavy industry has long sold **interruptible load**, since an aluminium smelter that pauses for an hour releases hundreds of megawatts instantly.
- **Diversity of source and of timing** — Victorian offshore wind is strongest in winter, when solar is weakest and the winter peak is growing. Complementary profiles reduce the amount of firming needed, which is why a *mix* answers this dot point better than any single source.

Boundaries with the neighbouring subtopics. What each source *is*, how it converts energy and what its impacts are belong to 12A and 12B; 12B classifies each as variable or dispatchable and then states expressly that matching those characteristics against a day's actual demand is this subtopic's work. That is the join. Rehabilitating the sites these fuels came from is 13A. The four options for a sustainable energy future — improving resource efficiency, improving conversion device efficiency, replacing fossil fuels, and reducing personal consumption — are 13C, and the test is direction: if a measure changes *when* energy is used, it is 13B; if it changes *how much* is used or emitted, it is 13C. Stakeholder values, regulatory tensions and the treatment of new technologies in decision-making are 13D. Peak oil is 12D, and is a different idea entirely: **peak oil** is a maximum in the rate of *extraction of a resource over decades*, while **peak load** is a maximum in the rate of *electricity consumption within a day*. Confusing the two is a reported trap.

Where students lose marks.

- Treating "base load" as a kind of power station rather than a level of demand, and so writing that solar "produces peak load electricity".
- Saying a source is "unreliable" when the examinable word is **non-dispatchable**, or "reliable" when the point is **dispatchable**.
- Answering with capacity factor alone. A high capacity factor does not make a plant able to meet a peak, and a low one does not make it useless — an open-cycle gas turbine is bought *because* it will sit idle.
- Confusing MW with MWh, and so claiming a 300 MW battery "replaces" a 300 MW coal unit without asking for how many hours.
- Forgetting that solar output is zero at the summer evening peak.
- Ignoring the **minimum** demand problem and discussing only the peak. Since 2020 the falling floor has been the harder half of the Victorian problem.
- Proposing nuclear or geothermal without the Australian qualifier — the legal prohibition for nuclear, and the absence of any commercial resource development for geothermal.

- Dropping the **individual and societal levels** limb, or offering "turn off lights" for the individual level when the question is about matching supply to demand in time.
- Quoting no numbers. This dot point has excellent real figures attached to it; an answer without any is capped low.
- Confusing peak load with peak oil.

Worked examples

Example 1 — scaffolded

Quenmara Grid Analytics Pty Ltd publishes the following three-hourly summary for the Tharnleigh supply region on a mild spring weekday. Operational demand is the demand met by grid-connected generation; distributed PV output is the rooftop solar generating behind the meter at the same time.

Time	Operational demand (MW)	Distributed PV output (MW)
00:00	420	0
03:00	380	0
06:00	460	10
09:00	520	180
12:00	300	400
15:00	480	190
18:00	900	15
21:00	640	0

a. State the base load and the peak load in operational demand, and calculate the peak-to-base ratio. (3 marks)

b. Calculate the mean operational demand and hence the load factor for the day. (3 marks)

c. Estimate the total electrical energy supplied by grid-connected generation over the 24 hours, in GWh. (2 marks)

d. Identify the time of minimum *underlying* demand, and explain why it differs from the time of minimum *operational* demand. (3 marks)

Step 1 — answer a. Read the floor and the ceiling straight off the operational demand column. The minimum is **300 MW** at 12:00, so base load = 300 MW; the maximum is **900 MW** at 18:00, so peak load = 900 MW. Peak-to-base ratio = 900 / 300 = **3.0** (or 3 : 1). A ratio is dimensionless — do not attach MW to it.

Step 2 — answer b. Mean = sum ÷ number of readings. Sum = 420 + 380 + 460 + 520 + 300 + 480 + 900 + 640 = 4,100 MW. Mean = 4,100 / 8 = **512.5 MW**. Load factor = mean ÷ peak = 512.5 / 900 = 0.569 = **56.9%**.

Step 3 — answer c. Energy = mean power × time = 512.5 MW × 24 h = 12,300 MWh = **12.3 GWh**. The readings are evenly spaced, so the mean of the eight samples is a fair estimate of the average power across the day. State the assumption: demand is taken to vary smoothly between samples.

Step 4 — answer d. Underlying demand = operational demand + distributed PV output:

Time	00:00	03:00	06:00	09:00	12:00	15:00	18:00	21:00
Underlying demand (MW)	420	380	470	700	700	670	915	640

Minimum underlying demand is **380 MW at 03:00**, but minimum operational demand is at 12:00. The reason is that rooftop PV is netted off before the market sees the load: at 12:00, 400 MW of the 700 MW that consumers were actually using was supplied behind the meter, leaving only 300 MW for grid-connected generation. So consumers used *most* at midday and *least* overnight, while the grid was asked for least at midday. This is the duck curve, and it is why the traditional overnight trough is no longer the operational minimum.

Example 2 — scaffolded

Quenmara Grid Analytics Pty Ltd is assessing options for the Tharnleigh region's evening peak. A 200 MW wind farm in the region generated 630,000 MWh over the past year. The regional evening peak rises above 600 MW for five hours. The peak reaches 900 MW, and the energy required above the 600 MW line is 1,200 MWh. A grid battery is proposed with a round-trip efficiency of 88%.

a. Calculate the wind farm's capacity factor, as a percentage. (2 marks)

b. Determine the minimum power rating and the minimum energy capacity a battery must have to cover the whole of the peak above 600 MW, and state the storage duration this implies. (3 marks)

c. A supplier offers a 300 MW / 600 MWh battery. Evaluate whether it meets the requirement. (2 marks)

d. Calculate the energy that must be charged into the battery each day to deliver 1,200 MWh, and state where that energy would best come from. (3 marks)

Step 1 — answer a. Capacity factor = actual energy ÷ maximum possible energy. Maximum possible = 200 MW × 8,760 h = 1,752,000 MWh. Capacity factor = 630,000 / 1,752,000 = 0.3596 = **36.0%**. This sits in the normal onshore range of 30–40%.

Step 2 — answer b. Two separate requirements, and both must be met. Power: the battery must supply the *height* above the line, 900 − 600 = **300 MW**. Energy: it must supply the *area* above the line, **1,200 MWh**. Duration = energy ÷ power = 1,200 / 300 = **4 hours**.

Step 3 — answer c. The power rating is adequate: 300 MW is exactly what the peak height requires. The energy capacity is **not**: 600 MWh is half of the 1,200 MWh needed, giving a duration of 600 / 300 = 2 hours against a five-hour peak. The battery would meet the highest part of the peak and then empty, leaving the later hours unserved. This is the MW-versus-MWh error, and stating both numbers is what earns the marks.

Step 4 — answer d. Round-trip efficiency means only 88% of what goes in comes out. Energy charged = 1,200 / 0.88 = **1,363.6 MWh**, about 1,364 MWh. It should be charged in the middle of the day, from the surplus solar generation that is depressing operational demand to its minimum at that time. That is the point of storage in this system: it takes energy from the hour of lowest value and returns it in the hour of highest need, converting a midday surplus problem and an evening deficit problem into one solution.

Example 3 — unscaffolded

On 27 December 2025, Victoria's operational demand fell to a record low of 1,287 MW. On 27 January 2026, during extreme heat, it reached a record high of 10,736 MW.

Explain why the record *low* presents a problem for the operation of Victoria's electricity system, and why that problem is made harder rather than easier by the need to also serve the record high. (6 marks)

Solution. The two records are a month apart and differ by a factor of about 8.3, and the difficulty is that the same physical fleet must handle both.

The record low is a problem for three connected reasons. First, thermal plant cannot turn down without limit. Each Latrobe Valley brown coal unit has a minimum stable generation level of the order of 50–60% of its rated output, below which it cannot hold combustion and steam conditions and must shut down; a cold restart then takes many hours to about two days. At 1,287 MW of operational demand there is simply not enough room in the market for the units that were built to run continuously. Second, low operational demand means few **synchronous** machines online, and it is synchronous machines that provide the system's inertia and strength. With less of both, frequency and voltage move faster and further after a fault and are harder to control, so a low-demand period is a *system security* problem, not only an economic one. Third, the low was not caused by consumers using little energy — underlying demand was ordinary for a summer's day — but by more than enough distributed PV to supply most of it. Rooftop PV is behind the meter, so it is largely invisible to the market operator and, historically, not centrally controllable, which is why emergency backstop powers to curtail distributed PV have been introduced.

The peak makes this harder, not easier, because the two requirements pull in opposite directions. Serving 10,736 MW requires a large fleet of capacity to exist. Serving 1,287 MW requires most of that fleet to be switched off or turned down for hours in the middle of the day, and then brought back for the evening. Plant that is good at one is bad at the other: a coal unit has the availability for the peak but neither the ramp rate nor the turn-down for the daily cycle, whereas the solar generation that creates the midday minimum contributes nothing at all at 6.30 pm on a heatwave evening, when the peak actually occurs. Between the midday minimum and the evening peak the system must therefore ramp by many thousands of megawatts within a few hours, every day. That daily ramp — not the annual total of energy — is what the fleet now has to be designed for, and it is why fast, dispatchable, energy-shifting resources such as batteries, pumped hydro, hydro and open-cycle gas have become the valuable assets, and why inflexible continuous plant has become progressively harder to operate profitably.

Example 4 — unscaffolded

A submission to a Victorian parliamentary inquiry argues: *"Wind and solar cannot provide base load power. Victoria's brown coal stations run 24 hours a day and are the only thing standing between us and blackouts. Closing Yallourn W in 2028 and Loy Yang A in 2035 is therefore reckless, and the 95% renewable target should be abandoned."*

Evaluate this argument. (8 marks)

Solution. The submission contains one correct technical observation, one category error, and a conclusion that does not follow from either.

What is correct. Wind and solar are **non-dispatchable**: their output is set by the weather, they can be curtailed downwards but cannot be turned up on instruction, and solar output is zero at the time of Victoria's summer evening peak. Onshore wind capacity factors of 30–40% and Victorian utility solar factors of 15–25% mean that neither can be committed to deliver a nominated megawatt figure in a nominated hour. Any credible plan must answer that, and the submission is right to demand an answer.

The category error. "Base load power" is not a product that some generators make and others do not. Base load is the *minimum level of demand* that persists continuously; electricity from a wind farm and from a coal unit are indistinguishable on the wire. The properties the submission is reaching for are dispatchability, ramp rate, minimum stable generation and storage duration — and once the argument is restated in those terms, it stops supporting its own conclusion, because those properties can be supplied by things other than coal. Hydro reaches full output from standstill in about 90 seconds; open-cycle gas starts in 5–15 minutes; a grid battery responds in under a second; Snowy 2.0 will offer 2,200 MW with 350,000 MWh behind it, about 159 hours at full output.

Where the argument is factually weakest. The claim that coal is what stands between Victoria and blackouts is the reverse of the current operational difficulty. Brown coal's high minimum stable generation and slow ramping make it poorly suited to a system whose operational demand now falls to 1,287 MW in the middle of the day and rises to 10,736 MW on a heatwave evening. Coal cannot follow that daily ramp, and it cannot serve the peak: peaks are met by hydro, gas turbines and batteries, not by base load plant. The submission also treats closure dates as though they were arbitrary. Yallourn W is being retired by its owner by mid-2028, ahead of its licence to 2032, on commercial grounds, and Loy Yang A's 2035 date was announced by AGL in 2022. An ageing fleet does not become more reliable by being told to stay; unplanned outages of old units are themselves a reliability risk.

What a complete answer requires instead. Reliability is already a legal obligation, not an aspiration: the National Electricity Rules set a reliability standard of a maximum 0.002% expected unserved energy per region per year. Meeting it as coal exits is the express purpose of the firming build-out — 35 GW of shallow and medium grid-scale storage, 5 GW of new deep storage from pumped hydro and 17 GW of flexible gas by 2050 in AEMO's 2026 Integrated System Plan, Victoria's legislated storage targets of 2.6 GW by 2030 and 6.3 GW by 2035, and the Commonwealth's Capacity Investment Scheme, expanded in July 2025 to underwrite 40 GW including 14 GW of dispatchable capacity. Diversity does further work: Victorian offshore wind, legislated at 2 GW by 2032 and 9 GW by 2040, blows most strongly in winter, when solar is weakest and the growing winter peak — a record 8,818 MW in June 2025 — occurs. Demand-side measures count as well, since a megawatt not consumed at 6 pm is worth a megawatt generated.

Judgement. The submission correctly identifies the firming problem and then misdescribes it as a coal problem. Its conclusion is unsupported: what the analysis actually establishes is that closing coal requires dispatchable capacity, storage duration, transmission and demand response to be built to schedule — an argument for delivering the replacement portfolio on time, not for abandoning the target. The one legitimate residual concern is **sequencing risk**:

if storage, transmission and firming are delayed while the coal units retire on schedule, reliability is genuinely exposed. That is a case for monitoring delivery against the 2030 and 2035 milestones, which is what the legislated targets and the ISP's biennial revision exist to do.

Practice questions

Scaffolded

Q1. Define the term *base load*. (1 mark)

Q2. Distinguish between base load and peak load, referring to both the level of demand and how long it lasts. (2 marks)

Q3. Explain why the expression "base load power station" can be misleading, and state what property of the station it is actually describing. (2 marks)

Q4. Complete the table. (4 marks)

Source	Dispatchable? (yes/no)	Best suited to base load, peak load, or neither
Latrobe Valley brown coal		
Open-cycle gas turbine		
Utility-scale solar PV		
Grid-scale battery		

Q5. Define *dispatchability*, and name one dispatchable and one non-dispatchable energy source from the study design's lists. (2 marks)

Q6. Explain what is meant by *capacity factor*, *ramp rate* and *minimum stable generation*. (3 marks)

Q7. A wind farm rated at 150 MW generated 460,000 MWh in a year. Calculate its capacity factor as a percentage. Show your working. (2 marks)

Q8. Quenmara Grid Analytics Pty Ltd reports that a regional network had a minimum demand of 250 MW, a peak demand of 1,000 MW and a mean demand of 540 MW across a day.

Calculate the peak-to-base ratio and the load factor, and state what a low load factor implies for the cost of supplying that network. (3 marks)

Q9. Explain why utility-scale solar PV cannot serve Victoria's summer evening peak, and describe two ways its contribution to meeting that peak can be increased. (4 marks)

Q10. A regional evening peak rises above 500 MW for four hours. The peak reaches 800 MW, and the energy required above the 500 MW line is 900 MWh. A battery with a round-trip efficiency of 90% is proposed.

a. Determine the minimum power rating and minimum energy capacity the battery requires. (2 marks)

b. Calculate the storage duration this implies, and state whether a 300 MW / 600 MWh battery would be sufficient. (2 marks)

c. Calculate the energy that must be charged into the battery to deliver 900 MWh. (1 mark)

Q11. On 27 December 2025 Victoria's operational demand fell to a record 1,287 MW, while distributed PV was supplying most of what consumers were actually using.

a. Distinguish between *operational demand* and *underlying demand*, and explain why the two differ so much on a sunny day. (3 marks)

b. State two distinct reasons a record *minimum* demand is a problem for the operation of the power system, and explain the consequence of one of them if it is not managed. (3 marks)

Unscaffolded

Q12. State two reasons an open-cycle gas turbine is well suited to serving peak load but poorly suited to serving base load. (2 marks)

Q13. Nuclear energy has one of the highest capacity factors of any generation technology. Explain why it nevertheless cannot contribute to Victoria's projected base load needs, naming the relevant legal instruments. (3 marks)

Q14. Compare hydro-electricity and wind in terms of their ability to meet peak load demand. (4 marks)

Q15. Victoria's record minimum operational demand was 1,504 MW on 1 January 2025 and 1,287 MW on 27 December 2025.

a. Calculate the percentage change between the two records. Show your working. (2 marks)

b. Explain what this trend implies for the operation of Victoria's remaining coal-fired units. (2 marks)

Q16. Explain four actions available at the *individual* level that help match electricity supply to demand, stating for each how it changes the shape of the daily load curve. (5 marks)

Q17. A commentator states: *"A 300 MW battery can simply replace a 300 MW coal unit."* Evaluate this statement. (6 marks)

Q18. AEMO's 2026 Integrated System Plan projects that NEM electricity consumption will grow from about 205 TWh in 2026 to about 390 TWh in 2050, while two-thirds of the remaining coal fleet closes by 2035.

Evaluate the extent to which renewable energy sources can supply Victoria's projected base and peak load needs, and explain the societal-level measures required for them to do so. (8 marks)

Q19. *"Victoria's legislated target of 95% renewable electricity by 2035 cannot be reconciled with the need to serve both a record minimum demand of 1,287 MW and a record maximum demand of 10,736 MW."*

Discuss this statement. Refer to the properties that determine whether a source can serve base or peak load, to the extent to which specific sources can do so, and to measures available at both individual and societal levels. (10 marks)

Answers

Q1. The minimum level of demand for electricity that persists continuously over a period — the floor of the load curve, present at all hours (1).

Q2. Base load is the continuous minimum level of demand, present 24 hours a day (1). Peak load is the maximum demand reached in the period, typically lasting only tens of minutes to a few hours (1).

Q3. Base load is a property of *demand*, not a category of generator, and electricity from any source is identical on the wire (1). The expression actually describes a station suited to running near-continuously at high output — that is, one with low short-run marginal cost, high availability, a high minimum stable generation level and a slow ramp rate (1).

Q4. Brown coal — yes (slowly, within a narrow band); base load (1). Open-cycle gas turbine — yes, very fast; peak load (1). Utility-scale solar PV — no, curtailable downwards only; neither (1). Grid-scale battery — yes, within its storage duration; peak load (1).

Q5. Dispatchability is the ability to raise or lower output on instruction to a level the operator chooses (1). Dispatchable: coal, natural gas, coal seam gas, oil, nuclear, hydro-electric, biomass, biofuels or geothermal. Non-dispatchable: wind, solar or tidal (1).

Q6. Capacity factor — the energy actually generated over a period divided by the energy that would be generated at rated power for the whole period, as a percentage (1). Ramp rate — the rate at which output can be changed, in MW per minute (1). Minimum stable generation — the lowest output a unit can hold without having to shut down (1).

Q7. 150 × 8,760 = 1,314,000 MWh; 460,000 / 1,314,000 = 0.350 = **35.0%** (2 — 1 for working, 1 for the value as a percentage).

Q8. Peak-to-base ratio = 1,000 / 250 = **4.0** (1). Load factor = 540 / 1,000 = 0.54 = **54%** (1). A low load factor means capacity must be built for a peak it rarely serves, so the fixed cost of that capacity is spread over relatively little energy sold, raising the average cost per MWh (1).

Q9. Solar output depends on incident sunlight, and Victoria's summer peak occurs in the early evening when the sun is low or set, so PV output is near zero at exactly the time of maximum demand (2). Two ways to increase its contribution: pair it with storage — batteries or pumped hydro — that charges at midday and discharges into the evening peak (1); and either orient panels further west to extend generation later into the afternoon, or combine it with sources whose output profile differs, such as wind, which is not tied to daylight (1).

Q10. a. Power = 800 − 500 = **300 MW**; energy = **900 MWh** (2). **b.** Duration = 900 / 300 = **3 hours** (1). A 300 MW / 600 MWh battery is **not** sufficient: its power rating is adequate but its energy capacity is only two-thirds of the 900 MWh required, so it would empty before the peak ended (1). **c.** 900 / 0.90 = **1,000 MWh** (1).

Q11. a. Underlying demand is the electricity consumers actually use; operational demand is the part of it that grid-connected generation must supply, that is underlying demand minus distributed PV output (2). On a sunny day, rooftop PV sits behind the meter and supplies a large share of consumption directly, so operational demand falls far below underlying demand (1). **b.** Any two of: thermal units cannot turn down below their minimum stable generation (1); too little synchronous generation online means low inertia and system strength (1); distributed PV is largely invisible to and not centrally controllable by the market operator, and feeder voltages rise (1). Then one mark for the consequence of one of those reasons if it is not managed — for example, a unit forced to shut down faces a restart of many hours to two days and may miss the evening peak; or with low inertia, frequency moves further and faster after a fault, so load shedding becomes more likely; or unmanaged voltage rise forces emergency backstop curtailment of distributed PV (1).

Q12. Any two of: it starts in about 5–15 minutes and ramps very fast, so it can follow a sudden peak (1); its short-run marginal cost is high because open-cycle operation is fuel-inefficient, so it is uneconomic to run continuously and sits at the top of the merit order, dispatched only when prices are high (1); its capacity factor is 1–10% by design, meaning it is bought for capacity rather than energy (1).

Q13. Nuclear is technically well suited to base load, with capacity factors of 80–90% (1), but nuclear power generation is prohibited by the *Australian Radiation Protection and Nuclear Safety Act 1998* (Cth) s 10, the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) s 140A, and in this State the *Nuclear Activities*

(Prohibitions) Act 1983 (Vic) s 8 (1). Even if those prohibitions were repealed, the construction lead time would place first generation well after Yallourn W closes by mid-2028 and Loy Yang A in 2035 (1).

Q14. Hydro-electricity is fully dispatchable and reaches full output from standstill in about 90 seconds, making it very well suited to peaks (1), though it is energy-limited by rainfall and storage volume, so it is used for peaking and firming rather than continuous output (1). Wind is non-dispatchable — it can be curtailed downwards but not turned up — so it cannot be committed to a nominated hour and cannot be relied on for a peak (1). Wind supplies cheap energy with no fuel cost and sits at the bottom of the merit order, but it requires firming, whereas hydro *provides* firming (1).

Q15. a. (1,287 − 1,504) / 1,504 × 100 = −217 / 1,504 × 100 = **−14.4%**, a decrease of about 14.4% (2 — 1 for working, 1 for the value with direction). **b.** The operating window for inflexible plant is shrinking: with less and less room in the market at midday, coal units are increasingly forced towards or below their minimum stable generation and face shutdown and slow restart (1), which worsens their economics and makes early closure more likely (1).

Q16. See fully-worked solutions. Any four of: rooftop PV, home battery, smart EV charging or V2G, controlled-load hot water, response to time-of-use or demand tariffs, efficiency and building fabric, or joining a virtual power plant — each with its effect on the curve (4, one per action). The fifth mark is for the framing: the individual level *shifts and shaves* the curve rather than reducing total consumption, and aggregation is what turns trivial devices into a dispatchable fleet (1). (5)

Q17. The statement confuses power with energy. The 300 MW ratings match, so the battery can meet the same instantaneous demand, and it responds far faster — under a second, against 1–3 MW per minute for a coal unit. But a battery also has an energy capacity: at, say, 600 MWh it can hold 300 MW for only two hours before emptying, whereas the coal unit can hold 300 MW continuously while fuel is supplied. The battery is a store, not a source, and must be recharged. It replaces the coal unit's *capacity* for a limited duration, not its *energy*. (6)

Q18. See fully-worked solutions. (8)

Q19. See fully-worked solutions. (10)

Fully-worked solutions

Q1. Two elements earn the single mark together: *minimum* level of demand, and *continuous* or persistent. "The power used by a country" describes total demand, not base load, and "the electricity from coal stations" makes the category error the whole subtopic is built to prevent.

Q2. The discriminators are **level** and **duration**, and the question names both, so an answer that gives only "base load is low and peak load is high" earns one mark at most. Base load is the floor and is present at every hour; peak load is the ceiling and lasts a short time — in Victoria, typically the early evening of a summer heatwave.

Q3. Say plainly that the term names a *role* rather than a *product*. The full-mark version identifies the properties: low short-run marginal cost so the plant is dispatched first in the merit order, high availability, a high minimum stable generation level, and a slow ramp rate. Those properties are what make a station suitable for continuous operation, and none of them is a property of the electricity produced.

Q4. One mark per row, and each row needs *both* columns. The commonest losses are marking solar PV as "peak load" because Australia's demand used to peak in the afternoon, and marking a battery as "base load" because it is dispatchable — a battery is energy-limited, so it can serve a peak but not a continuous floor. Brown coal must be marked dispatchable: it *is* controllable, just slowly and within a narrow band, and calling it non-dispatchable confuses inflexibility with variability.

Q5. The definition must include the idea of *instruction* or *operator choice*; "it can generate whenever" is too loose. Choose the examples from the study design's own lists so the answer is anchored to scope. Note that curtailment does not make wind dispatchable — being able to turn something *down* is not the same as being able to turn it *up*.

Q6. Three separate definitions, one mark each, and each needs its unit or form. Capacity factor is a ratio and therefore a percentage. Ramp rate is MW per minute. Minimum stable generation is an output level, usually quoted as a percentage of rated output — 50–60% for Latrobe Valley brown coal. A frequent error is defining capacity factor as "how much of the time the plant is available", which is *availability*, a different quantity.

Q7. The denominator is the whole year at rated power: 150 MW × 8,760 h = 1,314,000 MWh. Then 460,000 / 1,314,000 = 0.350, so 35.0%. Two avoidable errors: using 365 instead of 8,760 and so mixing days with hours, and reporting the answer as a bare decimal. A capacity factor of 35% is unremarkable for onshore wind and is not evidence of a poorly performing farm — it reflects the wind resource, not a fault.

Q8. Two ratios from the same three numbers, and they are easily transposed. Peak-to-base uses the *minimum*: 1,000 / 250 = 4.0. Load factor uses the *mean*: 540 / 1,000 = 54%. The third mark is the economic inference, and it must be about cost rather than a restatement of the number: capacity sized for a peak that occurs rarely earns revenue over relatively little energy, so the fixed cost per MWh delivered rises. This is precisely why peaking plant has a high price and low utilisation, and why shaving the peak is valuable.

Q9. The first two marks are for the mechanism, stated with the timing. Victoria's maximum demand occurs in the early evening — the all-time record of 10,736 MW was set on the evening of 27 January 2026 — by which time solar irradiance has fallen to near zero. PV output therefore cannot coincide with the peak, no matter how much capacity is installed; adding panels deepens the midday minimum instead. For the remaining marks, the strongest pair is storage (charge at midday, discharge into the evening, which is what the ISP's 35 GW of shallow and medium storage and 5 GW of new deep storage are for) and profile-shifting or complementarity (west-facing arrays generate later in the afternoon; wind, and particularly Victorian offshore wind, is not tied to daylight). Naming demand-shifting also earns credit, since moving load into the solar middle of the day matches supply to demand from the other side.

Q10. a. Two requirements, two numbers. Power is the *height* above the line: 800 − 500 = 300 MW. Energy is the *area* above the line, given as 900 MWh. **b.** Duration = 900 / 300 = 3 hours. The offered battery fails on energy: 600 MWh gives 600 / 300 = 2 hours, so it would empty an hour before the four-hour peak ended. Note that the *peak* lasts four hours but the required duration is three, because the shortfall is not 300 MW for the whole period — the area is what matters, not the width. **c.** 900 / 0.90 = 1,000 MWh. Dividing by the efficiency is correct; multiplying by it (giving 810 MWh) reverses the loss and is the standard error.

Q11. a. Define both, then explain the gap. Underlying demand is what consumers use; operational demand is what grid-connected generation must supply. The difference is distributed PV, which is behind the meter and therefore netted off before the market sees the load. On 27 December 2025, more than enough rooftop output was available to supply the majority of Victorian consumption, so operational demand fell to 1,287 MW while underlying demand was ordinary for a summer's day. **b.** Two marks for two reasons, and they should come from different categories rather than being two versions of "coal can't turn down". The technical-plant reason is minimum stable generation. The system-security reason is the loss of synchronous generation, and with it inertia and system strength. A third available reason is visibility and control: distributed PV is not centrally dispatchable and feeder voltages rise. The third mark is the *consequence*, and it is the one most often missed — carry one of the reasons through to what actually goes wrong: the unit that shuts down faces a restart of many hours to two days and may not be back for the evening peak; the system with too little inertia sheds load after a fault it would otherwise have ridden through; the uncontrolled feeder forces AEMO and the distribution business to use their emergency backstop curtailment powers.

Q12. The two reasons must be *different in kind* to score both marks. One is technical — start-up in about 5–15 minutes and a very fast ramp, which is what a peak requires. The other is economic — open-cycle operation is fuel-inefficient, so short-run marginal cost is high, placing the plant at the top of the merit order where it is dispatched only when prices are high. Giving "it is fast to start" and "it can respond quickly" is one reason written twice.

Q13. The trap is answering with an opinion about nuclear. The question concedes the capacity factor, so the marks are for the *legal* position and the *timing*. Name all three instruments with jurisdiction and section: ARPANS Act 1998 (Cth) s 10 (the regulator cannot license such a plant), EPBC Act 1999 (Cth) s 140A (the Commonwealth Minister cannot approve such an action), and the Nuclear Activities (Prohibitions) Act 1983 (Vic) s 8. Then add the lead-time point: repeal would be necessary at both Commonwealth and State level, and construction would still place first generation well after Yallourn W's mid-2028 retirement and Loy Yang A's 2035 closure, so nuclear cannot fill the gap those closures create even on optimistic assumptions.

Q14. "Compare" requires both sources on the same criteria, not a paragraph on each. Use dispatchability, speed of response and the nature of the limit. Hydro is dispatchable and reaches full output from standstill in about 90 seconds, so it is among the best peaking resources available; its limit is *energy* — inflows and storage volume — which is why NEM hydro runs at a 10–30% capacity factor by choice rather than necessity. Wind is non-dispatchable; it can be curtailed but not commanded upward, so its availability at the peak hour is a matter of weather. Its limit is *timing*, not total energy: at a 30–40% capacity factor it produces a great deal of cheap energy and displaces coal in the merit order, but it cannot be committed. The one-sentence synthesis that lifts the answer: hydro provides firming, wind requires it.

Q15. a. The base is the earlier value: (1,287 − 1,504) / 1,504 × 100 = −14.4%. Use the proper minus sign or state "a decrease of 14.4%"; a bare "14.4%" without direction is incomplete, and dividing by 1,287 gives −16.9% and is wrong. Note how little time the fall took: the two records are less than twelve months apart. **b.** The inference is about the *operating window*, not about total generation. Each new minimum leaves less room in the market at midday, pushing coal units towards or below their minimum stable generation. Their choices are to run at a loss at low output, or shut down and accept a restart of many hours to two days with the risk of missing the evening peak. Either outcome worsens their economics, which is a substantial part of why Yallourn W is retiring by mid-2028, ahead of its licence to 2032.

Q16. *Model response (5 marks).* Four actions, each with its effect on the shape of the curve. The examinable idea running through all of them is that the individual level is about *shifting and shaving*, not about using less overall, which belongs to 13C.

Rooftop PV. A 6.6 kW system in Melbourne generates about 24 kWh a day averaged over the year. It cuts the household's daytime draw on the grid to near zero and may export, which lowers midday *operational* demand and deepens the midday minimum. On its own it does nothing for the evening peak, because output is zero by then — so it reshapes the curve rather than flattening it.

A home battery. A 10 kWh / 5 kW unit stores the midday surplus and discharges it across roughly two hours of the household's evening peak. This is the direct fix for what rooftop PV alone cannot do: it raises the midday trough by charging and lowers the evening peak by discharging, flattening the curve from both ends. AEMO projects 35 GW of household and small business batteries nationally by 2050, so the aggregate effect is grid-scale.

Smart electric-vehicle charging, and vehicle-to-grid. An EV drawing 7 kW from 6 pm is one of the largest single additions a household can make to the system peak; the same energy taken overnight or at midday fills a trough instead. A 60 kWh battery holds roughly six days of an average household's electricity, so the timing decision is significant. With a bidirectional charger, vehicle-to-grid discharge turns the parked car into a peak-serving resource, subtracting from the peak rather than adding to it.

Controlled load, tariffs and fabric. Off-peak electric hot water is the oldest demand-shifting technology in the system — a thermal store filled in the overnight trough, and increasingly retimed to the solar middle of the day. Time-of-use and demand tariffs are what make shifting worthwhile, and Victoria's mandated smart meter rollout of 2009–2013 is near-universal, so time-based pricing is genuinely available here. Insulation, draught sealing, shading and a thermostat at 24–25 °C rather than 20 °C cut the height of the peak itself on a 40 °C day, which is peak *shaving* rather than shifting.

Aggregation is the step that connects this to the societal level: individually these devices are trivial, but orchestrated as a **virtual power plant** thousands of them behave as one dispatchable fleet.

Q17. *Model response (6 marks).* The statement is right about one quantity and silent about the one that matters, and the distinction is between **power** and **energy**.

On power, the statement holds and can be put more strongly than it is. Both are rated at 300 MW, so both can meet the same instantaneous demand, and the battery is far better at doing so quickly: it responds in under a second against a coal unit's ramp of the order of 1–3 MW per minute, it can be dispatched from zero without a start-up sequence, and with a grid-forming inverter it can also supply fast frequency response and synthetic inertia. For serving the sharp evening neck of the load curve, 300 MW of battery is more useful than 300 MW of coal.

On energy, the comparison fails. A battery has two ratings, and the statement quotes only one. A 300 MW battery with 600 MWh of storage can deliver 300 MW for two hours and is then empty; a 300 MW coal unit can deliver 300 MW continuously for as long as fuel is supplied, at a capacity factor historically of 60–80%. The battery is a **store**, not a source: it generates nothing, it must be charged from elsewhere, and it returns less than it takes because round-trip efficiency is around 88%. Replacing a coal unit's annual *energy* therefore requires generation to be built as well as storage — which is exactly why AEMO's 2026 ISP pairs 35 GW of shallow and medium grid-scale storage with about 120 GW of grid-scale wind and solar, rather than treating storage as a substitute for generation.

The judgement is that the equivalence is valid for capacity over a limited duration and invalid for energy. Longer-duration storage narrows but does not close the gap: Snowy 2.0's 350,000 MWh behind 2,200 MW is about 159 hours at full output, which is multi-day rather than seasonal, and it too must be charged from surplus generation. The defensible version of the claim is that a portfolio — variable generation for energy, storage for shifting, and some flexible gas for the rare deep peak — can replace a coal unit. A single battery cannot.

Q18. *Model response (8 marks).* The projections set the task precisely: consumption roughly doubling from about 205 TWh in 2026 to about 390 TWh in 2050, while two-thirds of the remaining coal fleet closes by 2035. Both the quantity of energy and the shape of demand change at once, so the extent to which renewables can serve base and peak load has to be answered separately for each.

Base load: largely yes, on energy grounds. Base load is a continuous *floor of demand*, and meeting it requires energy delivered in every hour rather than any particular technology. Wind at a 30–40% onshore capacity factor and solar at 15–25% in Victoria generate very large quantities of energy at near-zero marginal cost, which places them at the bottom of the merit order and displaces coal energy first. Hydro, biomass and biofuels add dispatchable renewable energy, though hydro is energy-limited by inflows and biomass by fuel supply, land and transport. Geothermal would serve base load excellently on the checklist — capacity factors of 70–90% overseas — but Australia's hot dry rock resource is deep and remote and there is no commercial generation, so its practical contribution is presently nil. Nuclear is prohibited by the ARPANS Act 1998 (Cth) s 10, the EPBC Act 1999 (Cth) s 140A and the Nuclear Activities (Prohibitions) Act 1983 (Vic). So the energy can be supplied; what cannot be supplied by wind and solar alone is a *guaranteed level in a nominated hour*, because they are non-dispatchable.

Peak load: only with firming. Victoria's peak is a summer early evening — 10,736 MW on 27 January 2026 — at which solar output is zero and wind is uncommitted. Renewables can serve that peak only through dispatchable partners, and the growing winter peak of 8,818 MW in June 2025 must be served too as homes electrify. The societal-level measures required are therefore specific:

- **Storage for duration.** Shallow and medium storage, mostly batteries — 35 GW nationally by 2050 in the 2026 ISP — covers the intra-day job, the shape of the evening neck. Deep storage covers days: 5 GW of new pumped hydro on top of the NEM's existing 7 GW of hydro, with Snowy 2.0 offering 2,200 MW behind 350,000 MWh, about 159 hours at full output. Together that is nearly 50 GW of grid-scale storage and hydro. Victoria's legislated storage targets of 2.6 GW by 2030 and 6.3 GW by 2035, inserted by the *Climate Change and Energy Legislation Amendment (Renewable Energy and Storage Targets) Act 2024* (Vic), are the mechanism.
- **Flexible gas as insurance.** 17 GW nationally by 2050, running few hours a year — high capacity value, small energy share and therefore a small emissions contribution. This is the capacity-versus-energy distinction applied.
- **Transmission, interconnection and renewable energy zones.** Weather is correlated over hundreds of kilometres but not thousands, so geographic spread converts variable local output into more predictable aggregate output, and interconnectors let one region's surplus serve another's peak.
- **Diversity of profile.** Victorian offshore wind, legislated at 2 GW by 2032, 4 GW by 2035 and 9 GW by 2040, is strongest in winter when solar is weakest and the winter peak occurs.
- **Demand response.** A megawatt not consumed at 6 pm is equivalent to one generated. The Wholesale Demand Response Mechanism has allowed large consumers to bid demand reductions into the market since 24 October 2021, AEMO's RERT contracts emergency reserves, and interruptible industrial load can release hundreds of megawatts within minutes.
- **Market and policy settings.** The National Electricity Rules impose a reliability standard of a maximum 0.002% expected unserved energy per region per year, and the Commonwealth's Capacity Investment Scheme — expanded on 29 July 2025 to 40 GW, including 14 GW of dispatchable capacity — underwrites the firming that energy-only markets underprovide.

The falling floor is the other half. Renewables also create a problem at minimum demand: Victoria's record low of 1,287 MW on 27 December 2025 arose because distributed PV supplied most of underlying demand. This is addressed by the same toolkit read in reverse — storage charging at midday, load shifted into the middle of the day, and orchestration of distributed PV — plus the projected 87 GW of rooftop solar and 35 GW of household batteries, which are individual-level assets aggregated to societal scale.

Judgement. The extent is high for base load energy and conditional for peak load. Renewables can supply the projected energy, including a near-doubling of consumption; they can serve the peak only if storage duration, firming capacity, transmission and demand response are built to schedule. The binding constraint is not the resource but the *delivery timetable*, which is why the reliability standard, the legislated targets and the ISP's biennial revision exist.

Q19. *Model response (10 marks).* The statement treats an operational difficulty as a logical impossibility. The two records are real and the gap between them is the central engineering problem of the transition, but nothing in the physics or the market design makes a 95% renewable system incompatible with serving both — provided the right *properties* are procured alongside the energy.

What actually determines whether a source can serve base or peak load. Six properties do the work, and the statement invokes none of them. **Dispatchability** — whether output can be raised on instruction — is decisive; wind and solar are non-dispatchable, curtailable downwards but not commandable upwards. **Capacity factor** measures energy delivered against rated output over time, and it grades suitability for a continuous floor. **Ramp rate** governs how fast output can follow a rising peak: brown coal manages of the order of 1–3 MW per minute per unit, hydro reaches full output from standstill in about 90 seconds, a battery responds in under a second. **Minimum stable generation** — 50–60% of rated output for Latrobe Valley brown coal — determines whether a unit can survive a midday minimum without shutting down and facing a restart of many hours to two days. **Short-run marginal cost** sets the merit order, which is why zero-fuel-cost renewables are dispatched first and expensive peakers last. **Storage duration** — energy divided by power, in hours — decides whether a store can cover a whole evening peak or only its highest part.

Applying them to the sources. Solar PV is the sharpest case: excellent at suppressing midday demand, worth nothing at 6.30 pm on a January evening, so it is the direct cause of the 1,287 MW minimum and no part of the answer to the 10,736 MW maximum unless paired with storage. Wind contributes large quantities of cheap energy at a 30–40% onshore capacity factor and cannot be committed to an hour; Victorian offshore wind, legislated at 2 GW by 2032 and 9 GW by 2040, is valuable partly because it is strongest in winter, when solar is weakest and the winter peak — a record 8,818 MW in June 2025 — falls. Hydro is dispatchable and fast but energy-limited by inflows. Biomass and biofuels are dispatchable at modest scale. Geothermal would be a fine base load source but Australia has no commercial resource in production. Nuclear is the best base load performer on the checklist and is prohibited by the *Australian Radiation Protection and Nuclear Safety Act 1998* (Cth) s 10, the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) s 140A and the *Nuclear Activities (Prohibitions) Act 1983* (Vic) s 8, quite apart from a construction lead time that runs past Yallourn W's mid-2028 retirement and Loy Yang A's 2035 closure. Coal, which the statement implicitly defends, is the poorest performer against the *daily ramp* the two records define: it can neither follow the evening rise nor turn down through the midday trough.

Why the statement's premise is the wrong way round. The record minimum is not evidence that renewables fail; it is evidence that inflexible plant fails. The 8.3 to 1 ratio between 10,736 MW and 1,287 MW is a requirement for *flexibility*, and flexibility is precisely what coal lacks and what storage, hydro, gas turbines and demand response supply. Read correctly, the two records make the case for the replacement portfolio rather than against it.

Societal-level measures. Shallow and medium grid-scale storage, batteries above all — 35 GW nationally by 2050 in AEMO's 2026 Integrated System Plan, published 25 June 2026 — covers the evening neck; Victoria's legislated targets of 2.6 GW by 2030 and 6.3 GW by 2035 are the largest in Australia. Deep storage (5 GW of new pumped hydro, additional to 7 GW of existing hydro) covers multi-day shifting, Snowy 2.0 offering 2,200 MW behind 350,000 MWh, about 159 hours at full output — nearly 50 GW of grid-scale storage and hydro in all. Flexible gas (17 GW) is bought as insurance for the rare deep peak: high capacity value, few operating hours, small energy and emissions share. Transmission, interconnection and renewable energy zones convert local variability into more predictable aggregate output and let one region's surplus serve another's peak. Demand response makes reduction equivalent to supply, through the Wholesale Demand Response Mechanism in force since 24 October 2021, AEMO's RERT, and interruptible industrial load. Underpinning all of it, the National Electricity Rules set a reliability standard of a maximum 0.002% expected unserved energy per region per year — about ten and a half minutes per customer — and the Commonwealth's Capacity Investment Scheme, expanded on 29 July 2025 to 40 GW including 14 GW of dispatchable capacity, underwrites the firming that an energy-only market underprovides.

Individual-level measures. These are not marginal. AEMO projects 87 GW of rooftop and small-scale solar and 35 GW of household and small business batteries by 2050 — larger than much of the grid-scale fleet. A home battery raises the midday trough by charging and lowers the evening peak by discharging, flattening the curve from both ends.

Smart electric-vehicle charging decides whether a 7 kW load lands on the peak or in the trough, and vehicle-to-grid can reverse it into a peak-serving resource. Controlled-load hot water, once an overnight technology, is increasingly retimed into the solar middle of the day. Time-of-use and demand tariffs make the shifting worthwhile, and Victoria's near-universal smart meters from the 2009–2013 mandated rollout make such tariffs actually available. Insulation, shading and a thermostat at 24–25 °C shave the peak itself. Aggregated as virtual power plants, these individually trivial devices become a dispatchable fleet at gigawatt scale — which is the study design's "individual and societal levels" resolving into one system.

Judgement. The statement is wrong as a matter of logic and right as a matter of warning. It is wrong because a 95% renewable system is not required to serve either record with variable generation alone: it serves them with a portfolio in which wind and solar supply energy and storage, hydro, flexible gas, transmission and demand response supply dispatchability, ramp rate and duration. The gap between 1,287 MW and 10,736 MW is a specification for that portfolio, not a refutation of it. It is right in that the target is contingent on delivery: the risk is **sequencing** — coal retiring on schedule while storage, transmission and firming arrive late — which is why Victoria's storage and offshore wind targets carry dated milestones, why the reliability standard is legally binding, and why the ISP is revised every two years against observed demand rather than settled once.

Chapter 13 Managing the impacts of human energy use — 13C Options for a sustainable energy future

Theory

What this subtopic owns. The key knowledge dot point reads: *options for building a sustainable energy future that produces lower greenhouse gas emissions and supplies reliable and affordable energy services: improving resource efficiency; increasing the efficiency of energy conversion devices; replacing fossil fuels with non-fossil fuel energy sources; and reducing personal energy consumption.* The wording is unusually generous with instruction. It names **four** options — you are expected to know all four, distinguish them, and apply them — and it imposes **three** simultaneous tests that every option has to pass. A proposal that lowers emissions but leaves the hospital dark, or keeps the lights on at a price a quarter of households cannot pay, is not an option for a sustainable energy future in the sense the study design means. Unit 4 Outcome 2 puts the same demand in the assessed verb: *evaluate the suitability and impacts of their use in terms of upholding sustainability principles*. The three tests, and the words that carry them:

- **lower greenhouse gas emissions** — measured, not asserted, and measured *per unit of energy service delivered*, over the whole chain, with the place the emissions move to accounted for;
- **reliable** — the service is available when it is wanted, to the standard the user requires;
- **affordable** — the cost of the service over the life of the option, counting both capital and running cost, and counting *who bears each*.

Where this sits in the chapter and the series. Chapter 12 supplied the raw material: **12A** and **12B** described the non-renewable and renewable sources themselves, **12C** the carbon-cycle consequences of combustion, **12E** the method for calculating conversion efficiency, **12F** the two laws of thermodynamics that constrain every device in this subtopic, and **12G** the six sustainability principles as they apply along the energy supply chain. This subtopic does not re-derive any of them; it uses them by name. Within Chapter 13, **13A** owns the rehabilitation of extraction sites and **13B** owns the base-load and peak-load question — *whether a given source can serve the load, and how those needs are met at individual and societal levels*. 13C is deliberately narrower and deliberately different: it owns the **four named option families**, the discipline of testing each against the three criteria, and the way the four interact. Where reliability appears here it appears as a *test applied to an option*, not as a lesson in load curves; that lesson is 13B's. **13D** then owns the stakeholder values, regulatory tensions and contested-evidence dimensions of choosing between the options, so this subtopic states what the options *are* and *how they measure up*, and leaves the politics of choosing to 13D. **11B** owns mitigation options across the whole economy, including land use and agriculture; 13C is the energy system specifically, and it carries two criteria — reliability and affordability — that 11B does not.

1 Energy services, not energy

Nobody wants a kilowatt-hour. People want a house at 20 °C on a July night in Ballarat, food that is still cold on Thursday, a lit workshop, a hot shower, a trip to Bendigo, steel, bricks, treated water. Those are **energy services** — the useful outcome — and the study design's phrase *supplies reliable and affordable energy services* is doing real work. It means the question is never "how do we generate the same number of joules from something cleaner?" but "how do we deliver the same *service* with lower emissions, undiminished reliability and acceptable cost?"

That reframing is what makes four options possible instead of one. The same service can be delivered with less energy (**improve the efficiency of the system**), with the same energy converted better (**improve the device**), with the same energy from a different source (**substitute**), or by wanting less of the service (**reduce consumption**). Confusing the service with the energy is the single commonest conceptual error in this material, and it produces answers that treat substitution as the only option available.

The energy service	Measured in	Ways to deliver it with less fossil energy
A house at 20 °C	°C maintained, hours per year	Insulate and draught-seal the shell; replace an 82% gas heater with a heat pump; power the heat pump from renewable generation; heat fewer rooms, for fewer hours, at 20

The energy service	Measured in	Ways to deliver it with less fossil energy
		°C rather than 23 °C
Refrigerated food	m³ held below 4 °C	Insulate the cold store and fit rapid-roll doors; variable-speed compressors; on-site solar; hold less stock, and stop lighting an empty chamber
A 12 000 km yr^{-1} commute	passenger-kilometres	Route and load optimisation; a battery electric vehicle at about 78% grid-to-wheel against 22% tank-to-wheel; renewable charging; fewer or shorter trips, or the same trip by train

2 The conversion chain, and why losses compound

Every energy service sits at the end of a chain, and the efficiency of the chain is the **product** of the efficiencies of its links, not their average. That single fact is why a small improvement at the end of the chain saves a large quantity of primary energy at the beginning, and it is the strongest argument for working from the service backwards rather than from the source forwards.

Take a resistance heater on a brown-coal path. A Victorian brown-coal generating unit converts roughly **25%** of the coal's chemical energy into electricity at its terminals; transmission and distribution across the National Electricity Market deliver about **90%** of what is generated, the remaining tenth being lost as heat in lines and transformers; a resistance heater converts essentially **100%** of the electricity into heat. The chain is $0.25 \times 0.90 \times 1.00 = \mathbf{0.225}$, so under a quarter of the coal's energy becomes warmth. Swap the resistance heater for a reverse-cycle heat pump with a seasonal coefficient of performance of 4, and the chain becomes $0.25 \times 0.90 \times 4 = \mathbf{0.90}$: four times the service from the same coal. Nothing changed at the mine or the power station. One device changed at the end. Two cautions, both examinable. First, **primary energy efficiency and emissions intensity are different tests and can disagree**, because fuels differ in carbon per joule; a chain can improve on energy and worsen on emissions, or the reverse. Second, the average Victorian grid is no longer a brown-coal chain — renewables supplied **44.6% of Victoria's electricity generation in 2025**, exceeding the 40%-by-2025 target legislated in the *Renewable Energy (Jobs and Investment) Act 2017* (Vic) — so the honest calculation uses a published **grid emission factor**, not an assumed generating technology.

3 Option 1 — improving resource efficiency

Improving resource efficiency means delivering the same service with less energy and less material by changing the *system*, not the conversion device. It is the option students most often omit, because its measures are undramatic and largely invisible. The main families, each with the mechanism stated:

- **Building fabric.** Insulation, draught sealing, glazing and shading reduce the rate at which heat leaks out in winter and in during summer, so the heating and cooling plant has less work to do. The **National Construction Code** raised the minimum for new Victorian homes from 6 to 7 stars under the **Nationwide House Energy Rating Scheme**, and added a **Whole-of-Home** annual energy budget covering fixed appliances; both became mandatory in Victoria on **1 May 2024**.
- **Waste heat recovery and cogeneration.** Heat rejected by one process pre-heats the input to another — a kiln's cooling zone drying the product, a pasteuriser pre-heating wash water. Because the recovered heat replaces purchased fuel one-for-one, this is usually the cheapest tonne of abatement available to an industrial site.
- **Reducing distribution losses.** Line losses, steam-line losses, compressed-air leaks and hot-water dead legs are energy already paid for and never delivered.
- **Load and process optimisation.** Right-sizing plant, variable-speed drives on pumps and fans, better scheduling, and avoiding the demand entirely — the cheapest joule is the one never needed.

- **Material efficiency and circularity.** Recycled aluminium requires of the order of 5% of the electricity of primary smelting; using less material, for longer, and recovering it removes the **embodied energy** of making it again. Circular economy thinking is defined at 8E and applied here.

The Victorian instrument is the **Victorian Energy Upgrades** program, established by the *Victorian Energy Efficiency Target Act 2007* (Vic) and administered by the **Essential Services Commission**. Accredited persons who install eligible efficiency measures create **Victorian energy efficiency certificates (VEECs)**, each representing one tonne of CO_2-e abated; liable energy retailers must surrender certificates against an annual target, and the cost of doing so is recovered through tariffs. Understand the two features that matter for an evaluation: the abatement is **deemed** from an engineering formula rather than metered at the premises, and the scheme is funded by all energy customers, which is a user-pays and intragenerational-equity question of exactly the kind 12G frames.

4 Option 2 — increasing the efficiency of energy conversion devices

This limb is narrower and more concrete: the **device** that converts energy from one form to the useful form is replaced with one that wastes less. Efficiency here is 12E's η — useful output over input — with one important exception dealt with below.

Conversion device	Typical efficiency or performance	The loss, and where it goes
Victorian brown-coal generating unit	≈ 25% (fuel → electricity at the terminals)	Latent heat in the water driven off the fuel, plus condenser heat to cooling water and air
Open-cycle gas turbine	≈ 30–40%	Hot exhaust straight to atmosphere
Combined-cycle gas turbine	≈ 55–60%	The exhaust raises steam for a second turbine, which is why it beats the open cycle
Transmission and distribution, NEM	≈ 90% delivered	Resistive heating in conductors and transformers
Halogen downlight	≈ 18 lm W^{-1}	Almost all of the input becomes heat inside the conditioned space
LED lamp	≈ 100–160 lm W^{-1}	Roughly seven times the light per watt of a halogen
Electric resistance heater	≈ 100% (COP 1)	Nothing wasted at the device — and no better than 1 is possible
Reverse-cycle air conditioner, heating	**COP 3–5**	Not a conversion efficiency; see below
Gas ducted heater, current	≈ 80–85%	Flue gases and cabinet losses; older units 60–70%
Gas storage hot water	≈ 60–80%	Flue losses plus standing loss from the tank, day and night
Heat-pump hot water	**COP 3–4**	As above
Petrol car, tank to wheels	≈ 20–25%	Exhaust and radiator heat, idling, friction
Battery electric car, grid to wheels	≈ 75–80%	Charging, inverter and motor losses; regenerative braking recovers some

The exception is the **heat pump**, which moves heat rather than converting energy into it, and whose performance is therefore reported as a **coefficient of performance (COP)** — useful heat delivered divided by electrical work supplied — a ratio that may exceed 1. **12F** establishes why that breaches neither law and why the Carnot ceiling collapses as the temperature difference widens; none of it is repeated here. Two consequences of 12F's analysis are what 13C actually uses, and both change answers. A COP is **not an efficiency**, so it cannot be multiplied into an efficiency chain without saying what it is a ratio of; and a manufacturer's best-case COP overstates performance on a frosty Ballarat morning, so an evaluation must use a **seasonal** figure and should say where it came from. Devices are regulated nationally, not by the states. The *Greenhouse and Energy Minimum Standards Act 2012* (Cth) — the **GEMS**

Act, administered by the **GEMS Regulator** — makes it unlawful to supply a covered product in Australia unless it meets the **minimum energy performance standards (MEPS)** and carries the **energy rating label** set for it by a GEMS determination. MEPS remove the worst products from the market altogether; labels let a buyer choose among the rest.

5 The arithmetic that decides an electrification argument

Replacing a gas appliance with an electric one moves the emissions from the customer's flue to the generator. Whether total emissions fall is a calculation, and it has exactly three inputs. Learn it as a rule, because it converts a vague argument into a numerical answer. Using the **National Greenhouse Accounts Factors 2025** (DCCEEW), the two numbers for Victoria are:

- **natural gas distributed in a pipeline: 51.5 kg CO_2-e GJ^{-1}** of fuel burnt (scope 1);
- **Victorian grid electricity: 0.78 kg CO_2-e kWh^{-1}** (scope 2) — the highest of any Australian state, because of brown coal.

Since 1 kWh = 3.6 MJ, that electricity factor is **0.78 × 277.8 = 217 kg CO_2-e GJ^{-1}** of delivered electricity. Victorian grid electricity therefore carries **about 4.2 times** the emissions of natural gas *per unit of energy delivered to the site*. Electrification wins only if the electric device is more than 4.2 times better at turning that energy into the service. Setting the two emissions rates per gigajoule of **useful heat** equal:

Break-even COP = 4.2 × (efficiency of the gas appliance it replaces)

Against an 82%-efficient gas ducted heater the break-even is a COP of **3.4**; against a 60%-efficient gas storage hot water unit it is **2.5**; against a 40%-efficient gas cooktop it is **1.7**. A modern reverse-cycle heat pump at seasonal COP 4 clears the first, but by under a fifth. An induction cooktop does **not** clear the third, and the comparison has to be made in one currency or the other to see why: an induction hob converts electricity into heat rather than pumping heat, so its COP-equivalent is simply its own efficiency of about **0.83** — half the break-even COP of 1.7. Put the other way, in ratio terms it is about **2.1 times** better than the gas hob it replaces, where **4.2 times** is required. Either currency gives the same verdict, and it fails by about half, so induction slightly *increases* emissions in Victoria today while still being the right long-run choice. Rearranged the other way, the rule gives the grid emission factor at which an option starts to pay:

Break-even grid factor (kg CO_2-e kWh^{-1}) = 51.5 × COP ÷ (277.8 × efficiency of the gas appliance)

Two consequences follow, and both are worth marks. First, **options 2 and 3 are not independent**: the emissions case for electrifying an end use gets stronger every year the grid decarbonises, so the same proposal can be correctly rejected in 2026 and correctly accepted in 2032. Second, **an option can be right on cost and wrong on emissions at the same time**, because electricity and gas prices bear no fixed relationship to their emission factors. Say which test you are applying.

6 Option 3 — replacing fossil fuels with non-fossil fuel energy sources

Substitution is the limb students know best and describe least precisely. Three distinctions carry the marks. **Direct substitution versus electrification.** A fossil fuel can be displaced by burning something else in the same equipment — biomass, biogas or certified **biomethane** in a gas boiler, biodiesel in a truck — or by changing the end use to electricity and decarbonising the electricity. Direct substitution is quick and needs little capital but is limited by the quantity of sustainable feedstock available, and its emissions claim depends entirely on whether the feedstock is genuinely renewable and what would otherwise have happened to it. Electrification is capital-intensive and slower but scales with the grid.

What counts as non-fossil. The renewable sources of 12B, plus **nuclear**, which is non-fossil but not renewable and is presently prohibited for electricity generation in Australia by the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) and the *Australian Radiation Protection and Nuclear Safety Act 1998* (Cth). **Hydrogen is not a source**: it is an energy carrier, and its emissions depend on how it was made — by electrolysis from renewable electricity, or by steam reforming of natural gas. Calling hydrogen "clean energy" without saying which is a reported error.

Firming, not just energy. Wind and solar are **variable**: the resource is not available on demand. Replacing a fossil generator's *energy* therefore does not by itself replace its *service*, and the gap is closed by storage (batteries, pumped hydro), by transmission that pools weather across regions, by demand response, and by a residual dispatchable fleet. 13B analyses that matching problem; here it enters as the **reliability test** applied to a substitution proposal. Victoria's response is legislated alongside the renewable targets: **65% renewable by 2030 and 95% by 2035**, with **energy storage targets of 2.6 GW by 2030 and 6.3 GW by 2035** and offshore wind targets of 2 GW by 2032, 4 GW by 2035 and 9 GW by 2040. Nationally, the Commonwealth's **Capacity Investment Scheme** underwrites new generation and dispatchable capacity by tender, and **AEMO's Integrated System Plan** sets out the transmission, generation and storage development path for the National Electricity Market.

Two limits belong in any full answer. **Hard-to-abate end uses** — high-temperature process heat above roughly 400 °C, long-haul aviation and shipping, and the chemistry of steel, cement and alumina — cannot simply be plugged in, and are where the residual emissions of an energy transition sit. And substitution has its own **Earth systems footprint**: land and habitat for wind, solar and transmission; lithium, copper, nickel and rare earths for storage and motors; and end-of-life panels, blades and cells. Naming that is not an argument against substitution; it is the difference between an evaluation and an advertisement.

Finally, an **offset is not one of the four options**. Buying certificates, or a "100% renewable" retail electricity product, is a market instrument: it may reduce net emissions if the abatement it represents is additional and durable, but it changes neither the energy the site uses, nor the efficiency of the device using it, nor the reliability or the underlying cost of the service. Two of the three tests are untouched. An evaluation should say so plainly.

7 Option 4 — reducing personal energy consumption

The fourth limb is about **wanting less of the service**, and it is distinguished from the first two by containing no technology at all. Efficiency delivers the same service with less energy; reduced consumption delivers **less service**, by choice. Turning the thermostat from 23 °C down to 20 °C, heating occupied rooms only, shorter showers, cold-water washing, full loads, switching off standby loads, combining trips, cycling or taking the train, and buying fewer and longer-lived goods are all this limb.

Its virtues are real and should be stated precisely: it requires **no capital**, so it is available to renters, apartment dwellers and low-income households who cannot access the other three; it takes effect **immediately** rather than on a construction timetable; and it reduces demand at the moment of use, which relieves peak as well as total consumption. Its limits are equally real, and an answer that omits them is not an evaluation:

- **Durability.** A behaviour that is not embedded in a control setting, a piece of hardware or a policy decays. Campaign savings characteristically appear in the first months and disappear within a year or two.
- **Scale.** Household direct energy use is a minority of the energy consumed on a household's behalf. Roughly 40% of Australian household energy goes to space heating and cooling and about a fifth to water heating, which is why Victorian homes — where the large majority still have at least one gas appliance — are gas-heavy in winter. But the **embodied energy** in the food, goods, buildings and services a household buys is larger again, and no thermostat reaches it.
- **Arithmetic ceilings.** Order-of-magnitude estimates should be done rather than asserted. Victorian residential electricity consumption is of the order of 13 000 GWh a year; standby loads are a few per cent of it; at 0.78 kg CO_2-e kWh^{-1} eliminating standby entirely across the state abates of the order of 0.3 Mt CO_2-e — well under 1% of Victoria's emissions, against a legislated 2035 target of **75–80% below 2005 levels** under the *Climate Change Act 2017* (Vic), on the way to **net zero by 2045**. Personal consumption is a genuine option and it is not a substitute for the other three.
- **Distribution.** Asking a household in an uninsulated rental to be cold is not the same policy as asking a household in a 7-star home to lower the thermostat, and treating them as one is an intragenerational equity failure.

8 The options interact: sequence, rebound and lock-in

The four options are not a menu from which one item is chosen. They compose, and three interactions decide whether a package works. **Sequence.** Efficiency first, then substitution, is the standard order and it has an engineering reason, not just an economic one: a measure that cuts the *load* also cuts the *size* of every downstream asset that must serve it. Insulate first and the heat pump is smaller; recover waste heat first and the electric dryer that replaces the gas one is a third of the size; cut a factory's demand first and the solar array and battery that supply it shrink with it. Doing substitution first strands most of the later efficiency gain in an oversized asset that has already been paid for.

Rebound. A saving that is reinvested in more service is a **rebound effect**, and it is why intensity data alone can never establish that consumption fell. LED street lighting that uses 68% less per lamp leaves each lamp at 0.32 of its former consumption, so lighting three times as many laneways leaves absolute consumption almost exactly where it started, and any more than that raises it; irrigation efficiency that funds an expansion of irrigated area is the same phenomenon in another resource. Always ask for the **absolute** quantity beside the intensity ratio.

Lock-in and timing. Energy assets last decades: a gas boiler installed today will still be burning gas in 2045; a house built to 6 stars will still be leaking heat in 2085. Two evaluative consequences follow. An option that is marginal on today's grid factor may be clearly correct over the life of the asset, so the comparison should be made across the asset's life and not at a single instant. And the cheapest moment to change an appliance is when the existing one fails, because the relevant cost is then the **incremental** cost of the better option, not its full price — which is precisely the logic Victoria's minimum rental standards use, requiring end-of-life heating and hot water in rental homes to be replaced with efficient electric systems from **1 March 2027**, alongside ceiling insulation, with draught proofing from 1 July 2027 and full application to all rental homes by 1 July 2030, under regulations made under the *Residential Tenancies Act 1997* (Vic).

9 Applying the three tests, and the Victorian instruments

Test	The question to ask	What a full-mark answer supplies	The standard failure
Lower greenhouse gas emissions	How many tonnes of CO_2-e per year, per unit of energy service, and where do the emissions move to?	A calculation with the published emission factors, an explicit boundary, and the absolute figure beside the intensity	Reporting an intensity gain while absolute emissions rise; ignoring the emissions that moved to the generator; counting an offset as a physical reduction
Reliable	Is the service available when it is wanted, to the standard required, and what firms it when the resource is not available?	The timing of the demand set against the availability of the supply, and the named firming or backup arrangement	Matching annual energy and calling it matched supply; ignoring a critical load that cannot be interrupted
Affordable	What does the service cost over the life of the option, counting capital and running cost — and who pays each?	Simple payback or cost per tonne abated, plus the distributional question: who can access the capital, and who carries the residual charge	Quoting the bill saving and omitting the capital cost; assuming every household can borrow $15 000

Option	Commonwealth instrument	Victorian instrument
Improving resource efficiency	National Construction Code energy provisions (7 stars plus Whole-of-Home, mandatory in Victoria from 1 May 2024)	**Victorian Energy Upgrades**, under the *Victorian Energy Efficiency Target Act 2007* (Vic), administered by the Essential Services Commission; minimum rental standards under the *Residential Tenancies Act 1997* (Vic)
Efficiency of conversion devices	**MEPS and energy rating labels** under the *Greenhouse and Energy Minimum Standards Act 2012* (Cth)	Victorian Energy Upgrades activities for heat pumps, hot water and lighting; Solar Victoria hot water rebates
Replacing fossil fuels	*Renewable Energy (Electricity) Act 2000* (Cth); Capacity Investment Scheme; AEMO's Integrated System	**Renewable energy and storage targets** under the *Renewable Energy (Jobs and Investment) Act 2017*

Option	Commonwealth instrument	Victorian instrument
	Plan; *Climate Change Act 2022* (Cth)	(Vic); the ban on reticulated natural gas connections for new dwellings requiring a planning permit, introduced by **Amendment VC250** on 1 January 2024 (clause 53.03)
Reducing personal energy consumption	Energy rating labels as consumer information	Solar Victoria and retailer information programs; the *Climate Change Act 2017* (Vic) targets that frame them

10 Writing for marks

Five moves, in this order. Three of them answer a 2-mark item; all five answer a 10-mark one, applied to several options.

1. **Name the option family** — resource efficiency, device efficiency, substitution, or reduced consumption — and say which measure belongs to which.
2. **State the mechanism** by which it changes the energy or the emissions, in one sentence.
3. **Quantify** against the emissions test, with the factor used and the boundary stated.
4. **Apply the reliability and affordability tests**, not just the emissions one.
5. **Name the interaction, the limitation or the condition** — sequence, rebound, lock-in, or the grid factor at which the verdict flips.

Marks	What the item will ask	What full marks require
1	state / identify	One option, one measure or one criterion. One answer only
2	describe / distinguish / explain	The distinction **plus** its application to the case given. A definition alone is the standard 1-of-2
2	calculate	The value **and** its unit; a decrease signed with a proper minus sign
3–4	explain / compare / evaluate	Mechanism, figures from the stimulus, and the comparison the figures are made against
6	evaluate / justify	A ranked position, at least two options tested against at least two criteria, with the interaction named
8–10	extended evaluate	All four option families addressed, all three tests applied, quantified, an overall verdict that is not an average, limitations named, and the further evidence identified

Six traps, each by name: **substitution treated as the only option**, leaving three limbs unwritten; **intensity reported as if it were absolute**, so a rebound goes unnoticed; **emissions assumed to fall on electrification** without the grid factor; **capacity confused with energy**, so annual megawatt-hours are treated as a matched supply; **capital cost omitted** from an affordability claim; and **an offset presented as a reduction**.

Worked examples

Example 1 — scaffolded

A Melbourne household heats with a ducted natural gas system that is 82% efficient and delivers **30 GJ of useful heat** a year. It is considering a reverse-cycle heat pump with a **seasonal COP of 3.5**. Use: natural gas 51.5 kg CO_2-e GJ^{-1}; Victorian grid electricity 0.78 kg CO_2-e kWh^{-1}; gas \$32 GJ^{-1} plus a supply charge of \$1.05 per day; electricity \$0.30 kWh^{-1}; 1 GJ = 277.8 kWh.

(a) Calculate the annual gas consumed and the annual emissions of the existing heater. (2 marks)

Gas input = 30 ÷ 0.82 = **36.6 GJ**. Emissions = 36.6 × 51.5 = 1 885 kg = **1.89 t CO_2-e**.

(b) Calculate the annual electricity consumed and the annual emissions of the heat pump. (2 marks)

Electricity = 30 ÷ 3.5 = 8.57 GJ = 8.57 × 277.8 = **2 381 kWh**. Emissions = 2 381 × 0.78 = 1 857 kg = **1.86 t CO_2-e**.

(c) Calculate the percentage change in emissions, and explain why the change is so small. (3 marks)

(1.86 − 1.89) ÷ 1.89 × 100 = **−1.6%**. It is small because Victorian grid electricity carries about 4.2 times the emissions of natural gas per unit of energy delivered to the house (217 against 51.5 kg CO_2-e GJ^{-1}), so the heat pump has to be more than 4.2 times better at producing heat merely to break even. The break-even COP against an 82% gas heater is 4.2 × 0.82 = **3.4**, and this unit is at 3.5 — barely above it. The emissions gain from electrifying is **contingent on the emissions intensity of the grid**, not intrinsic to the device.

(d) Recalculate the heat pump's emissions at a grid factor of 0.20 kg CO_2-e kWh^{-1}, and state what this shows about the relationship between options 2 and 3. (2 marks)

2 381 × 0.20 = 476 kg = **0.48 t CO_2-e**, which is 75% below the gas heater. Increasing the efficiency of a conversion device and replacing fossil fuels are not independent options: the same appliance swap that is worth almost nothing on today's Victorian grid is worth three-quarters of the emissions on a decarbonised one, so the two options have to be evaluated together and over the life of the asset.

(e) Compare the two options on the affordability test. (3 marks)

Running cost, gas: 36.6 × \$32 = \$1 171, plus a supply charge of 365 × \$1.05 = \$383, giving **\$1 554** if gas is retained for heating alone. Running cost, heat pump: 2 381 × \$0.30 = **\$714**. The annual saving is \$840 if the gas connection is removed and \$457 if it is retained for other appliances — so the *size* of the saving depends on whether this is the household's last gas appliance, which is an interaction, not a detail. Against that saving sits the capital cost of a ducted heat pump retrofit, typically of the order of \$10 000–\$15 000, giving a simple payback of roughly 12 to 18 years at the full saving. The affordability verdict therefore turns on **when** the change is made: at end of life the relevant figure is the incremental cost over a replacement gas unit, which is a fraction of the full price, and the payback is short.

Example 2 — scaffolded

Thrapstone Cold Chain Pty Ltd operates a refrigerated distribution warehouse. Between 2019 and 2025 it insulated the roof and fitted rapid-roll doors and air curtains, replaced fixed-speed compressors with variable-speed units, replaced 380 metal-halide high-bay lamps with LEDs, installed 700 kW of rooftop solar, and introduced a door-discipline and set-point protocol for staff.

Indicator	2019	2025
Electricity purchased from the grid / MWh yr^{-1}	4 200	2 460
On-site solar generation consumed / MWh yr^{-1}	0	640
Total electricity used / MWh yr^{-1}	4 200	3 100
Throughput / kt yr^{-1}	38	46
Peak site demand / kW	980	610

(a) Assign each of the five measures to one of the four options in the dot point. (2 marks)

Roof insulation, rapid-roll doors and air curtains — **improving resource efficiency** (they reduce the heat load the plant must remove). Variable-speed compressors and LED high-bays — **increasing the efficiency of energy conversion devices**. Rooftop solar — **replacing fossil fuels with a non-fossil energy source**. The door-discipline and set-point protocol — **reducing consumption** by behaviour, the organisational equivalent of the dot point's fourth limb.

(b) Calculate the percentage change in energy intensity and in total electricity used. (2 marks)

Intensity 2019 = 4 200 ÷ 38 = 110.5 kWh t^{-1}; 2025 = 3 100 ÷ 46 = 67.4 kWh t^{-1}; change = **−39%**. Total electricity used: (3 100 − 4 200) ÷ 4 200 = **−26%**.

(c) Explain why both figures are needed, and what it means that they point the same way here. (2 marks)

Intensity alone cannot show that consumption fell, because a fall in energy per tonne is consistent with rising total energy if throughput grows — that is the rebound pattern. Here throughput rose 21% and total electricity nonetheless fell 26%, so the efficiency gain was **not** reinvested in additional service: absolute consumption genuinely declined. Reporting only the intensity figure would have concealed whether that was true.

(d) Calculate the annual emissions saving from grid electricity, at 0.78 kg CO_2-e kWh^{-1}. (2 marks)

2019: 4 200 MWh × 0.78 = 3 276 t CO_2-e. 2025: 2 460 × 0.78 = 1 919 t. Saving = **1 357 t CO_2-e yr^{-1}**, a fall of **41%** — larger than the 26% fall in energy used, because 640 MWh of the remaining demand is now met on site.

(e) Explain why doing the efficiency work before installing the solar array reduced the cost of the substitution, and identify one limitation of solar for this site. (3 marks)

The fabric and device measures cut the site's load before the array was sized, so the same proportion of demand is met by a smaller and cheaper array; had the solar gone in first, part of it would have been sized to supply demand that was subsequently eliminated, and that capital would have been stranded. The same sequence cut peak demand from 980 to 610 kW, which reduces network demand charges as well as energy charges. The limitation is timing: a cold store draws power continuously, including overnight, while the array generates only in daylight, so solar supplies 640 of 3 100 MWh — about 21% — and the remaining load is grid-supplied at the prevailing emissions intensity. Closing that gap requires storage, a contracted renewable supply, or shifting load into daylight hours by pre-cooling the chamber, which is the reliability test applied to a substitution option.

Example 3 — unscaffolded

Windermarsh Regional Health Service operates a 120-bed hospital in regional Victoria. Since 2019 it has upgraded the building envelope in two wings, replaced steam-raising gas boilers serving space heating and hot water with high-temperature heat pumps, installed 600 kW of solar, and retained its diesel standby generators, which are tested monthly and must be capable of carrying theatres, intensive care and life-support circuits without interruption.

Indicator	2019	2025
Natural gas / GJ yr^{-1}	41 200	22 600
Grid electricity / MWh yr^{-1}	5 100	5 950
On-site solar consumed / MWh yr^{-1}	0	780
Conditioned floor area / m^2	18 400	21 000
Diesel for standby generator testing / L yr^{-1}	3 100	3 200

Gas \$16 GJ^{-1}; electricity \$200 MWh^{-1}; gas 51.5 kg CO_2-e GJ^{-1}; electricity 0.78 kg CO_2-e kWh^{-1}; 1 MWh = 3.6 GJ.

Evaluate this program against the three tests the study design sets for a sustainable energy future. (8 marks)

Model response (8 marks).

Energy intensity — a large and real improvement. Total delivered energy in 2019 was 41 200 GJ of gas plus 5 100 MWh × 3.6 = 18 360 GJ of electricity, or 59 560 GJ across 18 400 m², an intensity of **3 237 MJ m⁻² yr⁻¹**. In 2025 it was 22 600 GJ of gas plus (5 950 + 780) × 3.6 = 24 228 GJ of electricity, or 46 828 GJ across 21 000 m², an intensity of **2 230 MJ m⁻² yr⁻¹** — a fall of **31%**, achieved while the conditioned floor area grew 14%. Absolute delivered energy fell 21%, so this is not a rebound case: the envelope work and the heat pumps between them cut both the ratio and the total.

Emissions — a much smaller gain than the energy figures suggest, and the reason is the grid. 2019: gas 41 200 × 51.5 = 2 122 t, plus electricity 5 100 MWh × 0.78 = 3 978 t, plus about 8 t from generator testing — **6 108 t CO_2-e**. 2025: gas 22 600 × 51.5 = 1 164 t, plus 5 950 × 0.78 = 4 641 t, plus about 9 t — **5 814 t CO_2-e**. The reduction is **294 t, or 4.8%**, against a 31% improvement in intensity and a 45% cut in gas. The arithmetic is the break-even rule: at 0.78 kg CO_2-e kWh⁻¹ Victorian electricity carries 217 kg CO_2-e GJ⁻¹ against gas at 51.5, so every gigajoule of heat moved from gas to electricity has to be delivered with a COP above roughly 4.2 × the boiler efficiency simply to break even, and high-temperature heat pumps serving a hospital's hot water and heating loads do not comfortably clear that bar. The program has substituted the fuel far more successfully than it has cut the emissions — *at today's grid factor*. That qualification is the finding, not a hedge: the same asset base will deliver a large emissions reduction as Victoria moves towards its legislated 65% renewable share by 2030 and 95% by 2035, and the plant installed now will still be in service then.

Reliability — the test that constrains the whole program, and it is met. A hospital is a critical load: theatres, intensive care and life-support circuits cannot be interrupted, and the standard is availability at 3 a.m. in a storm, not availability on average. Three features of the program respect that. The diesel standby generators were **retained and are tested monthly**, so electrification has not removed the backstop; the solar array is a daytime energy source and has not been treated as a capacity resource — 780 MWh of 6 730 MWh, about 12% of consumption; and the envelope work raises the building's thermal mass and reduces its heat loss rate, which lengthens the time the wards stay habitable if plant fails. One matter the data do not resolve: heat pump capacity has to be sized at the design minimum outdoor temperature, where COP is lowest, and there is no evidence here of the winter design-day performance or of what carries the heating load if a unit fails.

Affordability — favourable, and driven by the fuel switch rather than by price. Gas purchases fell 18 600 GJ, saving 18 600 × \$16 = **\$297 600**. Grid electricity purchases rose 850 MWh, costing 850 × \$200 = **\$170 000** more. Net running cost saving is about **\$128 000 a year**, of which the 780 MWh of self-consumed solar is worth \$156 000 and is what makes the switch pay — without the array the electrification would have been close to cost-neutral. The evaluation is incomplete on this test because no capital cost is given, and a boiler-to-heat-pump conversion plus 600 kW of solar at a hospital is a multi-million-dollar program; a simple payback cannot be calculated, and stating that is the correct answer rather than guessing.

Overall verdict, and two changes. The program is **effective** on resource efficiency and device efficiency, **partially effective** on substitution, and **not yet effective** on the emissions test, which is its own stated purpose — 4.8% in six years is not a trajectory to net zero. It is effective on reliability and, on the running-cost evidence available, on affordability. Two changes follow directly. First, contract or build additional non-fossil supply — the emissions gain is now almost entirely a function of the electricity's emissions intensity, so a power purchase agreement or on-site storage does more than any further device upgrade. Second, publish the seasonal COP measured on site and the winter design-day performance, since the whole emissions case rests on a number nobody has yet verified against the break-even threshold.

Example 4 — unscaffolded

A Ballarat household on the gas network is offered the following package. Its space heating is a ducted gas system, 82% efficient, meeting a useful heat requirement of 24.6 GJ yr⁻¹; hot water is a gas storage unit, 60% efficient, using 12.0 GJ yr⁻¹; cooking is a gas cooktop using 2.4 GJ yr⁻¹; and it runs one petrol car, 12 000 km yr⁻¹ at 8.4 L per 100 km. Gas \$32 GJ⁻¹ with a \$1.05 per day supply charge; electricity \$0.30 kWh⁻¹; feed-in tariff \$0.033 kWh⁻¹; petrol \$1.95 L⁻¹. Emission factors: gas 51.5 kg CO_2-e GJ⁻¹, electricity 0.78 kg CO_2-e kWh⁻¹, petrol 2.3 kg CO_2-e L⁻¹.

#	Measure	Capital / $	Annual energy effect	Annual bill effect / $	Annual emissions effect / t CO_2-e
1	Ceiling insulation top-up and draught sealing	3 400	Useful heat need 24.6 → 18.9 GJ	−224	−0.36
2	Halogen downlights → LED	320	−620 kWh	−186	−0.48
3	Ducted gas heater → heat pump, seasonal COP 4.2 (after measure 1)	13 500	−23.0 GJ gas, +1 250 kWh	−361	−0.21
4	Gas storage hot water → heat-pump unit, COP 3.2	4 200	−12.0 GJ gas, +625 kWh	−196	−0.13
5	6.6 kW rooftop solar, 9 000 kWh yr^{-1}, 45% self-consumed	6 500	+9 000 kWh generated	−1 378	−7.02
6	Thermostat 22 → 20 °C, heat occupied rooms only, cold washing, standby off	0	−150 kWh heating, −300 kWh other	−135	−0.35
7	Gas cooktop → induction	1 900	−2.4 GJ gas, +320 kWh	+19	+0.13
8	Petrol car → used battery electric vehicle, 16.5 kWh per 100 km	22 000	−1 008 L petrol, +1 980 kWh	−1 372	−0.77

Evaluate this package against the three tests, rank the measures for a household that can fund only part of it, and state what the household cannot achieve by these means. (10 marks)

Model response (10 marks).

Assign the measures to the four options first, because the dot point is the marking scheme. Improving resource efficiency: measure 1. Increasing the efficiency of conversion devices: measures 2, 3, 4, 7 and 8 — each replaces a converter with a better one. Replacing fossil fuels with a non-fossil source: measure 5, and measures 3, 4, 7 and 8 in their second aspect, since each moves an end use from a fossil fuel onto electricity that can then be decarbonised. Reducing personal consumption: measure 6. All four limbs are present, which is what a complete package looks like.

The emissions test. The package abates 0.36 + 0.48 + 0.21 + 0.13 + 7.02 + 0.35 − 0.13 + 0.77 = **9.19 t CO_2-e a year**, and **76% of it comes from one measure**: the solar array. That is the correct and slightly counter-intuitive finding for Victoria, and its cause is the same 0.78 kg CO_2-e kWh^{-1} that makes the appliance swaps look weak. Because Victorian grid electricity carries about 4.2 times the emissions of gas per delivered gigajoule, displacing a kilowatt-hour of it is worth a great deal, while shifting a gigajoule of heat from gas to electricity is worth almost nothing until the device clears a break-even COP of 4.2 × the gas appliance's efficiency. Measure 3 clears it (COP 4.2 against a break-even 3.4) and abates only 0.21 t; measure 4 clears it (COP 3.2 against 2.5) and abates 0.13 t; **measure 7 does not clear it** — an induction hob converts rather than pumps heat, so its COP-equivalent is its own efficiency: 0.96 GJ of useful heat from 1.152 GJ of electricity, or **0.83 against a break-even of 1.7**. In ratio terms that is 2.1 times better than the 40%-efficient gas hob where 4.2 times is needed. Either way it falls short by about half, and on the numbers given it *adds* 0.13 t. Every one of those verdicts reverses as the grid decarbonises, which is the single most important qualification in this answer.

The reliability test. No measure degrades the household's service, and one improves it: measure 1 raises the building's ability to hold temperature during an outage. Two qualifications belong here. The array generates only in daylight and only 45% of its output is self-consumed, so it does not make the household independent of the grid; and the heat pump's rated COP falls on the coldest Ballarat mornings, which is exactly when the heat is wanted, so a seasonal COP of 4.2 must be a seasonal figure and not a nameplate one. The electric vehicle introduces a new dependency — a household with a single EV and no charging redundancy is more exposed to an extended outage than one with a petrol car — and an evaluation should say so rather than treat electrification as costless on this test.

The affordability test, and the ranking that follows. Total capital is \$51 820 against total annual savings of \$3 833 — a portfolio payback of about 13.5 years, which conceals an enormous spread. Ranked by simple payback: measure 6 (immediate, no capital), measure 2 (1.7 years), measure 5 (4.7 years), measure 1 (15 years), measure 8 (16 years), measure 4 (21 years), measure 3 (37 years), measure 7 (never, on running cost alone). Ranked by emissions abated per dollar of capital the order is identical, and on that metric it is measure 2, not measure 5, that leads the measures needing capital — **1.50 t per \$1 000 against measure 5's 1.08** — with measure 6 ahead of both at 0.35 t for no capital at all, and everything else an order of magnitude behind (measure 1 at 0.11, measure 8 at 0.035, measure 4 at 0.031, measure 3 at 0.016, measure 7 negative). Measure 5 leads on **total** abatement, 7.02 of the 9.19 t, which is a different claim and the one that matters for the package as a whole. For a household that can fund only part of the package the recommended order is therefore **6, 2, 5, then 1**, which captures \$1 923 of the \$3 833 in annual saving and 8.2 of the 9.2 tonnes for \$10 220 — under a fifth of the capital.

Three interactions that a mark-scoring answer must name. First, **sequence**: measure 1 cuts the useful heat requirement from 24.6 to 18.9 GJ before the heat pump is sized, so the heat pump is smaller, cheaper and cheaper to run — installing measure 3 first would strand part of its capacity. Second, **the last-appliance effect**: measures 3, 4 and 7 individually look poor, but together they remove the household's last gas appliance and allow the connection to be abandoned, saving the \$383 annual supply charge that no individual measure can claim. That converts the combined payback on 3, 4 and 7 from about 36 years to about 21, and it is the reason measure 7 — which increases emissions and running cost on its own — belongs in the package. Third, **self-consumption coupling**: the array supplies only 45% of its output to the house now, but adding the heat pumps and the EV shifts load into daylight and raises that share, so measure 5 gets *better* as measures 3, 4 and 8 are added. The measures are not additive, and treating them as a list of independent line items is the standard error.

Timing and lock-in. Measures 3, 4 and 7 should be taken at the end of the existing appliance's life, when the relevant cost is the difference between the two replacements rather than the full purchase price; the paybacks above are worst-case figures for early replacement. Against that, an appliance replaced with gas today locks in roughly fifteen years of gas burning, and Victoria's ban on reticulated gas connections for new dwellings requiring a planning permit (Amendment VC250, from 1 January 2024) signals the direction the network is travelling.

What this household cannot achieve, and why it matters. The package reaches the household's direct energy use only. It does not reach the **embodied energy** in the household's food, goods, housing and services, which is larger than its direct use and is not addressed by any thermostat. It cannot change the emissions intensity of the grid that determines most of its own verdicts — that is a societal decision made under the *Renewable Energy (Jobs and Investment) Act 2017* (Vic) and the Commonwealth's Capacity Investment Scheme, not a household one. And it is available only to a household that owns its home and can raise \$50 000: a renter cannot install any of measures 1, 3, 4, 5 or 7, which is precisely why the minimum rental standards phasing in from 1 March 2027 and the Victorian Energy Upgrades program exist. An evaluation that concludes "households should do this" without stating which households can is failing the affordability test and the intragenerational equity principle at the same time.

Practice questions

Scaffolded

Q1. State the three requirements the study design places on a sustainable energy future. (1 mark)

Q2. Distinguish between energy and an energy service, giving one example. (2 marks)

Q3. Distinguish between improving resource efficiency and increasing the efficiency of an energy conversion device, giving one example of each. (2 marks)

Q4. Explain why replacing a gas appliance with an electric one does not automatically lower greenhouse gas emissions. (2 marks)

Q5. For each measure below, identify which of the four options in the dot point it belongs to. (3 marks)

Measure	Option
Adding ceiling insulation and sealing draughts around external doors	
Replacing halogen downlights with LED lamps of the same light output	
Setting the thermostat to 20 °C and heating only occupied rooms	

Q6. An office replaces 240 halogen downlights (50 W each, 900 lm) with LED lamps (7 W each, 900 lm). The lights operate 2 500 hours a year.

a. Calculate the annual electricity saving in kWh. (1 mark)

b. Using luminous efficacy, explain why this is an increase in conversion-device efficiency, and state one resource-efficiency co-benefit. (2 marks)

Q7. A Bendigo school's buildings require 96 000 kWh of useful heat a year, currently supplied by electric resistance panel heaters. The school is considering reverse-cycle heat pumps with a seasonal COP of 3.6. Electricity is 0.78 kg CO_2-e kWh^{-1}.

a. Calculate the annual electricity use and annual emissions before and after. (2 marks)

b. The 3.6 figure is taken from the manufacturer's brochure. State one reason the school may not achieve it, and explain the consequence for the emissions saving you calculated. (2 marks)

Q8. A Melbourne household's ducted gas heater is 82% efficient and delivers 28 GJ of useful heat a year. Natural gas is 51.5 kg CO_2-e GJ^{-1}; 1 GJ = 277.8 kWh.

a. Calculate the heater's annual emissions. (2 marks)

b. The household replaces it with a heat pump of seasonal COP 4.0. Calculate the annual emissions at Victoria's current grid factor of 0.78 kg CO_2-e kWh^{-1} and at a projected 0.15 kg CO_2-e kWh^{-1}, and state what the comparison shows. (2 marks)

Q9. Larrowby Shire Council replaced its street lighting with LEDs, cutting the electricity used per lamp by 68%. It then used part of the saving to light 24 previously unlit laneways.

a. Explain what the rebound effect is, and how it applies here. (2 marks)

b. State what data would show whether the upgrade reduced the council's absolute lighting electricity use, and explain why intensity data alone cannot answer that question. (2 marks)

Q10. A student writes: "If every Victorian household switched off its standby appliances, Victoria would meet its 2035 emissions reduction target."

Evaluate this claim, using an order-of-magnitude estimate. (4 marks)

Unscaffolded

Q11. Explain why purchasing carbon offsets, or a "100% renewable" retail electricity product, is not one of the four options named in the dot point, and state what such a purchase does and does not change. (2 marks)

Q12. Explain why improving resource efficiency is normally undertaken before substituting the energy source, giving two reasons. (3 marks)

Q13. Meldrith Dairy Co-operative reports the following, and claims: *"We have cut our energy use by 16% and replaced fossil fuels."*

Indicator	2019	2025
Milk processed / ML yr^{-1}	118	176
Total energy used / TJ yr^{-1}	214	268
Energy intensity / MJ L^{-1}	1.81	1.52
Share of energy from natural gas / %	71	48
Share of energy from grid electricity / %	29	52

Evaluate the claim. (4 marks)

Q14. Explain why an energy option can lower the total cost of energy services across a state and still leave some households worse off, and identify two features of a program design that reduce that risk. (4 marks)

Q15. Hoxby Freight Pty Ltd states in its annual report: *"Our depot now runs on 100% renewable electricity, so our energy use is carbon neutral, and we have improved our resource efficiency."* The depot operates a fleet of 34 diesel prime movers.

Evaluate this statement. (5 marks)

Q16. Return to Meldrith Dairy in Q13. Three projects are proposed. Gas is \$14 GJ^{-1} and electricity \$0.16 kWh^{-1}; gas 51.5 kg CO_2-e GJ^{-1}, electricity 0.78 kg CO_2-e kWh^{-1}.

Project	Capital / \$	Effect
A Recover pasteuriser waste heat to pre-heat wash water	1 400 000	34 000 GJ yr^{-1} less gas
B Replace a gas boiler (88% efficient, 35 TJ yr^{-1} of useful heat) with a high-temperature heat pump, COP 2.8	4 200 000	Gas duty transferred to electricity
C 4 MW solar array generating 6 200 MWh yr^{-1}, all self-consumed	5 600 000	Displaces purchased electricity

Rank the three projects, justify the ranking against the three tests, and state the condition under which your ranking of B would change. (6 marks)

Q17. A Victorian secondary school runs a "Switch It Off" campaign that cuts electricity use 6% during term 3. By term 1 of the following year, consumption has returned to its previous level.

Explain why options that rely on reduced personal consumption are less durable than efficiency and substitution options, and describe a redesigned program that would make the saving persist. (6 marks)

Q18. Brackwell Brickworks Pty Ltd fires bricks in a natural gas tunnel kiln at 1 060 °C and dries the green bricks in a separate gas-fired dryer (85% efficient). It uses 96 000 GJ yr^{-1} of gas in the kiln, 34 000 GJ yr^{-1} in the dryer and 4 800 MWh yr^{-1} of electricity. Gas is \$16 GJ^{-1} and electricity \$180 MWh^{-1}.

Option	Capital / \$M	Effect
A Recover kiln cooling-zone waste heat to the dryer	2.6	Dryer gas −26 000 GJ yr^{-1}; electricity +140 MWh yr^{-1}
B Recuperative burners on the kiln	1.8	Kiln gas −11 500 GJ yr^{-1}
C Substitute 30% of kiln gas with certified biomethane	0.4	28 800 GJ yr^{-1} switched; \$15 GJ^{-1} premium
D Replace the gas dryer with a high-temperature heat pump, COP 2.6	5.2	All 34 000 GJ yr^{-1} of dryer gas transferred to electricity

Evaluate these options against the three tests, and recommend an order of implementation. (8 marks)

Q19. Nyeburn Shire Council has $37 million for a four-part energy plan covering a town of 4 200 dwellings in north-west Victoria. Gas is assumed to be replaced from appliances of 75% average seasonal efficiency by heat pumps of seasonal COP 3.5.

Workstream	Capital / $M	Energy effect	Emissions effect / t CO_2-e yr^{-1}	Reach
W1 Ceiling insulation and draught sealing, 900 low-income dwellings	3.4	−5 800 GJ gas	−299	900 dwellings
W2 Heat-pump hot water and heating subsidy, 1 500 dwellings	12.0	−27 000 GJ gas, +1 610 MWh	−135	1 500 dwellings
W3 12 MW community solar farm with a 20 MWh battery	21.0	+24 500 MWh yr^{-1} generated	−19 110	whole town
W4 Energy coaching, in-home displays and a schools program	0.6	−1 900 MWh, −3 100 GJ gas	−1 642	4 200 dwellings

Evaluate the plan: identify which option in the dot point each workstream belongs to, assess the workstreams against the three tests, name two interactions between them, and state what further evidence you would need before committing the funds. (10 marks)

Answers

Q1. That it produces lower greenhouse gas emissions, and supplies energy services that are reliable and affordable — all three at once.

Q2. Energy is the input, measured in joules or kilowatt-hours; an energy service is the useful outcome the energy is wanted for, such as a room held at 20 °C, refrigerated food or a completed trip. The same service can be delivered with different quantities of energy, which is what makes four options possible.

Q3. Resource efficiency changes the system so the service needs less energy (insulating a roof, recovering waste heat, fixing compressed-air leaks). Device efficiency changes the converter so a given input yields more useful output (an LED for a halogen, a heat pump for a resistance heater).

Q4. Because the emissions move to the generator rather than disappearing. Whether the total falls depends on the grid emission factor and on how much more efficient the electric device is: Victorian grid electricity is 217 kg CO_2-e GJ^{-1} against natural gas at 51.5, so the electric device must be more than about 4.2 times better at delivering the service to break even.

Q5. Insulation and draught sealing — improving resource efficiency. Halogen to LED — increasing the efficiency of energy conversion devices. Thermostat at 20 °C and heating occupied rooms only — reducing personal energy consumption.

Q6. a. (50 − 7) × 240 × 2 500 ÷ 1 000 = **25 800 kWh yr⁻¹**. **b.** Efficacy rises from 900 ÷ 50 = 18 lm W^{-1} to 900 ÷ 7 = 129 lm W^{-1}, about seven times more light per watt, so more of the input becomes the useful output. Co-benefit: the 43 W per lamp that used to become waste heat inside the conditioned space no longer does, so the cooling load falls as well.

Q7. a. Before: resistance heating is ~100% efficient, so 96 000 kWh, emitting 96 000 × 0.78 = 74 880 kg = **74.9 t CO_2-e**. After: 96 000 ÷ 3.6 = 26 667 kWh, emitting **20.8 t CO_2-e** — a fall of 72%. **b.** A brochure COP is measured at a mild rated outdoor temperature, and COP falls as the temperature difference widens (12F), so on cold Bendigo mornings — when the heat is actually wanted — the achieved seasonal COP will be lower. The consequence is that electricity use and emissions will both be higher than calculated: at a seasonal COP of 2.8 rather than 3.6, consumption is 34 286 kWh and emissions 26.7 t, so the saving falls from 54.1 to 48.2 t. The verdict does not reverse, but the quoted figure is optimistic.

Q8. a. Gas input = 28 ÷ 0.82 = 34.15 GJ; emissions = 34.15 × 51.5 = 1 759 kg = **1.76 t CO_2-e**. **b.** Electricity = 28 ÷ 4.0 = 7.0 GJ = 1 944 kWh. At 0.78: **1.52 t**, 14% below gas. At 0.15: **0.29 t**, 83% below gas. It shows the emissions benefit of electrification depends almost entirely on the emissions intensity of the electricity, so options 2 and 3 must be evaluated together and across the life of the asset.

Q9. a. The rebound effect is the reinvestment of an efficiency saving in additional service, so that the energy saved is partly or wholly consumed again. Here the 68% saving per lamp was partly spent on lighting 24 more laneways, so the fall in total consumption is smaller than the per-lamp figure implies. **b.** Total annual lighting electricity in kWh before and after, together with the lamp count. Intensity — energy per lamp — cannot answer it, because energy per lamp can fall while the number of lamps rises enough to leave the total unchanged or higher.

Q10. Not supportable. Victorian residential electricity use is of the order of 13 000 GWh a year; standby loads are a few per cent of it, so eliminating them entirely saves of the order of 400 GWh, which at 0.78 kg CO_2-e kWh^{-1} abates about 0.3 Mt CO_2-e — well under 1% of Victoria's emissions. The legislated 2035 target is 75–80% below 2005 levels, requiring reductions of tens of megatonnes. Reducing personal consumption is a genuine option, but it acts on a small part of demand and not at all on the emissions intensity of supply.

Q11. The four options change physical energy flows — the energy needed, the efficiency of the device, the source, or the quantity of service demanded. An offset or a renewable retail product is a market instrument that claims abatement elsewhere. It may reduce net emissions if the abatement is additional and durable, but it changes neither the energy used, nor the device efficiency, nor the reliability or the underlying cost of the service, so two of the three tests are untouched.

Q12. Any two, developed: efficiency reduces the load, so the substitute supply and its storage or firming can be smaller and cheaper — doing substitution first strands capacity in an oversized asset; efficiency measures usually have a lower cost per tonne abated and a shorter payback, so they release capital for the more expensive substitution; and efficiency reduces peak demand as well as total energy, which eases the reliability test that a variable renewable supply must meet.

Q13. The claim fails on both limbs. Intensity fell 16% (1.81 → 1.52 MJ L^{-1}), but absolute energy use **rose** 25% (214 → 268 TJ) because throughput rose 49%; the co-operative has reported the ratio as though it were the total. On substitution, gas fell from 152 to 129 TJ — only 15% in absolute terms, and 48% of energy is still gas, so "replaced fossil fuels" overstates a partial shift. Worse, the replacement is Victorian grid electricity at 217 kg CO_2-e GJ^{-1} against gas at 51.5, so unless the new electrical equipment is more than about four times as efficient as the gas plant it replaced, total emissions have risen, not fallen. No emissions figure is reported, which is the figure the claim needs.

Q14. Because the average and the distribution are different things. Households that cannot raise the capital — renters, apartment dwellers, low-income owners — cannot take up the option, while as adopters reduce their volumetric consumption the fixed costs of the network are recovered from a smaller volume, raising unit charges for those who did not adopt. The split incentive between landlord and tenant compounds it. Two design features from: capital-free access such as no-interest loans or full subsidy for low-income households; minimum standards for rental properties so the benefit does not depend on the landlord's incentive; recovering program cost from a broad base rather than a volumetric tariff; and direct upgrades to social housing.

Q15. Three separate failures. "100% renewable electricity" bought as a retail product or certificates is a market claim — the electricity physically delivered is the prevailing grid mix — so the emissions effect depends on whether the generation is additional. "Carbon neutral" is false regardless: 34 diesel prime movers are scope 1 combustion emissions that no electricity product touches, and the statement ignores embodied energy. And nothing here evidences resource efficiency, which is energy per unit of service — tonne-kilometres per litre, kWh per pallet handled — and is unchanged by who supplies the electrons. Two of the four options are untouched and one of the three tests is unaddressed.

Q16. Rank **A, C, B**. A: 34 000 GJ × 51.5 = 1 751 t abated and $476 000 saved for $1.4 M, a 2.9-year payback and the cheapest tonne available; it also reduces the duty B would have to serve. C: 6 200 MWh × 0.78 = 4 836 t abated and $992 000 saved for $5.6 M, a 5.6-year payback and the largest single abatement, subject to whether a seasonal dairy load really absorbs all output in daylight. B: gas input 35 ÷ 0.88 = 39.8 TJ, so 2 051 t and $557 000 now; the heat pump needs 35 ÷ 2.8 = 12.5 TJ = 3 472 MWh, giving 2 708 t and $556 000 — cost-neutral and **657 t worse** on emissions at today's grid factor, for $4.2 M. B becomes worthwhile when the grid factor falls below 51.5 × 2.8 ÷ (277.8 × 0.88) = **0.59 kg CO_2-e kWh^{-1}**; Victoria is at 0.78.

Q17. Behavioural savings decay because nothing physical changed: they depend on continuing attention, and attention is lost to staff and student turnover, competing priorities and the absence of feedback once the campaign ends. Efficiency and substitution embed the saving in hardware that keeps delivering it without anyone remembering to act. A durable redesign converts behaviour into settings and equipment — timers, occupancy sensors and locked building-management setpoints; sub-metering with a visible dashboard; a procurement rule that only appliances above a nominated star rating may be bought; a named staff owner and an annual audit; and fabric measures so the underlying load falls. Savings should be judged against a weather-normalised baseline so a mild term is not read as success.

Q18. A first: −26 000 GJ gas and +140 MWh gives −1 339 + 109 = **−1 230 t** and about $391 000 saved for $2.6 M, a 6.6-year payback, with no reliability effect. B next: −11 500 GJ gives **−592 t** and $184 000 for $1.8 M, a 9.8-year payback. C: 28 800 GJ of biogenic fuel abates about **1 483 t** for only $0.4 M of capital, but costs $432 000 a year in premium and depends on a contracted feedstock — cheap to start, exposed on affordability and supply security. D increases emissions today: 28 900 GJ of useful heat at COP 2.6 needs 3 088 MWh, so −1 751 + 2 409 = **+658 t**, roughly cost-neutral, for $5.2 M; it only abates once the grid factor falls below 0.57 kg CO_2-e kWh^{-1}. Order: **A, B, then C or D depending on the grid trajectory** — and A must precede D, because A removes most of the dryer's gas duty and so shrinks D from a 34 000 GJ problem to an 8 000 GJ one. The kiln at 1 060 °C is genuinely hard to abate and none of the four options decarbonises it fully.

Q19. W1 is improving resource efficiency; W2 is device efficiency combined with substitution; W3 is replacing fossil fuels; W4 is reducing personal consumption. On emissions, W3 dominates: 19 110 of the 21 186 t abated, at $1 099 per annual tonne, against W4 at $365, W1 at $11 371 and W2 at $88 889. On reliability, W3's battery firms the daytime resource and W1 improves the resilience of dwellings during outages; W2 must be sized at winter design conditions. On affordability, W4 is cheapest per tonne but least durable, and W1 is poor per tonne yet delivers comfort, health and equity benefits to households that can access no other workstream. Two interactions: W1 must precede W2 in the same dwellings, or the heat pumps are oversized for a load that later falls; and W3 raises the emissions value of W2 over time, since W2 abates only 135 t at 0.78 kg CO_2-e kWh^{-1} but far more as the local supply decarbonises. Further evidence: metered rather than deemed savings, a persistence estimate for W4, the winter design-day performance and seasonal COP behind W2, the solar farm's modelled capacity factor and self-consumption profile, and the distribution of benefits across income groups and between owners and renters.

Fully-worked solutions

Q1. (1 mark) One mark for all three: **lower greenhouse gas emissions**, **reliable** energy services and **affordable** energy services. Answers giving only "lower emissions" do not score. The three are set out in the dot point as simultaneous requirements, and the reason the study design lists all three is that an option is easy to design if only one of them has to be satisfied — the difficulty, and the examinable content, is in satisfying all three at once.

Q2. (2 marks) One mark for the distinction, one for the example. **Energy** is a physical input, measured in joules, megajoules or kilowatt-hours. An **energy service** is the useful outcome for which the energy is wanted: a room maintained at 20 °C, food held below 4 °C, a lit workspace, a hot shower, a 12 km trip. The distinction matters because it defines the target of an evaluation. If the objective is "supply the same number of joules from a cleaner source", only one option exists. If the objective is "deliver the same service", four exist, because the service can also be delivered with less energy, with the same energy converted better, or by demanding less of the service.

Q3. (2 marks) One mark for the distinction, one for a matched pair of examples. **Improving resource efficiency** acts on the *system* so that the service requires less energy in the first place: insulating a building shell, recovering waste heat from one process to serve another, fixing compressed-air leaks, right-sizing plant, using recycled rather than primary material. **Increasing the efficiency of an energy conversion device** acts on the *converter*: an LED lamp in place of a halogen, a combined-cycle turbine in place of an open-cycle one, a heat pump in place of a resistance heater. A useful test — if the measure would still save energy with the device unchanged, it is a resource-efficiency measure.

Q4. (2 marks) One mark for the emissions moving, one for the condition that decides the outcome. Electrifying an end use removes the emissions from the site's flue and adds them at the generator, so what changes is the *location* of the emissions, not necessarily the *quantity*. Whether the quantity falls depends on two numbers: the grid emission factor, and the ratio of the electric device's performance to the gas device's efficiency. In Victoria, at 0.78 kg CO_2-e kWh^{-1}, grid electricity carries 0.78 × 277.8 = 217 kg CO_2-e per gigajoule delivered, against 51.5 kg for natural gas — about 4.2 times as much — so the electric device has to be more than 4.2 times better at producing the service simply to break even. Credit an answer that states this as the break-even COP rule.

Q5. (3 marks) One mark each. Insulation and draught sealing reduce the heat the building loses, so less heat has to be supplied: **improving resource efficiency**. LED lamps deliver the same 900 lm from 7 W rather than 50 W: **increasing the efficiency of energy conversion devices**. Lowering the thermostat and heating fewer rooms provides *less service* by choice, with no change to the building or the appliance: **reducing personal energy consumption**. The third is the one most often mis-assigned to efficiency; the distinguishing question is whether the occupant receives the same service afterwards.

Q6. (3 marks)

a. (1 mark) Power saved per lamp = 50 − 7 = 43 W. Annual energy saved = 43 × 240 × 2 500 = 25 800 000 Wh = **25 800 kWh yr^{-1}**.

b. (2 marks) One mark for the efficacy comparison, one for the co-benefit. **Luminous efficacy** is the useful output — lumens — per watt of input. The halogen delivers 900 ÷ 50 = **18 lm W^{-1}**; the LED delivers 900 ÷ 7 = **129 lm W^{-1}**, about seven times as much light per watt for identical light output, which is precisely the definition of a more efficient conversion device. The co-benefit belongs to a different option family and is worth naming as such: the 43 W per lamp that formerly appeared as waste heat inside a conditioned space no longer does, so the air conditioning has 43 × 240 = 10.3 kW less internal gain to remove during cooling hours. That saving is a **resource-efficiency** gain produced by a device-efficiency measure — an interaction, and a good illustration that the four options are not watertight compartments. Note that in winter the removed heat was doing some useful work, so the net benefit is smaller in a heating-dominated climate.

Q7. (4 marks)

a. (2 marks) One mark for each pair. Electric resistance heating converts essentially all the electricity into heat, so delivering 96 000 kWh of heat requires **96 000 kWh** of electricity, emitting 96 000 × 0.78 = 74 880 kg = **74.9 t CO_2-e yr^{-1}**. With heat pumps at COP 3.6, electricity = 96 000 ÷ 3.6 = **26 667 kWh**, emitting 26 667 × 0.78 = 20 800 kg = **20.8 t CO_2-e yr^{-1}**. The saving is 54.1 t, a reduction of **72%**.

b. (2 marks) One mark for a reason, one for the quantified consequence. **The reason.** A brochure COP is a rated figure, measured at a mild standard outdoor temperature. As 12F establishes, a heat pump's ceiling collapses as the temperature difference it works across widens, so performance is worst on the coldest mornings — which is precisely when a Bendigo school's heating load is greatest. Accept also: cycling and defrost losses; oversized or poorly commissioned plant; distribution losses in ducts running through an unconditioned roof space; or the units being run at a higher flow temperature than the rating condition. What the answer must show is that the **seasonal** COP achieved in service is the relevant number, and it is lower than the rated one.

The consequence. Electricity use varies inversely with COP, so the emissions saving shrinks. At a seasonal COP of 2.8 rather than 3.6, consumption is 96 000 ÷ 2.8 = **34 286 kWh** and emissions 34 286 × 0.78 = **26.7 t CO_2-e**, so the saving falls from 54.1 t to **48.2 t** — about 11% less abatement than claimed. The direction of the verdict is unchanged, because resistance heating at COP 1 is far worse either way; what changes is the size of the benefit, and therefore any payback or cost-per-tonne figure built on it. The general point, and the one worth carrying into every question in this subtopic, is that a rated performance figure is an input to an evaluation and should be reported with its source and its uncertainty, not treated as a measurement.

Q8. (4 marks)

a. (2 marks) One mark for the gas input, one for the emissions. Gas input = useful heat ÷ efficiency = 28 ÷ 0.82 = **34.15 GJ**. Emissions = 34.15 × 51.5 = 1 758.7 kg = **1.76 t CO_2-e yr^{-1}**.

b. (2 marks) One mark for both values, one for the interpretation. Electricity = 28 ÷ 4.0 = 7.0 GJ = 7.0 × 277.8 = **1 944 kWh**. At 0.78 kg CO_2-e kWh^{-1}: 1 944 × 0.78 = 1 517 kg = **1.52 t**, which is (1.52 − 1.76) ÷ 1.76 = **−14%** against the gas heater. At 0.15 kg CO_2-e kWh^{-1}: 1 944 × 0.15 = 292 kg = **0.29 t**, which is **−83%**. The comparison shows that almost all of the emissions benefit of electrification is a property of the *grid*, not of the appliance: the identical heat pump saves a seventh of the emissions on today's Victorian grid and five-sixths on a decarbonised one. Since the appliance will last fifteen years or more, the correct evaluation is made across the asset's life against the projected grid factor, not at a single instant.

Q9. (4 marks)

a. (2 marks) One mark for the definition, one for the application. The **rebound effect** is the phenomenon in which part or all of the energy saved by an efficiency improvement is consumed again, because the improvement makes the service cheaper and so more of it is taken. Here the LED conversion cut consumption per lamp by 68%, and the council then spent part of the saving on lighting 24 laneways that were previously dark. The efficiency gain per lamp is entirely real; the reduction in the council's total lighting electricity is smaller than 68%, by however much the new lamps consume. Note that this is not necessarily a bad decision — the additional lit laneways are an additional service, with safety and amenity benefits — but it must not be reported as though the 68% figure described the council's consumption.

b. (2 marks) One mark for the data, one for the explanation. What is needed is the **total annual lighting electricity in kWh, before and after**, together with the lamp count in each year, so that the change in the total can be separated from the change per lamp. Intensity data — energy per lamp, or per kilometre of street lit — cannot answer the question, because intensity is a ratio and a ratio can improve while its numerator rises: if consumption per lamp falls 68% and the number of lamps rises by more than a factor of about three, total consumption increases. This is the general rule for all four options: **always report the absolute quantity beside the ratio**.

Q10. (4 marks) One mark for the estimate, one for the target comparison, one for the correct verdict, one for what the claim gets right. **The estimate.** Victorian residential electricity consumption is of the order of **13 000 GWh a year**.

Standby loads are a few per cent of household electricity — take 3%, which is about **400 GWh**. At Victoria's grid emission factor of 0.78 kg CO_2-e kWh^{-1}, that is 400 000 000 × 0.78 = 312 000 000 kg ≈ **0.3 Mt CO_2-e a year**. State the assumptions; an order-of-magnitude estimate with its assumptions stated is a stronger answer than an unsupported assertion.

The comparison. Victoria's legislated interim target under the *Climate Change Act 2017* (Vic) is **75–80% below 2005 levels by 2035**, on the way to net zero by 2045, and Victoria's annual emissions are of the order of tens of megatonnes. Meeting the target requires reductions measured in tens of megatonnes; the standby measure delivers a few tenths of one. It is under 1% of what is required, and probably nearer a fraction of a per cent.

The verdict, correctly worded. The claim is **not supportable by two to three orders of magnitude**. That is not an argument against reducing personal consumption, which the study design names as one of the four options and which has genuine merits — it needs no capital, it is available to renters and low-income households who can access none of the other three, and it takes effect immediately. The error is one of scale and of mechanism: reducing personal consumption acts on a minority share of demand and does nothing at all to the emissions intensity of supply, which is where the large reductions have to come from. Credit an answer that also notes that most of the energy consumed on a household's behalf is embodied in the goods, food, housing and services it buys, and is untouched by a standby switch.

Q11. (2 marks) One mark for the category distinction, one for what is and is not changed. The four options in the dot point all alter a **physical** quantity: the energy the service requires, the efficiency of the converter, the source of the energy, or the amount of service demanded. An offset, or a retail "100% renewable" product backed by certificates, is a **financial and accounting instrument**. It may reduce net emissions, but only if the abatement it represents is genuinely additional — that is, it would not have occurred anyway — and durable. What it certainly does not change is the energy the site consumes, the efficiency with which the site converts it, the reliability of the supply, or the real cost of producing the service; it adds a cost. So two of the study design's three tests are untouched by it, and none of the four options has been exercised. An evaluation should treat such a claim as a statement about the buyer's accounts rather than about the buyer's energy system.

Q12. (3 marks) One mark for the framing, one for each of two developed reasons. **Framing.** Efficiency and substitution are not alternatives but stages, and the order matters because a measure that reduces the *load* also reduces the *size* of everything downstream that must serve it.

Reason 1 — asset sizing. If demand is cut before the substitute supply is designed, the array, the heat pump, the battery and the network connection are all smaller and cheaper for the same proportion of demand met. Reversing the order means part of the new supply is built to serve demand that is subsequently eliminated, and that capital is stranded. This applies at every scale, from a house to a state.

Reason 2 — cost per tonne and cash flow. Efficiency measures generally abate at a lower cost per tonne and pay back faster — waste heat recovery and lighting are commonly under five years, while a fuel switch is often over ten — so doing them first releases the operating saving that helps finance the substitution.

Accept as an alternative second reason: **the reliability test**. Efficiency reduces peak demand as well as total energy, which reduces the quantity of firming, storage or backup a variable renewable supply must be paired with, making the substitution easier to pass on the reliability criterion as well as cheaper.

Q13. (4 marks) One mark for the intensity-versus-absolute point with figures, one for the incomplete substitution with figures, one for the emissions-intensity point, one for a correctly worded verdict. **"Cut our energy use by 16%" is false as stated.** What fell 16% was the **intensity**: 1.81 → 1.52 MJ L^{-1}, a change of (1.52 − 1.81) ÷ 1.81 = **−16.0%**. Absolute energy use **rose** from 214 to 268 TJ, an increase of **+25%**, because milk processed rose from 118 to 176 ML, an increase of 49%. The efficiency gain is real and it was more than consumed by growth — the classic rebound pattern. Reporting the ratio as though it were the total is the error.

"Replaced fossil fuels" overstates a partial shift. Gas was 0.71 × 214 = **152 TJ** in 2019 and 0.48 × 268 = **129 TJ** in 2025, a fall of only **15%** in absolute terms, and gas remains **48%** of the co-operative's energy. Electricity rose from 62 to 139 TJ, an increase of 124%.

The emissions question the claim never asks. Victorian grid electricity is 217 kg CO_2-e per gigajoule delivered against natural gas at 51.5 — about 4.2 times as much — so shifting energy from gas to grid electricity **increases**

emissions unless the electrical equipment is more than about four times as efficient as the gas plant it replaced. On the figures given, the emissions attributable to this energy use rose from about 21 300 to about 36 800 t CO_2-e, an increase of roughly 73%. No emissions figure appears in the report, and that is the figure the claim requires.

Verdict. Neither limb of the claim is supported. The correct statement is that Meldrith improved its energy intensity by 16% while increasing absolute energy use by 25% and shifting part of its fuel mix from gas to grid electricity, with an emissions effect that is adverse at Victoria's current grid emission factor and will improve as the grid decarbonises.

Q14. (4 marks) Two marks for the mechanisms, one for each of two design features. **Why an average can improve while individuals are made worse off.** Three mechanisms, and any two developed will score. First, the **capital barrier**: insulation, heat pumps, solar and electric vehicles all require money up front to earn a saving later, so the households that most need the bill relief are the least able to access it, and renters and apartment dwellers frequently cannot install them at all. Second, **cost shifting through the tariff**: network costs are largely fixed, so as adopters reduce their volumetric consumption the same fixed cost is recovered from a smaller volume, and the unit charge rises for those who did not adopt — the non-adopters subsidise the adopters. Third, the **split incentive**: the landlord pays for the upgrade and the tenant receives the bill saving, so the investment is not made even where it is economic. The result is that a program can lower total system cost and simultaneously widen the gap between households, which is an **intragenerational equity** failure in the sense 12G and 3B define.

Two design features. From: capital-free access — full subsidy, or a no-interest loan repaid from the saving — targeted at low-income households; **minimum standards for rental properties**, so the benefit does not depend on a landlord's incentive, as Victoria's rental standards do from 1 March 2027; recovering program costs from a broad revenue base rather than a volumetric energy tariff, so non-adopters do not fund adopters; direct upgrade programs for social housing; and rebalancing network tariffs so that the fixed component reflects the cost of the connection rather than being recovered from volume.

Q15. (5 marks) *Model response (5 marks).*

The statement makes three claims and none of them survives.

"Runs on 100% renewable electricity." The depot is connected to a grid carrying the prevailing generation mix; no retail product changes which electrons arrive. What has been bought is a contractual claim backed by certificates, and its emissions effect depends entirely on **additionality** — whether the generation exists because of this purchase, or was going to be built anyway and has simply been re-labelled. The claim may be legitimate; it is not self-evidently so, and the report offers no evidence either way.

"Our energy use is carbon neutral." This is false regardless of how the electricity claim is resolved, because **34 diesel prime movers** are the dominant energy use at a freight depot and their combustion emissions are scope 1 — burnt on site, in the company's own assets, and untouched by an electricity contract. A rough scale check makes the point: a prime mover covering 100 000 km a year at about 40 L per 100 km burns of the order of 40 000 L, and at roughly 2.7 kg CO_2-e L^{-1} that is about 108 t per vehicle, or of the order of 3 700 t across the fleet — very likely more than the depot's entire electricity footprint. The statement has drawn its boundary around the part of the operation that suits the conclusion.

"We have improved our resource efficiency." Nothing in the statement bears on this at all. Resource efficiency is energy per unit of **service** — kWh per pallet handled, MJ per tonne-kilometre, litres per 100 tonne-km — and it is unaffected by who generates the electricity. Buying a different electricity product changes the supplier, not the depot's consumption, its lighting, its refrigeration, its building fabric or its fleet's fuel consumption. The company has confused a substitution claim with an efficiency claim, which is exactly the conflation the four-option framework exists to prevent.

What would support the claims. Metered energy per unit of throughput across at least two comparable years; the scope 1, 2 and 3 inventory with its boundary stated; evidence of additionality for the renewable product, such as a power purchase agreement with a named new facility; and a fleet decarbonisation measure of some kind, since two of the four options — resource efficiency and reducing consumption — are entirely absent from the depot's program.

Q16. (6 marks) One mark for each project correctly quantified, one for the ranking, one for the sequencing point, one for the threshold condition. **Project A — recover pasteuriser waste heat.** 34 000 GJ of gas no longer burnt: emissions 34 000 × 51.5 = **1 751 t CO_2-e** abated; cost saving 34 000 × $14 = **$476 000**; capital $1.4 M, so simple payback **2.9 years**. Nothing about the reliability of the plant changes — the recovered heat replaces purchased fuel in an existing service. This is the cheapest tonne on the table and the fastest payback, and it has no downside on any of the three tests.

Project C — 4 MW solar array. 6 200 MWh × 0.78 = **4 836 t CO_2-e** abated; cost saving 6 200 000 × $0.16 = **$992 000**; capital $5.6 M, so payback **5.6 years**. The largest single abatement, and the largest single cost saving. The reliability qualification is real and should be stated: the array generates in daylight, a dairy's load is seasonal and partly overnight, and the claim that all 6 200 MWh is self-consumed needs a half-hourly load profile to verify. If self-consumption is materially below 100%, the exported energy earns a feed-in tariff far below the $0.16 retail rate and the payback lengthens.

Project B — boiler to high-temperature heat pump. Present gas input = 35 ÷ 0.88 = **39.8 TJ**, emitting 39 800 × 51.5 = **2 051 t** at a cost of 39 800 × $14 = **$557 000**. The heat pump needs 35 ÷ 2.8 = 12.5 TJ = 12 500 × 277.8 = **3 472 MWh**, emitting 3 472 × 0.78 = **2 708 t** at a cost of 3 472 000 × $0.16 = **$556 000**. So B is almost exactly cost-neutral and **increases emissions by 657 t a year**, for $4.2 M of capital. It fails the emissions test outright today, which is the test it was proposed to satisfy.

Ranking: A, then C, then B. A first on payback and cost per tonne; C second, for the largest abatement at an acceptable payback; B last. **Sequencing.** A should precede B in any case, because A removes heat duty that B would otherwise have to serve, so B — if it proceeds later — is smaller and cheaper. Installing B first would size a $4.2 M asset against a duty that A subsequently eliminates.

The condition that changes B's ranking. B abates rather than adds once electricity's emissions per gigajoule of useful heat fall below gas's. Setting them equal: EF × 277.8 ÷ 2.8 = 51.5 ÷ 0.88, giving **EF = 0.59 kg CO_2-e kWh^{-1}**. Victoria's factor is 0.78 and falling as the state approaches its legislated 65%-renewable-by-2030 target, so B is a project whose emissions case is wrong now and will become right; a defensible recommendation is to defer B, or to specify a higher-COP machine, rather than to reject it permanently.

Q17. (6 marks) Three marks for the durability analysis, three for the redesign. **Why behavioural savings decay.** The saving exists only while the behaviour does, because **nothing physical changed**. A campaign works by holding attention, and attention is a depleting resource: the novelty passes, the organising staff member moves on, the student cohort turns over, competing priorities arrive, and the feedback that made the saving visible stops when the campaign's posters come down. There is no artefact carrying the saving forward. Contrast the other three options: an LED lamp keeps saving whether or not anyone remembers it was installed, insulation keeps working for the life of the building, and a solar array generates whether or not the school is thinking about energy. This is the general reason the study design's four options are not equivalent — they differ in **persistence**, not only in size. A second contributor at a school specifically is that the people asked to change behaviour do not pay the bill, so the feedback loop between action and consequence is broken.

A redesign that persists. The governing principle is to **convert behavioural savings into engineering and policy savings** — to lock in the setting that the behaviour was achieving.

1. **Automate the setpoints.** Lock heating to 20 °C and cooling to 24 °C in the building management system with password-controlled override; put timers on out-of-hours circuits; fit occupancy sensors in classrooms, corridors and toilets; and set computers and interactive panels to sleep by network policy. Every one of these turns a decision that must be made daily into a decision made once.
2. **Make consumption visible and owned.** Sub-meter by building and publish a weekly dashboard, with an annual comparison; name a staff member accountable for the energy budget; and run an annual audit with a written action list.
3. **Embed it in procurement.** A written rule that appliances, lighting and HVAC purchased by the school must exceed a nominated star rating under the GEMS energy rating label converts every future replacement into a permanent efficiency gain at no additional program cost.
4. **Reduce the underlying load.** Draught sealing, ceiling insulation and external shading mean the behavioural saving is being taken from a smaller base and does not have to be re-earned each year.
5. **Measure properly.** Compare against a **weather-normalised** baseline — heating degree days — and over a full twelve months, so that a mild term is not reported as a program success and a cold one is not reported as a failure. This is the same attribution discipline required of any management strategy at 8H.

Q18. (8 marks) *Model response (8 marks).*

The site's structure, first. Brackwell burns 130 000 GJ of gas a year, three-quarters of it in a kiln at **1 060 °C**. That temperature is the central fact of the evaluation: high-temperature process heat is among the genuinely **hard-to-abate** end uses, because no widely available electric or renewable substitute reproduces it at that scale and cost. Any honest verdict here will be that the site can be substantially improved and not fully decarbonised by these four options.

Option A — kiln waste heat to the dryer. Recommended first. Gas falls 26 000 GJ (−1 339 t) and electricity rises 140 MWh (+109 t), a net **−1 230 t CO_2-e** a year. Cost: 26 000 × \$16 = \$416 000 saved against 140 × \$180 = \$25 200 added, a net **\$391 000** for \$2.6 M of capital — a **6.6-year** payback. Reliability is unaffected or improved, since the dryer gains a second heat source. It is the only option that abates, saves money and improves reliability at the same time — C abates more tonnes, but pays \$432 000 a year for them — and it also **changes the size of option D**, which is the sequencing point below.

Option B — recuperative burners. Recommended second. Gas falls 11 500 GJ, abating 11 500 × 51.5 = **592 t** and saving \$184 000 for \$1.8 M — a **9.8-year** payback, no reliability effect. Straightforward device efficiency: pre-heating combustion air with flue gas raises the useful fraction of each gigajoule burnt.

Option C — 30% biomethane. Cheap to start, exposed on affordability and on evidence. Switching 28 800 GJ of kiln fuel to certified biomethane abates about **1 483 t** for only \$0.4 M of capital — by far the lowest capital per tonne — but at a premium of \$15 GJ^{-1} it costs **\$432 000 every year**, indefinitely. Two conditions attach to the emissions claim and both should be stated: the abatement rests on the feedstock being genuinely renewable and on the certification being additional, and biomethane supply is limited by feedstock availability, so a contract renewal is a real commercial risk. It is the only option that touches the kiln's own emissions at all, which is why it belongs in the plan despite the cost.

Option D — electrify the dryer. Not yet. Dryer useful heat = 34 000 × 0.85 = 28 900 GJ. At COP 2.6 the heat pump needs 28 900 ÷ 2.6 = 11 115 GJ = **3 088 MWh**. Emissions: −34 000 × 51.5 = −1 751 t from gas, +3 088 × 0.78 = +2 409 t from electricity, a net **+658 t CO_2-e** — it makes the site's emissions worse. Cost is roughly neutral (\$544 000 of gas saved against \$556 000 of electricity), for \$5.2 M of capital. The threshold is EF = 51.5 × 2.6 ÷ (277.8 × 0.85) = **0.57 kg CO_2-e kWh^{-1}**; Victoria is at 0.78, so D is a correct decision taken too early.

Sequence, and the interaction that decides it. A must precede D. A supplies 26 000 of the dryer's 34 000 GJ from heat the kiln is currently throwing away, so after A the dryer has only about 8 000 GJ of gas duty left and D shrinks to roughly a quarter of its proposed size and capital. Committing \$5.2 M to D first would build a machine four times larger than the site will need, and would then strand most of A's benefit because the recovered heat would have nowhere to go.

Recommended order and overall verdict. A, then B, then C, deferring D until the grid factor falls below 0.57 kg CO_2-e kWh^{-1} — which Victoria's legislated trajectory towards 65% renewable generation by 2030 makes a question of when rather than whether — and then sizing D against the post-A duty. A, B and C together abate about **3 305 t CO_2-e** a year — about half of the site's 6 700 t of gas-related emissions — for \$4.8 M of capital, and they are net cash-positive: A and B save \$391 000 and \$184 000 a year against C's \$432 000 premium, a net annual saving of about **\$143 000**. The residual is the kiln itself, and it remains unabated: the site should be honest that these options improve a hard-to-abate process rather than solving it, and that a full solution depends on technology and fuel supply outside its own control.

Q19. (10 marks) *Model response (10 marks).*

Assign the workstreams to the dot point's four options. W1 is **improving resource efficiency** — the dwellings need less heat. W2 is **increasing the efficiency of conversion devices** and **replacing fossil fuels** simultaneously, since the heat pumps are both more efficient and not gas-fired. W3 is **replacing fossil fuels with a non-fossil source**. W4 is **reducing personal energy consumption**. All four limbs are covered, which is the first thing an evaluation should record, because a plan that omits a limb is incomplete by the study design's own terms.

The emissions test, quantified. The plan abates 299 + 135 + 19 110 + 1 642 = **21 186 t CO_2-e a year** for \$37 M. The distribution is extremely uneven: W3 delivers **90%** of it. Cost per annual tonne abated: W4 **\$365**, W3 **\$1 099**, W1 **\$11 371**, W2 **\$88 889**. Two of those figures need explaining rather than merely reporting. W2 looks disastrous because the arithmetic of the break-even rule bites: 27 000 GJ of gas at 75% seasonal efficiency is 20 250 GJ of useful heat, which at COP 3.5 needs 1 610 MWh; the gas saved abates 1 391 t and the electricity added emits 1 256 t, leaving a net **135 t**. The break-even COP against a 75% appliance is 4.2 × 0.75 = 3.2, and 3.5 barely clears it. W4 looks outstanding because behaviour costs almost nothing — but see durability below.

The reliability test. W3 is the only workstream that changes supply, and it is designed with a 20 MWh battery, which firms the daytime resource into the evening peak; at 24 500 MWh from 12 MW the array runs at a capacity factor of about 23%, plausible for fixed-tilt solar in north-west Victoria, and the plan should state whether the town is islandable during a transmission outage, since that is a material benefit for a remote town and is not costed here. W1 improves dwelling resilience: better-insulated homes hold habitable temperatures for longer during an outage or a heatwave, which matters more in a north-west Victorian summer than the emissions figure suggests. W2 carries a reliability obligation the table does not address — heat pumps must be sized at the winter design temperature, where COP is lowest, and 1 500 simultaneous morning starts change the town's electricity peak. W4 reduces peak demand as well as energy and so helps on this test.

The affordability test, and the distributional question. On cost per tonne the ranking is W4, W3, W1, W2. On cost per household reached it is W4 ($143), W1 ($3 778), W3 (shared), W2 ($8 000). But **cost per tonne is not the whole affordability test**, and an answer that ranks on it alone is incomplete. W1 is targeted at 900 low-income dwellings and delivers a permanent bill reduction, warmer homes and health benefits to households that can access none of the other workstreams unaided — it is the workstream that carries the plan's intragenerational equity, and judging it on $11 371 per tonne alone misses what it is for. W2 removes gas appliances, and only when a dwelling's *last* gas appliance goes can the household escape the daily supply charge, so W2's household economics are far better than its tonnage suggests, provided it is targeted at dwellings where it completes the switch rather than at dwellings that will retain a gas cooktop.

Two interactions, which is where the marks separate. First, **W1 must precede W2 in the same dwellings**. Insulating first cuts the useful heat requirement, so the heat pump installed under W2 is smaller, cheaper and runs at a higher average COP; doing W2 first buys 1 500 machines sized for a load that W1 then reduces. Second, **W3 raises the value of W2 over time**. W2 abates only 135 t at 0.78 kg CO_2-e kWh^{-1}, but the workstream's whole point is that the electricity it consumes will get cleaner: at 0.30 kg CO_2-e kWh^{-1} the same 1 610 MWh emits 483 t instead of 1 256 t, and W2's net abatement rises from 135 to about 908 t. The plan's own W3 is part of what moves that factor. A third interaction is worth a mention: W4's savings will decay unless W1 and W2 lock them into fabric and equipment, so W4 should be delivered *with* the other workstreams rather than as a standalone campaign.

Overall verdict. The plan is well constructed in that it exercises all four options, and its emissions performance is overwhelmingly carried by W3, which is also its second-cheapest tonne — so the headline allocation of $21 M to the solar farm is defensible on the emissions and affordability tests together. W4 is excellent value and the least durable. W1 is poor value in tonnes and essential in equity. W2 is, on today's grid factor, the weakest emissions proposition in the plan and the strongest positioning for the decade after it; it should be sequenced behind W1 and targeted at complete-switch dwellings. An overall verdict is not an average of the four.

Further evidence needed before committing the funds. Six things. **Metered rather than deemed savings** for W1 and W2 from a pilot, since deemed engineering estimates systematically overstate in-service performance. **A persistence estimate for W4**, measured at 12 and 24 months against a weather-normalised baseline, because a saving that vanishes in a year is not abatement. **Winter design-day performance and measured seasonal COP** for the W2 heat pumps, since the whole workstream sits within 0.3 of its break-even COP. **The half-hourly load profile of the town against W3's generation profile**, to establish how much of the 24 500 MWh is used locally and how the 20 MWh battery is dispatched. **The projected grid emission factor trajectory**, because the ranking of W2 depends on it directly. And **the distribution of benefits** across income groups and between owners and renters, without which the plan cannot be assessed against intragenerational equity at all.

Chapter 13 Managing the impacts of human energy use — 13D Interconnections and tensions in energy decision-making

§2A RECORDED SCOPE DECISION

Aboriginal and Torres Strait Islander knowledge — deliberately not covered (ICIP). This workbook does not reproduce Aboriginal and Torres Strait Islander knowledge, cultures or histories. The Study Design's Aboriginal and Torres Strait Islander knowledge and perspectives requirement is therefore not covered here. Real Aboriginal and Torres Strait Islander knowledge must be sourced by teachers directly with the relevant community under the appropriate protocols; any Indigenous-looking example in this book is fictitious and must not be taken as real.

Theory

The key knowledge this subtopic answers is the last dot point of Unit 4 Area of Study 2: *"interconnections and tensions between factors that influence responsible decision-making around building a sustainable energy future, including diverse stakeholder values, knowledge and priorities, regulatory frameworks that inform environmental management strategies, use and interpretation of historical and current scientific data, and application of new technologies"*. The four factors are the same four met at **8F**, and the two operative nouns carry the same meanings there and here. An **interconnection** is a relationship of *influence*: move one factor, and what another factor requires, permits or wants moves with it. A **tension** is a relationship of *opposition*: the more fully one factor is satisfied, the less fully another can be. Both words name a relationship, so neither is answered by an inventory — four paragraphs, one per factor, answers a question nobody asked.

What is new is the setting, and the setting changes the answers. **8F** applied the framework to a management strategy at a place; **11D** applies it to managing climate change; this subtopic applies it to **building a sustainable energy future** — and an energy future is not a site, a project or a program. Four structural features make energy decisions behave differently from the environmental management decisions of Chapter 8, and almost every marked point in this subtopic descends from one of them.

- **It is a portfolio decision, not a project decision.** Electricity supply must match demand continuously, so no source is ever chosen on its own merits alone — it is chosen for what it contributes to a mix that has to hold together every second of every day (**13B**). "Is wind good?" is not a question the system can answer. "What does adding this wind farm do to the portfolio, and what else must be added with it?" is.
- **There is no single decision-maker.** Rules are made by the **Australian Energy Market Commission**, enforced by the **Australian Energy Regulator**, and the market is operated and planned by the **Australian Energy Market Operator**; targets are legislated by the Commonwealth and by the states; the generators, networks and retailers are mostly privately owned; and the planning permits sit with state and local government. No one body decides Australia's energy mix. Decisions are therefore **negotiated between parties with different powers**, which is why the stakeholder factor is not decoration here.
- **The assets outlive the decisions.** A power station runs for 30–50 years, a transmission line and its easement for longer, and a household's gas connection for the life of the building. Targets, costs and technologies move much faster than that, so almost every energy decision commits somebody to a pathway long after the reasoning that produced it has been superseded. This is **lock-in**, and it is the reason the precautionary principle bites so hard in this dot point.
- **Every household is both a stakeholder and a participant.** A householder who installs rooftop photovoltaics, buys an electric vehicle or replaces a gas heater is not merely holding a view about the energy system — they are altering it. Millions of individual decisions aggregate into a system-scale change that nobody planned. No other area of environmental management has this property.

The companies, projects and localities in the scenarios below are invented. Every Act, rule, agency, target and dated event named is real and is stated as at July 2026, with one deliberate exception. The **Marrowvale Heritage Protection Act 2011**, *the* **Heritage Landscape Management Plan** *it requires, the* **Registered Heritage Body** *that evaluates one, and the* **Verrowdale Settlement Heritage Association Inc.** *of the case studies are all* **fictitious** —

invented for this workbook so that the heritage-instrument step in an energy decision can be practised, and flagged as fictitious wherever they appear. Do not cite them in an assessment: no such Act, body or association exists.

Factor 1 — diverse stakeholder values, knowledge and priorities. The energy system's stakeholders are unusually varied in *what kind of thing* each of them holds, and the marks come from naming the kind, not the party.

Stakeholder	Values	Knowledge held	Power actually held
Generator or developer	Return on a 25–30 year asset; reputation	Plant performance, costs, construction risk	Whether to build at all, and when to close
Network business	Regulated return; reliability obligations	Network capability, fault and constraint data	Route selection; what can physically connect
AEMO	Security and reliability of the whole system	Half-hourly system data no other party holds	Dispatch; the planning scenarios everyone argues from
State government	Legislated targets; regional jobs; bills	Aggregated policy and program data	Targets, planning approvals, subsidies, prohibitions
Hosting landholders	Farm operations, amenity, land value, succession	Local hydrology, soils, fire behaviour, land use	Objection rights; consent for access; social licence
Heritage community body (*fictitious*: a Registered Heritage Body such as the Verrowdale Settlement Heritage Association)	Continuity of a settled landscape; heritage fabric; community identity	Location and condition of unregistered heritage fabric, recorded in no dataset	Statutory evaluation of a Heritage Landscape Management Plan (*fictitious instrument*)
Large industrial user	Energy price and continuity of supply	Its own process and load profile	Ability to relocate or close, taking regional jobs
Households	Bills, comfort, environment, control	Their own consumption and constraints	Individually negligible; collectively decisive
Future generations	—	—	**None**

The right-hand column is the one that decides outcomes, and the table's last row is the point of it: the parties with the longest stake in a sustainable energy future hold no power in the decision at all. Note also how the diversity works here. Nearly every party in the table shares the same **values** — reliable, affordable, lower-emissions energy — and they differ almost entirely on **priorities**, that is, on which of the three yields when all three cannot be had. This is why "consult the community and find the community view" is not available as a method: there is no single view to find, and two neighbouring landholders can hold opposite positions on the same wind farm. **Energy hardship** deserves separate mention, because electricity is an essential service and a decision that raises bills does not distribute its cost evenly: renters and low-income households cannot install the rooftop system that would insulate them from the increase, which makes many energy decisions a question of **intragenerational equity** whether or not anyone frames them that way.

Factor 2 — regulatory frameworks that inform environmental management strategies. Read every instrument below for three things kept apart: the **threshold** it sets, the **decision it allocates**, and the **procedure it creates** (**8F**). Energy carries more layers of instrument than anything else in the course — a national law, national rules, Commonwealth statutes, state statutes and a planning provision all bear on the same wind farm — and marks turn on naming the right one for the job in front of you.

Instrument (as at July 2026)	What it contributes to an energy decision
National Electricity Law, applied in Victoria by the *National Electricity (Victoria) Act 2005* (Vic)	The **national electricity objective**, which since September 2023 requires the market bodies to promote efficient investment and operation in the long-term interests of consumers **and** the achievement of jurisdictional greenhouse gas emissions targets
National Electricity Rules (made by the AEMC,	Registration, connection, dispatch and reliability

Instrument (as at July 2026)	What it contributes to an energy decision
enforced by the AER)	obligations; and the requirement that a scheduled generator give at least **42 months' notice of closure** unless the AER grants an exemption
Climate Change Act 2022 (Cth)	Legislated national targets — **43% below 2005 levels by 2030** and **net zero by 2050** — that the energy system is the largest single lever on
National Greenhouse and Energy Reporting Act 2007 (Cth)	Mandatory reporting, and the **Safeguard Mechanism**: facilities above **100 000 t CO_2-e** of covered scope 1 emissions a year hold baselines that decline year on year
Climate Action Act 2017 (Vic) — renamed from the *Climate Change Act 2017* by the 2024 amending Act below, so older sources cite the former name	Victoria's **net zero by 2045** target and legislated interim targets
Renewable Energy (Jobs and Investment) Act 2017 (Vic), as amended by the *Climate Change and Energy Legislation Amendment (Renewable Energy and Storage Targets) Act 2024* (Vic)	Legislated Victorian renewable electricity targets of **65% by 2030** and **95% by 2035** (s 7), storage targets of at least **2.6 GW by 2030** and **6.3 GW by 2035** (s 7A), and **offshore wind targets** of at least **2 GW by 2032**, **4 GW by 2035** and **9 GW by 2040** (s 7B) — all three sets are legislated, in the one Act
Offshore Electricity Infrastructure Act 2021 (Cth)	Declared areas, and the **four** kinds of licence the Act provides for — feasibility, commercial, research and demonstration, and transmission and infrastructure — for offshore wind. The Gippsland declared area is Australia's first
Planning and Environment Act 1987 (Vic)	Planning permits, third-party objection rights, and review at the **Victorian Civil and Administrative Tribunal**. Clause 53.03 of the Victoria Planning Provisions (Amendment **VC250**) prevents a permit granting a reticulated natural gas connection for a new dwelling, apartment development or residential subdivision where the application was lodged on or after **1 January 2024**
Environment Effects Act 1978 (Vic)	Whether an **Environment Effects Statement** is required for a large generation or transmission project, and the Minister for Planning's assessment
Environment Protection and Biodiversity Conservation Act 1999 (Cth)	Approval where a project is likely to have a significant impact on a **matter of national environmental significance**; and **section 140A**, which forbids the Minister approving the construction or operation of a **nuclear power plant**
Marrowvale Heritage Protection Act 2011 — **fictitious, invented for this workbook; not a real Act**	A **Heritage Landscape Management Plan** for a high-impact activity in an area of declared **heritage landscape sensitivity**, evaluated by the **Registered Heritage Body** for that area. Included so the heritage-instrument step can be practised: note that it *allocates a decision* rather than merely creating a right to be heard
Victorian Energy Efficiency Target Act 2007 (Vic)	The **Victorian Energy Upgrades** program, regulated by the **Essential Services Commission**: accredited providers create **Victorian energy efficiency certificates** for eligible upgrades and sell them to retailers, who carry annual liabilities
Nuclear Activities (Prohibitions) Act 1983 (Vic);	Prohibit the construction and operation of a nuclear

Instrument (as at July 2026)	What it contributes to an energy decision
Australian Radiation Protection and Nuclear Safety Act 1998 (Cth)	power plant in Victoria and forbid the Commonwealth regulator licensing one

Frameworks move, and their movement is itself a factor. Two Victorian examples from the last three years show how much can change without anything physical changing. The **VicGrid Stage 2** reforms, passed by the Victorian Parliament in **September 2025**, consolidated transmission planning in **VicGrid**: the **Victorian declared network functions** were transferred from AEMO, the renewable energy zone planning functions created by the Stage 1 reforms of 2024 moved from the CEO VicGrid to the VicGrid body corporate, and a new grid access regime — grid impact authorities and renewable energy zone scheme authorities — was created where none had existed. The decision-maker changed; the wind resource did not. And the addition of the emissions limb to the national electricity objective in **2023** was the first substantial change to those objectives in around fifteen years: from that date, every AEMC rule determination and AER decision had to weigh emissions, so decisions began coming out differently on unchanged evidence.

Factor 3 — use and interpretation of historical and current scientific data. The dot point names two operations, and they fail in different ways (**8F**). A failure of **use** is a failure of fitness — the series is too short, too coarse, drawn from the wrong place, or carries more uncertainty than the decision can absorb. A failure of **interpretation** is a failure of inference — the numbers are sound and the meaning read out of them is not. Energy adds three difficulties that do not arise in the same form elsewhere.

- **The historical record is a record of a system being replaced.** Half-hourly demand data going back decades describes a system with almost no rooftop generation, no electric vehicles and near-universal gas heating. Extrapolating it assumes the very thing the decision is trying to change. This is worse than a shifting baseline: it is a baseline that is being deliberately abolished.
- **Better technology alters the measurement, not just the system.** Rooftop photovoltaics reduce **operational demand** — what the grid must serve — without reducing what households consume, so a demand series can fall while consumption rises. Confusing the two is the energy version of a method change mistaken for a system change. The consequence that catches planners is **minimum demand**: the difficult hour is now a mild sunny Sunday, not a February heatwave, and no historical series contains that problem.
- **Most of the "data" in an energy argument is model output.** AEMO's **Integrated System Plan**, published every two years, sets out an **optimal development path** — the least-cost mix of generation, storage and transmission to 2050 under stated scenarios and assumptions. The **2026 ISP**, published on **25 June 2026**, again found the least-cost path to be renewables connected by transmission, firmed with storage and backed by gas, with electricity consumption close to doubling by 2050. That is an enormously valuable document and it is **not a measurement**. It is conditional arithmetic: change the assumed cost of storage, the demand trajectory or the policy inputs and the optimal path changes, which is exactly what happened between the 2024 and 2026 plans: solar and battery costs fell, wind costs and the capital cost of transmission **per kilometre** rose — and yet the **total** cost of transmission in the optimal path fell, because the path that came out of the revised assumptions needed well over a thousand kilometres less of it. A cost per unit and a total cost can move in opposite directions, and quoting one for the other is an error of interpretation, not of arithmetic. Treating a scenario as a forecast, or an optimal path as a decision already made, is the single commonest data error in this subtopic.

Factor 4 — application of new technologies. A technology enters an energy decision through the same four doors as at **8F** — it makes a **new option feasible**, it **moves the cost curve**, it changes **what can be measured**, and it **raises the standard** of what is reasonably practicable — but energy adds a fifth consideration that outweighs all four in the exam: **lock-in**. Because the assets are long-lived and expensive, choosing a technology chooses a pathway for decades, and the alternative not taken usually becomes harder rather than easier. A gas connection laid to a new suburb, a transmission easement, a coal unit refurbished for a further fifteen years and a household's new gas ducted heater are all commitments that outlast the reasoning behind them.

The **nuclear** case is worth stating precisely because it is the cleanest illustration in the study design of regulation acting *on* technology rather than following it. Nuclear generation is technically mature and used at scale overseas. In Australia it is nevertheless unavailable, because **section 140A** of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) forbids the Minister approving the construction or operation of a nuclear power plant, the

Australian Radiation Protection and Nuclear Safety Act 1998 (Cth) forbids the Commonwealth regulator licensing one, and in Victoria the *Nuclear Activities (Prohibitions) Act 1983* (Vic) prohibits it directly. Whether nuclear power *should* be part of an Australian energy mix is a live argument about cost, timing, waste and risk; whether it *may currently be built* is not an argument at all. Keeping those two questions apart is a marked distinction: the constraint is legal, and a legal constraint can be changed by a parliament in a way that a thermodynamic constraint (**12F**) cannot.

The interconnections. Seven of them do the work in energy decisions. In each case the mark is in the **mechanism** and the **direction**, never in the pairing.

Coupling	Mechanism	Direction
Data → Regulation	Reliability and emissions findings from AEMO's planning and reporting drive rule changes, targets and government underwriting	Reinforcing: better data makes intervention better targeted
Regulation → Data	The Rules prescribe what must be reported, published and modelled — including closure notices and the scenarios the market bodies must run — so the framework **bounds what the decision can see**	Reinforcing, and limiting
Technology → Data	Rooftop generation and smart metering change measured operational demand without changing consumption; storage changes what a "peak" even is	Often misread: the record moves while the underlying system moves differently
Technology → Regulation	Falling storage costs made a legislated 2.6 GW storage target writeable; cheap rooftop photovoltaics forced network tariff and export-limit rules that did not previously exist	Reinforcing
Regulation → Technology	A prohibition removes a mature technology from the option set regardless of its cost (nuclear, s.140A EPBC Act); a planning provision removes an established one (gas connections, clause 53.03)	**Opposing** — regulation acting on technology, not following it
Regulation → Stakeholders	Permits, objection rights, EES processes and heritage management plans decide who holds a decision and who holds only a submission; hosting payments convert a preference into a contract	Reinforcing for those given standing, opposing for those without
Stakeholders → Data	Millions of household investment decisions *become* the load shape the system plan is built on; and landholders supply local knowledge — fire behaviour, flood paths, soil — that no dataset holds	Both: households author the data, and trust in who generated it decides whether it is used

Two whole-system points follow. First, the couplings run **harder one way than the other**. Regulation shapes data far more tightly than data shapes regulation, because evidence accumulates continuously while a rule moves only when a body holding the power to move it decides to. Second, an intervention aimed at one factor lands on the others — declaring a renewable energy zone is simultaneously a technology decision, a land-use decision, a stakeholder decision and a data decision, since it determines what will be built, where, by whom, and what must then be measured.

The tensions. A disagreement is not a tension. The test is whether the opposition survives agreement on the facts: if both parties accepted every number, would they still have to choose? Six such oppositions recur in energy decisions, and each engages the study design's **sustainability principles** (**12G**) on both sides. Those principles are a closed list of six — conservation of biodiversity and ecological integrity, efficiency of resource use, intergenerational equity, intragenerational equity, the precautionary principle and the user pays principle. Reliability, affordability, jobs and avoiding lock-in are all real considerations in an energy decision and none of them is a sustainability principle; name one as such and the mark is lost.

Tension	Pole A	Pole B	The principles on each side
Retire early or run on	Close a fossil generator sooner, cutting emissions and local air pollution now	Keep it available, protecting reliability and a regional workforce until replacements exist	A: precautionary principle, intergenerational equity. B: intragenerational equity (a regional workforce, and reliable supply of an essential service to today's consumers), efficiency of resource use
Least-cost system or least-cost bill	Build the mix that is cheapest over decades	Minimise what customers pay in the next few years	A: efficiency of resource use, intergenerational equity. B: intragenerational equity, user pays
Where it is built, who benefits	Site generation and transmission where the resource and the corridor are — in regional areas	Concentrate the electricity benefit in the cities and industries that consume it	A and B: intragenerational equity, user pays, conservation of biodiversity and ecological integrity
Commit now or wait for better	Build a proven technology on the schedule the closures require	Wait for a cheaper or better-performing technology and avoid locking in the wrong asset	A: efficiency of resource use. B: precautionary principle
Firm with gas or refuse new fossil assets	Accept gas-fired plant that runs rarely but guarantees supply	Refuse new fossil infrastructure that could operate for 30 years	A: intragenerational equity (reliable supply now, and coal displaced sooner), efficiency of resource use. B: intergenerational equity, precautionary principle (the lock-in a 30-year asset creates)
Habitat against decarbonisation	Clear or fragment habitat for turbines, easements or a solar farm	Protect the habitat and forgo the generation	Both poles: **conservation of biodiversity and ecological integrity**, asserted at different scales

The last one deserves emphasis because students expect energy tensions to be industry against the environment. Frequently the sharpest ones are **one environmental good against another** — a transmission corridor through remnant vegetation, or an offshore wind array across a migratory bird route, weighed against the emissions the project avoids. No further data dissolves that: nothing about the mechanism is disputed. Underneath all six sit two cross-cutting tensions. **Cost now against harm later** — the discount-rate problem of **8E** — fixes how heavily a consequence decades away weighs against a dollar today, and every answer to it takes a position on **intergenerational equity**. **Certainty against adaptability** is sharper in energy than anywhere else, because a developer cannot finance a 25-year asset against a policy that might be revised, while a system facing genuine uncertainty needs decisions that can be revised.

What makes an energy decision *responsible*. Notice the word the dot point chose. Not “correct”, not “cheapest”, not “lawful” — a decision can be all three and fail this test, and can fail all three and pass it. Six questions carry the meaning, and between them they are what this subtopic actually grades.

1. **The tension is named, not concealed.** A decision presented as compelled by the modelling hides the judgement from scrutiny. The ISP identifies a least-cost path under assumptions; it does not decide how much reliability risk is acceptable, or who should pay.
2. **The finding and the judgement are reported separately.** What the data and the models show — with the uncertainty and the assumptions on the face of it — is one thing; what somebody then decided was an acceptable risk, and who that somebody was, is another (**3D**). Fusing the two makes a choice look like a measurement.
3. **The residual risks are placed explicitly, and there are several.** Reliability risk, price risk, stranded-asset risk, construction risk and amenity risk fall on different parties. A responsible decision says which party carries each rather than letting them fall where they fall.
4. **Review is built in.** Closure dates, staged approvals, transmission plans revisited on a cycle and the 42-month notice requirement are all reviewability mechanisms. Building revision in is not an admission of weakness — it is the only defensible posture toward a system that will keep producing evidence long after the decision is signed.
5. **Standing is given to those with a stake but no power.** Hosting landholders, heritage community bodies, renters who cannot install rooftop generation, future generations and non-human species have a stake in the outcome and, in several cases, no formal role in producing it.
6. **The benefit is distributed toward the burden.** This test is specific to energy and is why hosting payments and community funds exist at all: where the costs are concentrated regionally and the benefits spread nationally, a decision that does nothing about the mismatch is weakening intragenerational equity even where every approval is in order.

A real illustration — Victoria’s transition, 2017 to 2026. No invented scenario carries this dot point as well as the public record, because the record contains a decision being reversed, a target being missed and a decision-maker being changed.

Year	Event	Factor at work
2017	Hazelwood closes in March, removing about 1 600 MW at short notice	A private closure decision with system-wide consequences
2018–19	The Rules are amended to require **three years’** notice of closure, then **42 months**	Data → Regulation: experience of a short-notice exit written into the framework
2021	EnergyAustralia announces **Yallourn** will close in **mid-2028**, four years early, with a 350 MW four-hour battery	Technology → portfolio: the replacement is not like-for-like
Sept 2022	AGL brings the closure of **Loy Yang A** forward from **2045** — itself brought forward from 2048 earlier that year — to the end of **FY2035**	Stakeholder pressure and economics reshaping the replacement task
Sept 2023	The **national electricity objective** gains an emissions limb	Regulation moving: same evidence, different decisions
2023	Landholders hosting new transmission to receive **$8 000 per km per year for 25 years**, indexed — about **$200 000 per km** — in addition to compensation under the *Land Acquisition and Compensation Act 1986* (Vic), plus a REZ	Regulation → Stakeholders: a social-licence tension addressed with money

Year	Event	Factor at work
	Community Energy Fund	
1 Jan 2024	Amendment **VC250** bars a planning permit granting reticulated gas to a new dwelling, apartment development or residential subdivision	Regulation → households: a demand-side decision made through the planning system
March 2024	Victoria **legislates** 65% by 2030 and 95% by 2035 renewables, 2.6 GW and 6.3 GW storage, **and** offshore wind of 2 GW by 2032, 4 GW by 2035 and 9 GW by 2040 — announced as policy in 2022, given statutory force here	Regulation setting the frame every project is judged against
Aug 2025	The **2025 Victorian Transmission Plan** proposes six renewable energy zones plus a Gippsland shoreline zone	Planning published before the decision, so it can be argued with
Sept 2025	**VicGrid Stage 2** reforms pass, transferring the Victorian declared network functions from AEMO to VicGrid and creating a grid access regime	The decision-maker changed; the resource did not
Dec 2025	The Victorian Auditor-General reports the **2 GW offshore wind by 2032** target will not be met — delay to at least the end of **2033** — while the **2.6 GW storage by 2030** target is on track	Current data contradicting the plan it was set under
29 May 2026	Renewable energy zone orders declare **five** onshore REZs and the Gippsland shoreline zone; the **Central North** zone is **deferred for further consultation**	Adaptive management: the plan was revisable, and nine months later it was revised
25 June 2026	The **2026 ISP** is published: renewables, transmission and storage, firmed and gas-backed, remain the least-cost path; consumption close to doubles by 2050	The reference model all parties now argue from

Read against the four factors, the sequence shows what a list never could. **Data → Regulation** runs the whole way through and closes: the 2017 short-notice closure produced a notice rule, and the auditor's finding that an offshore wind target will slip is now evidence against the plan that set it. **Regulation → Stakeholders** is visible in standing and in money: a landholder's objection right and a hosting payment are different instruments aimed at the same tension, and an objection is a submission where a statutory evaluation is a decision. **Technology → Regulation** appears in the storage targets, which could not have been legislated at an earlier cost point. And the Central North zone is the clearest adaptive-management moment on the record, precisely because it is datable: the transmission plan of August 2025 proposed six zones, and the orders made nine months later, on 29 May 2026, declared five and held that one back for further consultation. A published intention was **not** carried into the instrument, because the stakeholder factor had not been discharged in the interval — which is what a revisable plan looks like when it is actually revised.

The **tension** here is instructive for the same reason as the missed offshore wind target. Victoria has a legislated 2035 renewables target and a coal fleet with announced closure dates; every year of delay in transmission and generation narrows the window between them. But transmission cannot be built faster than the consent processes that give hosting communities standing, and compressing those processes is exactly what weakens the social licence the build depends on. Moving toward speed moves away from consent, and moving toward consent moves away from the target date. That is structural, and no further modelling dissolves it.

Key ideas to keep straight.

- **An interconnection is not a tension.** If both factors can be satisfied at once it is a link, not an opposition — and a question asking for a tension earns nothing for a link, however well described.
- **Say which factor moved, which one followed, and by what mechanism.** Pairing two factors is not an answer. "Storage costs fell far enough that a 2.6 GW target became legislatable, so a technology change altered the law" is.
- **A scenario is not a forecast, and an optimal path is not a decision.** The ISP is conditional arithmetic under assumptions. Quoting it as though it settled a normative question is the commonest error here.
- **The historical demand record describes a system being replaced.** Rooftop generation, electrification and electric vehicles are changing both the size and the shape of demand, so the past is a weak guide and minimum demand is now as hard a problem as peak demand.
- **A legal prohibition is not a scientific finding.** Nuclear generation is excluded in Australia by statute, not by physics or cost — keep "may it be built" apart from "should it be built".
- **Lock-in makes new technology a source of tension, not only a solution.** Ask what a technology forecloses, who is committed by it, and for how long.
- **Meeting a target is not the same as deciding responsibly, and missing one is not the same as deciding irresponsibly.** Responsibility is a property of how the tension was named, disclosed, allocated and made reviewable — which is why a decision can be responsible and still turn out to be wrong.

Worked examples

Example 1 — scaffolded

Craythorne Grid Services Pty Ltd sizes a network upgrade for the town of Pentworth using 20 years of half-hourly demand records. Over that period recorded maximum demand rose by 6%, while recorded minimum demand fell by 22%. Rooftop photovoltaic uptake in Pentworth reached 41% of detached dwellings during the same period. Craythorne concludes that "demand growth is modest, so only a minor upgrade is required". Identify the interconnection at work and explain why the conclusion is unsafe.

Working	Comment
Two things changed over the record: what households consume, and what the grid is asked to serve. The series measures only the second.	Separate **operational demand** from underlying consumption.
Rooftop photovoltaics on 41% of dwellings supply part of the daytime load behind the meter, so recorded demand falls without consumption falling.	Name the coupling: **Technology → Data**.
The 22% fall in minimum demand is therefore evidence of generation being added, not of load disappearing — and a very low minimum is itself a system problem, not a comfort.	The measurement moved differently from the system.
The record also predates the electrification the framework is now driving: since 1 January 2024, new dwellings needing a planning permit cannot connect to reticulated gas (clause 53.03, Amendment VC250), so future heating and hot-water load will be electrical.	**Regulation → Data**: the framework has already invalidated the extrapolation.
∴ the interconnection is Technology → Data,	Conclude, and say what should be done instead.

Working	Comment
compounded by Regulation → Data. The series cannot be extrapolated, because it records a system that is being deliberately replaced; Craythorne must model the future load *shape* — including electrification, electric vehicle charging and minimum demand — rather than trend the historical peak.	

Example 2 — scaffolded

In December 2025 the Victorian Auditor-General reported that Victoria's legislated target of at least 2 GW of offshore wind by 2032 will not be met, with delay expected to at least the end of 2033, while the legislated 2.6 GW energy storage target for 2030 remains on track. A student writes: *"The offshore wind decision was irresponsible, because the target was missed."* Evaluate this claim.

Working	Comment
Establish what the claim assumes: that responsibility is measured by the outcome. The dot point asks about *decision-making*, and the tests of responsibility concern how the judgement was made and disclosed.	Identify the category error before arguing the facts.
A target set at the edge of what is achievable is doing a job — it mobilises investment, port infrastructure and supply chains that a comfortable target would not. Setting only targets certain to be met would be a different failure.	A missed stretch target is not by itself evidence of bad process.
The reported causes — port capacity and auction timing — are delivery constraints identified by an **independent auditor** and published. That is Data → Regulation working: the plan is being tested against current evidence by a body outside it.	Reviewability demonstrated on the record, not asserted.
Contrast the storage target, on track, which shows the same government's targets are not uniformly unachievable — so the offshore wind slippage is specific, not systemic.	Use the second data point; it is in the stimulus for a reason.
Where criticism *is* fair: whether the dependencies (port, transmission, auction design) were identified and disclosed **when the target was set**, whether the closure of Yallourn in mid-2028 was made contingent on capacity that was not yet certain, and who now carries the reliability risk created by the delay.	Relocate the criticism to the process tests, where it belongs.
∴ the claim is **rejected as stated**. Missing a target is a finding about the outcome; responsibility is a property of the process. The decision is criticisable if the dependencies were concealed or the residual risk left unallocated, and defensible if the target was set transparently, independently audited, and revised on the evidence.	Conclude two-sidedly.

Example 3 — unscaffolded

Harrowfen Aluminium Pty Ltd argues that its emissions and price problems would both be solved by a nuclear power station in Victoria, and that "the only obstacle is that the modelling has not been done properly". Evaluate this argument.

The argument fails at its first step, and the reason is a clean case of **Regulation → Technology**. Whether nuclear generation is technically capable of supplying firm, low-emissions electricity is one question; whether it may lawfully be built here is another, and it is not open. **Section 140A** of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) forbids the Minister approving the construction or operation of a nuclear power plant; the *Australian Radiation Protection and Nuclear Safety Act 1998* (Cth) forbids the Commonwealth regulator licensing one; and the *Nuclear Activities (Prohibitions) Act 1983* (Vic) prohibits it in Victoria directly. No quantity or quality of modelling alters any of those, because the constraint is **statutory, not evidentiary** — this is regulation acting *on* the technology factor rather than following it, the opposite of the usual direction in which a cheaper or better technique tightens what a duty requires. That distinction is the point: a legal constraint can be repealed by a parliament, so the real argument Harrowfen must make is a political and normative one about whether the prohibitions should stand, and it must be made on cost, construction lead time, waste, risk and public acceptance — not smuggled in as a modelling deficiency. **However**, Harrowfen's underlying interest is legitimate and should not be dismissed with the argument: a large industrial load genuinely needs firm, affordable supply, it has real power in the tension (it can relocate or close, taking regional employment with it), and the decision that actually faces it — firming with storage, contracted renewables, gas, demand response or some mix — is the one where its knowledge of its own load profile is worth most. ∴ the argument is rejected because it misclassifies a legal prohibition as an evidentiary gap, and the correct response is to separate "may it be built" from "should it be built" and to redirect Harrowfen to the options that are actually available to it.

Example 4 — unscaffolded

A submission to Dunmarrow Shire states: *"If enough households install rooftop solar and batteries, the tensions in the energy transition resolve themselves — the community generates what it needs and no transmission line is required."* Evaluate this claim.

The claim is **partly right and substantially wrong**, and the interesting part is why. It is right that household decisions aggregate into a system-scale factor — this is the **Stakeholders → Data** coupling that is peculiar to energy, and it is powerful. Distributed generation and storage genuinely reduce operational demand, shave peaks, defer some network augmentation and give households control over their own bills; the 2026 ISP itself treats consumer energy resources as a growing part of the least-cost path. **However**, three things survive universal uptake. First, **the physics of the portfolio** (**13B**): a community that generates its annual consumption still needs supply during a still, overcast week in winter, and household batteries are sized in hours, not days — so the connection is not removed, its *use* changes, which is a different claim and a weaker one. Second, **equity**: rooftop systems require a roof, capital and, usually, ownership, so renters, apartment residents and low-income households are largely excluded — and because networks recover largely fixed costs from a shrinking volume of grid-supplied energy, the households who cannot participate can end up paying a larger share. Universal uptake is not available, and partial uptake redistributes cost from those who can invest to those who cannot, weakening **intragenerational equity**. Third, **scale**: the community's own demand is a small part of the task; industrial process heat, smelting, freight and the electrification of everything currently burning gas cannot be served from suburban roofs, and the generation that serves them has to be somewhere and reach them somehow. ∴ the submission should be supported on its true merits — distributed generation is real, valuable and reduces the size of the transmission task — but rejected as a resolution: it relocates the tensions rather than dissolving them, and the equity tension it creates is the one least likely to be noticed by those making the submission.

Practice questions

Scaffolded

Q1. No single body decides Australia's energy mix. Name the four factors that the key knowledge for this subtopic identifies as influencing responsible decision-making around building a sustainable energy future. *(2 marks)*

Q2. Complete the following. (a) In one sentence, say what makes the relationship between two of those factors an *interconnection*. *(1 mark)* (b) In one sentence, say what makes it a *tension* instead. *(1 mark)* (c) State **one** reason why an energy decision cannot be settled by naming a single decision-maker. *(2 marks)*

Q3. For each situation below, identify which **one** of the four factors is principally in play. (a) The national electricity objective is amended to require the market bodies to consider jurisdictional greenhouse gas emissions targets. (b) Two neighbouring landholders make opposite submissions on the same transmission alignment. (c) A 20-year half-hourly demand series is used to size a network upgrade. (d) Falling battery costs make four-hour storage economic at a site where it previously was not. *(4 marks)*

Q4. For each of the following, name the **two** factors that are interconnected. (a) The National Electricity Rules require a scheduled generator to publish its closure date at least 42 months in advance, so that AEMO and investors know when the capacity will leave the system. (b) Householders installing rooftop photovoltaics reduce recorded operational demand across a region. (c) Section 140A of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) prevents approval of a nuclear power plant. *(3 marks)*

Q5. Bramwold Energy Analytics Pty Ltd reports that recorded maximum demand in a region has risen 6% in 20 years and recorded minimum demand has fallen by 22% over the same period. Rooftop photovoltaic uptake reached 41% of detached dwellings during that period. (a) State whether the record shows that households consumed less electricity, and justify your answer. *(2 marks)* (b) Name the interconnection responsible, and state **one** further reason the series should not simply be extrapolated. *(2 marks)*

Q6. For each instrument below, state whether its principal contribution to an energy decision is to **set a threshold**, to **allocate the decision** or to **create a procedure**, and justify your choice. (a) The Safeguard Mechanism under the *National Greenhouse and Energy Reporting Act 2007* (Cth). (b) The *Environment Effects Act 1978* (Vic). (c) Third-party objection and review under the *Planning and Environment Act 1987* (Vic). *(3 marks)*

Q7. Consider lock-in. (a) Define *lock-in* in the context of energy infrastructure. *(2 marks)* (b) Explain why lock-in means a new technology can create a tension rather than resolve one. *(2 marks)*

Q8. In September 2023 the national electricity objective was amended to include the achievement of jurisdictional greenhouse gas emissions targets. Explain why this is an example of a regulatory framework changing what a decision requires without any physical change to the energy system. *(2 marks)*

Unscaffolded

Q9. A student writes: *"Falling battery costs and Victoria's legislated storage targets are in tension, because one led to the other."* Identify the error in that sentence, and distinguish an *interconnection* from a *tension* using this pair and one other pair drawn from the energy system. *(3 marks)*

Q10. Explain why a sustainable energy future cannot be decided one energy source at a time, and identify which of the four factors this most affects. *(4 marks)*

Q11. Nuclear generation is technically mature and operates at scale overseas, but cannot currently be built in Victoria. Explain what this shows about the relationship between the regulatory framework factor and the new technologies factor, naming the relevant instruments. *(4 marks)*

Q12. New energy technologies are usually presented to a community as the thing that resolves an argument. Setting **lock-in** aside — it is dealt with at **Q7** — explain **two** *other* ways in which applying a new energy technology can create a tension where none existed. *(4 marks)*

Q13. *Use the data.* The *Renewable Energy (Jobs and Investment) Act 2017* (Vic) legislates renewable electricity targets of 65% by 2030 and 95% by 2035 (s 7), storage targets of at least 2.6 GW by 2030 and 6.3 GW by 2035 (s 7A), and offshore wind targets of at least 2 GW by 2032, 4 GW by 2035 and 9 GW by 2040 (s 7B). In December 2025 the Victorian Auditor-General reported that the 2 GW offshore wind target will not be met, with delay to at least the end of 2033, while the 2.6 GW storage target for 2030 remains on track.

Explain why the missed target is not, by itself, evidence that the decision to set it was irresponsible, and state what **would** make it so. *(5 marks)*

Q14. Craythorne Grid Services Pty Ltd tells a community meeting that *"the Integrated System Plan shows this is the least-cost path, so the decision is settled."* Discuss this statement. *(4 marks)*

Q15. *Case study.* Halvestone Energy Pty Ltd has given notice that the Pentworth Power Station (1 450 MW, brown coal) will close in 2031. Pendlemoor Wind Pty Ltd proposes a 480 MW wind farm in the declared Tarnbrook renewable energy zone, and Craythorne Grid Services Pty Ltd proposes a 500 kV line across the Tarnbrook Plains to carry it to load. The alignment crosses 34 properties, including remnant grassy woodland and an area of declared

heritage landscape sensitivity — the Verrowdale water races, the channels, weirs and stone culverts of an 1870s irrigation settlement — where a **Heritage Landscape Management Plan** must be evaluated by the **Verrowdale Settlement Heritage Association Inc.** as the Registered Heritage Body for the area. *(That Act, instrument, body and association are fictitious; see the note in the Theory section.)* Quilverton Storage Pty Ltd offers a long-duration storage system that would reduce the required line capacity but has operated at full scale at only one site. Harrowfen Aluminium Pty Ltd employs 620 people near Pentworth and says it cannot absorb a price rise. The Tarnbrook Plains Landholders Alliance Inc. wants the line undergrounded. Dunmarrow Shire supports the wind farm and opposes the alignment. Bramwold Energy Analytics Pty Ltd's modelling, commissioned by Pendlemoor, finds the project reliable and least cost.

(a) Choose **two** of the parties named. For each, state what it holds that no other party holds, and say whether that thing is a value, a kind of knowledge or a power. *(2 marks)*
(b) Explain **two** limitations of Bramwold's modelling as a basis for this decision, and state how a decision-maker should treat it. *(4 marks)*
(c) Name **one** tension this decision cannot avoid, state which factors sit on each side of it, and explain what a responsible decision would do about it instead of claiming to have dissolved it. *(4 marks)*

Q16. Suppose Victoria meets its 95% renewable electricity target and its 6.3 GW storage target for 2035, on time and in full. Explain how the decisions that delivered them could nonetheless have been irresponsible, referring to at least three of the tests of responsible decision-making. *(4 marks)*

Q17. Working from the same regional generation and demand dataset, the Tarnbrook Plains Landholders Alliance Inc. concludes that the Pentworth Power Station can close in 2031 without new transmission, and Pendlemoor Wind Pty Ltd concludes that it cannot. An independent check finds no arithmetical error on either side. Account for the disagreement, and set out how a decision-maker should proceed. *(5 marks)*

Q18. Landholders hosting new transmission infrastructure in Victoria receive \$8 000 per kilometre of hosted transmission per year for 25 years, indexed — about \$200 000 per kilometre — in addition to compensation available under the *Land Acquisition and Compensation Act 1986* (Vic), alongside a renewable energy zone Community Energy Fund. Analyse the tension these payments are addressing, identify the sustainability principles engaged on each side, and state what a responsible decision would place on the record. *(6 marks)*

Q19. *Extended response.* The Pentworth Power Station will close in 2031. Victoria's legislated targets require 95% renewable electricity by 2035 and 6.3 GW of storage by the same year. Pendlemoor Wind Pty Ltd's 480 MW project depends on Craythorne Grid Services Pty Ltd's 500 kV line, which crosses 34 properties, remnant grassy woodland and the area of declared heritage landscape sensitivity described at **Q15** (a fictitious designation), and which the Tarnbrook Plains Landholders Alliance Inc. wants undergrounded at four times the cost. Quilverton Storage Pty Ltd's long-duration system would reduce the line capacity required but is proven at one site. Harrowfen Aluminium Pty Ltd employs 620 people and cannot absorb a price rise. The regional demand record predates the electrification now required of new dwellings, and Bramwold Energy Analytics Pty Ltd's modelling was commissioned by Pendlemoor.

Analyse how the four factors interconnect here and where they pull against one another, and evaluate what would have to be true of the *process* before the outcome could be called a responsible decision. *(10 marks)*

Answers

Q1. Diverse stakeholder values, knowledge and priorities; regulatory frameworks that inform environmental management strategies; use and interpretation of historical and current scientific data; application of new technologies. **Q2.** (a) A relationship in which a change in one factor changes what another requires, permits or seeks. (b) A structural opposition in which satisfying one factor more fully means satisfying another less. (c) Because the powers are distributed — rules are made by the AEMC, enforced by the AER, the system is operated and planned by AEMO, targets are legislated by governments, and the assets are privately owned — so the outcome is negotiated between parties holding different powers. **Q3.** (a) regulatory frameworks; (b) diverse stakeholder values, knowledge and priorities; (c) use and interpretation of historical and current scientific data; (d) application of new technologies. **Q4.** (a) regulatory frameworks and data (Regulation → Data — the rule forces information into the market that would not otherwise exist); (b) new technologies and data (Technology → Data; Stakeholders → Data also credited, since it is household decisions that install the technology); (c) regulatory frameworks and new technologies (Regulation → Technology). **Q5.** (a) No — the series records **operational demand**, what the grid must supply. Rooftop generation meets part of the load behind the meter, so recorded demand falls without consumption falling. (b) Technology → Data; and the record predates the electrification now required of new dwellings under clause 53.03 (Amendment VC250), so future load will differ in size and shape. **Q6.** (a) Sets a **threshold** — a facility emitting more than 100 000 t CO_2-e of covered scope 1 emissions a year holds a baseline that declines, and the number decides who is caught. (b) **Allocates the decision** — it is the Minister for Planning, and no one else, who decides whether an Environment Effects Statement is required for a large generation or transmission project. (c) **Creates a procedure** — it gives a third party standing to object and to seek review at VCAT, without setting any emissions or amenity limit itself. **Q7.** (a) A long-lived, expensive asset or connection commits a user, community or system to one pathway for decades, and usually makes the alternatives harder rather than easier. (b) Because choosing the technology also chooses what is foreclosed, so a technology that solves the immediate problem can create a new tension between acting now and preserving future options. See solutions. **Q8.** The market bodies must now weigh jurisdictional emissions targets in every rule and regulatory decision, so decisions can come out differently on unchanged physical evidence; the framework changed, the system did not. See solutions. **Q9.** The error is the word *tension*: one factor enabling another is influence, not opposition, so falling battery costs and the storage targets are an **interconnection** (Technology → Regulation). A tension needs two things that cannot both be fully satisfied — e.g. the same targets' dates against the consent processes that give hosting landholders and heritage bodies standing. See solutions. **Q10.** Because supply must match demand continuously, so a source is chosen for its contribution to a portfolio, not on its own merits; this most affects the use and interpretation of data. See solutions. **Q11.** It shows regulation acting **on** technology rather than following it — a statutory prohibition, not an evidentiary gap: s.140A EPBC Act 1999 (Cth), the ARPANS Act 1998 (Cth) and the *Nuclear Activities (Prohibitions) Act 1983* (Vic). See solutions. **Q12.** Any two, **other than lock-in**, of: it carries new material, land or waste demands that set one environmental good against another; it is unproven at full scale, so reliability must be judged before the evidence exists; it changes what is measured, so performance appears to move when the system has not; it redistributes cost onto those who cannot adopt it. See solutions. **Q13.** Because responsibility is a property of the decision process, not the outcome; a stretch target mobilises capability a safe target would not, and the slippage was found and published by an independent auditor. It becomes irresponsible if the dependencies were concealed, if other decisions were made contingent on capacity that was not secured, or if the resulting reliability risk was left unallocated. See solutions. **Q14.** Reject as stated — the ISP identifies a least-cost path under stated scenarios and assumptions; it is conditional arithmetic, not a forecast, and it does not decide the normative questions. See solutions. **Q15.** (a) e.g. Craythorne — route selection and network data (power and knowledge); the Landholders Alliance — local knowledge of soils, fire behaviour and land use, and objection rights. (b) It is scenario modelling, not measurement, and it was commissioned by a party with an interest; the demand inputs predate electrification. Treat it as evidence to be tested, with assumptions published and independently reviewed. (c) e.g. speed against consent — regulatory and stakeholder factors against the closure timetable. See solutions. **Q16.** Targets are thresholds and are met or missed; responsibility concerns whether the tension was named, finding kept apart from judgement, residual risks allocated, review built in and the benefit distributed toward the burden. Any three of those tests, applied to the 2035 targets, earn the marks. See solutions. **Q17.** They differ on assumptions and weather years, on the reliability standard applied, on the system boundary, and on who carries the burden of proof under uncertainty — not on arithmetic. See solutions. **Q18.** The payments address the tension between where the burden of the build falls (regional hosts) and where the benefit falls (consumers generally): intragenerational equity and the user pays principle on one side, efficiency of resource use and intergenerational equity on the other. See solutions. **Q19.** Model response in solutions.

Fully-worked solutions

Q7. (a) Lock-in occurs when a decision commits a user, a community or the whole system to one pathway for a long period because the asset created is long-lived, expensive and difficult to reverse — a transmission easement, a power station refurbishment, a reticulated gas network in a new suburb, or a household's new gas appliance. The commitment routinely outlasts the reasoning that produced it, because costs, technologies and targets move faster than the assets do. **(b)** A new technology looks like a resolution because it makes an option feasible or affordable that was not. But adopting it also **forecloses** the alternatives: capital is spent, land is committed, and the next technology arrives into a system that has already been built around this one. The tension is therefore between **commit now** — meeting a closure date or a target with a technology that works today — and **wait for better** — preserving the option of a cheaper or better-performing technology, at the risk of not having capacity when it is needed. Moving toward one pole necessarily moves away from the other, which is what makes it structural rather than a disagreement.

Q8. Until September 2023, the national electricity objective directed the market bodies to promote efficient investment in and efficient operation of electricity services in the long-term interests of consumers with respect to price, quality, safety, reliability and security. From that date it also directs them to promote the achievement of targets set by participating jurisdictions for reducing Australia's greenhouse gas emissions. Nothing physical changed: the same generators, the same network, the same demand. What changed is the **test** every AEMC rule determination and AER decision must be measured against, so a proposal that previously failed on cost grounds alone can now succeed on an emissions ground, and vice versa. ∴ this is a regulatory framework moving, and it demonstrates that "the framework" is not a fixed background condition of an energy decision but one of the four factors in its own right.

Q9. The student has described the relationship accurately and then given it the wrong name. "One led to the other" *is* the definition of an **interconnection** — a relationship of **influence**, in which a change in one factor changes what another requires, permits or seeks. A **tension** is a relationship of **opposition**, in which satisfying one factor more fully necessarily means satisfying another less; "led to" and "pulls against" cannot describe the same pair. Take the student's own example first. Falling lithium-ion battery costs — the technology factor — made storage economic at a scale that had not previously been possible, and Victoria then legislated storage targets of 2.6 GW by 2030 and 6.3 GW by 2035 in s 7A of the *Renewable Energy (Jobs and Investment) Act 2017* (Vic). The technology changed what the regulatory framework could sensibly require: **Technology → Regulation**, reinforcing, and neither factor is worse off — which is precisely why it is not a tension. For a genuine tension, stay with the same instrument: those legislated targets set dates by which generation and transmission must be built, while the planning and consent processes that give hosting landholders and heritage bodies standing take time that cannot be compressed without weakening that standing. Building faster means consulting less; consulting properly means building later. ∴ the first pair is an interconnection because one factor **enabled** another, and the second is a tension because the two factors **cannot both be fully satisfied** — and no additional evidence removes the need to choose.

Q10. Electricity cannot be stored in the network itself, so generation and consumption must be balanced continuously, second by second, across the whole interconnected system. A single source therefore has no standalone verdict: wind and solar are variable and non-dispatchable, storage shifts energy in time but only for the hours it is sized for, and firm plant is expensive to run rarely and emitting if it is fossil-fuelled. What matters is what a source contributes to a **portfolio** that must serve both the base load and the peak (**13B**) at every hour, including still overcast periods and, increasingly, the low-demand middle of a mild sunny day. Adding one generator therefore changes what else the system requires: a wind farm implies transmission to reach load and firming to cover its variability, and a large battery implies something to charge it. The factor this most affects is **use and interpretation of historical and current scientific data**, and in two ways. First, the relevant question is not a single figure but a **time series** — the system must be assessed across every hour of a year, under a range of weather and demand conditions, which is why the evidence base is dominated by scenario modelling rather than measurement. Second, it means any argument that quotes an annual energy total, a capacity figure or a levelised cost as though it settled the question has used the wrong statistic: those numbers say nothing about whether supply and demand match at 6 pm on a still winter evening. ∴ the decision is a portfolio decision, and treating it as a series of independent source-by-source choices produces answers that cannot be delivered.

Q11. It shows that the relationship between the two factors runs in **both** directions, and that the direction usually taught is the less absolute one. The familiar direction is **Technology → Regulation**: once a better technique is available and affordable, duties framed by reference to what is reasonably practicable tighten, and standards move with the technique. Nuclear power in Australia is the opposite case, **Regulation → Technology**. **Section 140A** of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) provides that the Minister must not approve the construction or operation of a nuclear power plant; the *Australian Radiation Protection and Nuclear Safety Act 1998* (Cth) prohibits the Commonwealth regulator licensing one; and in Victoria the *Nuclear Activities (Prohibitions) Act 1983* (Vic) prohibits the construction and operation of a nuclear energy plant directly. The technology's maturity, cost and emissions performance are therefore **irrelevant to its current availability** — the option is removed from the set before any comparison begins. Two consequences follow for decision-making. First, the constraint is **statutory, not evidentiary**, so it cannot be answered with better modelling; arguments that treat it as an evidence gap have misclassified it. Second, unlike the thermodynamic limits on conversion efficiency (**12F**), a statutory prohibition **can be repealed**, so the honest argument is a normative and political one about whether it should be — conducted on cost, construction lead time, waste management, risk and public acceptance. ∴ regulation does not merely respond to technology; it can determine what counts as an option at all, which is why the framework is a factor in the decision rather than a backdrop to it.

Q12. *First — the technology brings its own environmental demands, and they land on a different good.* A low-emissions technology is not a low-impact technology. Grid-scale batteries need lithium, nickel, cobalt and graphite, mined somewhere and processed somewhere else; a wind array or a solar farm occupies land and can fragment habitat or displace agriculture; turbine blades, modules and cells become a waste stream at end of life that barely existed twenty years ago. The tension this creates is **habitat and materials against decarbonisation** — the same *conservation of biodiversity and ecological integrity* asserted at two scales, with **efficiency of resource use** engaged on the materials side — and it cannot be argued away by pointing at the emissions avoided, because the two costs fall on different systems and often on different people. A technology deployed to relieve one environmental pressure has generated a second one, and a decision-maker now has to weigh them against each other rather than simply adding up a benefit.

Second — it redistributes who bears cost and who captures benefit. Rooftop photovoltaics illustrate this cleanly. A household that installs a system reduces its own bill and the system's daytime operational demand, which is a genuine gain. But the system requires a roof, capital and usually ownership, so renters, apartment residents and low-income households are largely excluded; and because networks recover largely fixed costs from a shrinking volume of grid-supplied energy, the excluded households can end up carrying a larger share of those costs. The technology has therefore created a tension in **intragenerational equity** that did not exist before it, between the users who can adopt it and those who cannot. ∴ in both cases the technology solved a real problem and generated a new opposition in doing so — and neither opposition is lock-in, which is a third and separate mechanism (**Q7**). The four-factor analysis therefore asks what else a technology demands and who it disadvantages, not only what it delivers.

Q13. The claim confuses the **outcome** of a decision with the **quality of the decision-making**, which is the distinction the dot point turns on. Three arguments show why the missed target is not sufficient evidence of irresponsibility. First, an ambitious target is doing work that a safe target cannot: offshore wind at 2 GW by 2032 mobilises port capacity, transmission planning, supply chains and workforce commitments that would not be mobilised by a target certain to be met, and a government that set only achievable targets would be criticised on different and better grounds. Second, the slippage was identified and **published by the Victorian Auditor-General**, an independent body outside the program — which is the reviewability test being satisfied rather than failed, and is exactly the **Data → Regulation** coupling doing its job. Third, the comparison in the stimulus matters: the legislated **2.6 GW storage target for 2030 is on track**, so the government's targets are not uniformly unachievable and the offshore wind delay is specific to identifiable delivery constraints — port capacity and auction timing — rather than symptomatic of a target-setting process that does not work.

What **would** make it irresponsible is a failure on the process tests. If the dependencies were known and **not disclosed** when the target was set and then legislated — so the public and the market were given a commitment presented as more certain than it was — the tension was concealed rather than named. If other decisions were made **contingent** on the capacity arriving, so that a generator's retirement or a network decision now depends on 2 GW that will not exist until at least the end of 2033, the residual **reliability risk** has been created and not allocated. And if there is no stated trigger for revising the plan when the delay was identified, no review was built in. ∴ a missed target is a finding about delivery; irresponsibility would lie in concealed dependencies, unallocated residual risk or an absence of review — none of which the stimulus establishes, and all of which are the correct places to look.

Q14. The statement is right about what the Integrated System Plan is good for and wrong about what it decides. The ISP is the most authoritative planning document in the National Electricity Market: AEMO publishes it every two years, and it identifies an **optimal development path** — the least-cost combination of generation, storage and transmission that meets reliability standards and government policy to 2050. That makes it the correct common reference for a community meeting, and a party arguing against it carries a real burden. **However**, three limitations mean it cannot settle the decision. First, it is **conditional arithmetic under scenarios**, not a forecast: it runs stated assumptions about demand growth, technology costs, weather and policy, and when those assumptions move the optimal path moves with them — as it did between the 2024 and 2026 plans, when falling solar and battery costs, rising wind costs and a higher capital cost per kilometre of transmission produced a path needing over a thousand kilometres less transmission, and so a lower total transmission cost than the plan before it. Second, "least cost" is least cost **to the system, over a defined horizon**, which is not the same as least cost to a particular customer, region or generation of customers; the ISP does not decide how the cost is distributed, and distribution is where most of the tension in this decision lies. Third, and decisively, it is silent on the **normative** questions (**3D**): what reliability standard is acceptable, what weight to give a hosting community's amenity or a remnant woodland, and who should bear the risk of being wrong. ∴ the correct use of the ISP is as evidence — strong, independent and publicly documented — about the cost and feasibility of options, with its assumptions stated and open to challenge; presenting it as settling the decision misrepresents a scenario as a forecast and, worse, converts a judgement that belongs to the community and its decision-makers into an apparently technical finding.

Q15. (a) Any two, correctly distinguished — for example **Craythorne Grid Services Pty Ltd**, which holds route selection and the network capability data on which the alignment is justified (a **power** and a **knowledge** no other party has); and the **Tarnbrook Plains Landholders Alliance Inc.**, which holds experiential knowledge of the Plains — soils, flood paths, fire behaviour and farm operations — together with objection rights, but no power to select the route. Alternatively **Harrowfen Aluminium Pty Ltd** holds the ability to close or relocate, taking 620 jobs, which gives its price concern weight out of proportion to its formal standing; or the **Verrowdale Settlement Heritage Association Inc.**, which as the Registered Heritage Body for the area holds a statutory **evaluation** of a Heritage Landscape Management Plan under the fictitious *Marrowvale Heritage Protection Act 2011* — a **power**, and a decision rather than a submission — together with knowledge of the water races that appears on no register.

(b) *First, it is scenario modelling, not measurement.* It projects a system that does not yet exist under assumed technology costs, weather years, demand growth and policy settings; changing an assumption changes the result, and the demand inputs are drawn from a regional record that predates the electrification now required of new dwellings, so both the size and the shape of future load are uncertain in a direction the record cannot show. *Second, it was commissioned by Pendlemoor*, a party with a direct financial interest in the conclusion. That does not make it wrong — it is normal and often the only way the work gets funded — but it means the assumptions were chosen by an interested party, and the **Stakeholders → Data** coupling operates: whether a dataset is believed depends partly on who generated it, and here the doubt is reasonable rather than merely rhetorical. The decision-maker should treat the modelling as **evidence to be tested, not a finding to be adopted**: require the assumptions, scenarios and sensitivities to be published in full, commission independent review of the demand and reliability inputs, require the alternative configurations (including the Quilverton storage option and undergrounding) to be modelled on the same assumptions so they are comparable, and keep the modelling's conclusions clearly separate from the judgement about what is acceptable.

(c) Several defensible answers. For example, **speed against consent**: Halvestone's Pentworth station closes in 2031 and the legislated targets have fixed dates, so the wind farm and the line must be delivered on a timetable; but the alignment crosses 34 properties, remnant grassy woodland and an area of declared heritage landscape sensitivity, and the processes that give those interests standing — planning objection and review, an Environment Effects Statement, and a Heritage Landscape Management Plan evaluated by the Registered Heritage Body — take time that cannot be compressed without hollowing out the standing they confer. The factors in opposition are **regulatory frameworks and stakeholder values and priorities** on one side, and the **closure and target timetable** the same regulatory framework has set on the other — which is worth naming precisely, because the framework is generating the tension from both ends. A **responsible** decision would name that rather than presenting either delay or haste as compelled; would **stage** the works so that the components not dependent on the contested alignment proceed now; would state explicitly **who carries the reliability risk** if the line is not complete by 2031, and who carries the cost risk if it is built and the storage alternative later proves cheaper; and would set the consent processes running in parallel with, not after, the technical design so that the local and heritage knowledge changes the alignment rather than merely reviewing it.

(Habitat against decarbonisation, or cost against equity for Harrowfen's workforce, are equally creditable if the poles and the response are argued as carefully.)

Q16. Suppose both 2035 targets are delivered on time. A **target** is a threshold — 95% renewable electricity and 6.3 GW of storage by 2035 under the *Renewable Energy (Jobs and Investment) Act 2017* (Vic), alongside net zero by 2045 under the *Climate Action Act 2017* (Vic) — and a threshold is answerable yes or no. **Responsibility** is a property of the judgement inside the decisions that delivered it, and those decisions can clear every threshold and still fail in at least four ways. They can hit the renewable percentage while **concealing the tension** — for example by presenting a transmission alignment as compelled by the modelling when the modelling identified several feasible corridors and the choice between them was a judgement about whose land, whose habitat and whose amenity. They can leave the **residual risks unallocated**: reliability risk if replacement capacity is late, price risk for a large industrial user and its workforce, and stranded-asset risk if a better technology arrives, all of which fall on identifiable parties and none of which a target addresses. They can hit both numbers while **distributing benefit away from burden** — the generation and the easements in the regions, the electricity and the industrial employment elsewhere — which weakens intragenerational equity no matter how good the headline figure is. And they can be framed as **final** when the demand record they rest on describes a system being replaced, so no monitoring trigger and no power to revise are built in. ∴ a target is a floor, not a standard: it constrains the outcome, while responsibility concerns whether the tension was named, whether finding was kept apart from judgement, where the risks of being wrong were placed, whether those with a stake and no power were given standing, and whether the decision can be revised when the evidence moves.

Q17. Opposite conclusions from one dataset with no arithmetical error are normal in energy analysis, because a dataset of past generation and demand does not contain the answer to a question about a future system. Four sources of divergence are available here. First, **assumptions**: whether Pentworth can close in 2031 without new transmission depends on assumed demand growth, electrification uptake, rooftop and storage installation, plant availability and — decisively — which **weather years** are modelled, since the binding condition is a still, overcast winter period, and choosing a mild historical year rather than a severe one can reverse the sign of the answer. Second, the **reliability standard applied**: the parties may be answering "can the region be supplied in a typical year?" and "can it be supplied in a one-in-ten year?", which are different questions with different answers from identical data. Third, the **boundary**: the Alliance may be counting imports across the interconnected system, demand response and behind-the-meter storage as supply, while Pendlemoor assesses the region's own firm capacity in isolation — the same dataset, two different systems. Fourth, **uncertainty and the burden of proof**: with wide confidence intervals one party can say adequacy is not demonstrated and the other that inadequacy is not demonstrated, and both are correct — they differ on who must prove what, which is a normative allocation, not a finding.

The decision-maker's response should be to **separate the components**. Require both parties to publish their assumptions, weather years, reliability standard and system boundary, which converts an apparent factual dispute into a visible set of choices; require both to run the **same** scenario set so the outputs are comparable; commission independent review of the inputs that are genuinely technical, particularly the demand trajectory, since the historical record predates the electrification now being required; and then decide the remaining question — what standard of reliability the region should be held to, and who bears the consequence of being wrong — as the **judgement** it is, stated as such rather than presented as a technical result. ∴ the disagreement is about assumptions, standards and burden of proof rather than arithmetic, and the correct treatment is to make those choices explicit rather than to seek a decisive number.

Q18. The payments address a **spatial mismatch between burden and benefit** that is intrinsic to a renewables-based system. The generation resource is where the wind and sun are, the corridor is where the land is, and the consumption is somewhere else — so the hosting landholder carries easement restrictions, amenity and visual change, potential land value and operational effects, and the risk of being the party the whole project depends on, while the benefit (electricity, emissions reduction, system cost savings) is spread across consumers generally. On the **burden** side the principles engaged are **intragenerational equity**, since a small identifiable group carries a cost for a diffuse population, and the **user pays principle**, which says the cost of a service should fall on those who benefit from it — both of which are weakened by an uncompensated easement and strengthened by a payment funded through the system. On the **benefit** side sit **efficiency of resource use** — the corridor is the least-cost route to connect the resource, and forcing it elsewhere or underground raises the cost to every consumer — and **intergenerational equity**, since the transmission is what makes the emissions reduction deliverable at all. **Conservation of biodiversity and ecological integrity** cuts across both: the corridor may fragment remnant vegetation while enabling the generation that reduces climate pressure on it.

A payment is a real and defensible response, but it does not dissolve the tension, and a responsible decision would put four things on the record. It would **name what the payment is and is not**: it converts an uncompensated burden into a compensated one and gives hosts an interest in the project's success, but it does not confer consent, and treating acceptance of a payment as agreement to the alignment misdescribes it. It would state **what remains uncompensated** — amenity, the loss of choice about one's own land, and effects on neighbours who host nothing and receive nothing. It would show the **alternatives priced on the same basis**, including undergrounding and the storage configuration that would reduce the line capacity required, so that the community can see what its preference costs and who would pay. And it would set the payment in the context of the **other distributional instruments** — in particular the renewable energy zone Community Energy Fund — and explain how the two together are meant to distribute benefit toward burden. ∴ the payments serve intragenerational equity and the user pays principle against efficiency of resource use, and responsibility lies in stating what they compensate, what they do not, and what the alternatives would cost — not in treating a payment as having settled the question.

Q19. *Model response (10 marks).* **The decisions and the frameworks.** Several decisions are in play, not one, and they sit with different bodies. Halvestone Energy decides when Pentworth closes, constrained by the National Electricity Rules requirement to give at least **42 months' notice** unless the AER grants an exemption. Pendlemoor Wind and Craythorne Grid Services decide whether to invest. The Minister for Planning decides whether an **Environment Effects Statement** is required under the *Environment Effects Act 1978* (Vic); Dunmarrow Shire and, on review, VCAT deal with planning permits under the *Planning and Environment Act 1987* (Vic); the **Verrowdale Settlement Heritage Association**, as Registered Heritage Body, evaluates a **Heritage Landscape Management Plan** under the fictitious *Marrowvale Heritage Protection Act 2011* for the sensitive part of the alignment and may refuse it; and if the remnant grassy woodland supports a matter of national environmental significance, the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) engages as well. Above all of it sit the **legislated targets** — 95% renewable electricity by 2035 and 6.3 GW of storage by 2035 under the *Renewable Energy (Jobs and Investment) Act 2017* (Vic), and net zero by 2045 under the *Climate Action Act 2017* (Vic) — and the **national electricity objective**, which since 2023 requires the market bodies to weigh jurisdictional emissions targets alongside price, reliability and security. No single party decides the outcome; it is negotiated among parties holding different powers, which is the first thing a strong response establishes.

The interconnections. *Regulation → Stakeholders* is the most consequential here: the framework gives the Heritage Association an evaluation and the Landholders Alliance an objection, which are different instruments of different strength, so standing rather than strength of feeling determines whose position must be accommodated — and Harrowfen, with no special standing at all, has real power because it can close and take 620 jobs. *Regulation → Technology* runs in both directions: the targets make the wind farm and storage buildable propositions, while the planning and heritage processes can remove a particular alignment from the option set entirely. *Technology → Data*: Quilverton's long-duration storage, if it performs, changes how much line capacity is needed, so a technology choice rewrites the evidence base for the transmission decision rather than merely responding to it. *Stakeholders → Data* operates twice — the Alliance holds knowledge of the Plains that no dataset contains, and Bramwold's modelling was commissioned by Pendlemoor, so the assumptions were chosen by an interested party. *Data → Regulation* is the coupling currently weakest: the regional demand record predates the electrification now required of new dwellings under clause 53.03, so the series describes a system being replaced and cannot be extrapolated to justify either the line's capacity or the claim that it is unnecessary.

The tensions. *Speed against consent*: Pentworth closes in 2031 and the targets have fixed dates, but the consent processes that give 34 landholders, the woodland and the heritage landscape their standing cannot be compressed without hollowing them out. *Commit now against wait for better*: Craythorne's line is proven technology on the schedule the closure requires, while Quilverton's storage would reduce the line needed but is proven at one site — so adopting it serves efficiency of resource use and staying with the line serves the precautionary principle, and the choice must be made before the reliability evidence exists. *Habitat against decarbonisation*: the alignment fragments remnant grassy woodland in order to deliver the generation that reduces climate pressure on that same woodland — both poles are **conservation of biodiversity and ecological integrity** at different scales, and no further survey dissolves it. *Cost against equity*: undergrounding at four times the cost serves the hosting community and burdens every consumer, including Harrowfen and its workforce, while overhead construction does the reverse — **intragenerational equity** and the **user pays principle** are engaged on both sides at once. Beneath all four sits **cost now against harm later**: deferring the build keeps prices down for Harrowfen and transfers an unmet target and a less reliable, more emitting system to a later generation, against **intergenerational equity**.

Evaluation — what would make the decision responsible. Not a particular outcome. More than one defensible configuration exists on these facts, and the evidence cannot choose between them, because the decisive questions — what reliability standard the region should be held to, what the woodland and the Plains are worth against a target date, and who should pay for undergrounding — are normative (**3D**). Responsibility requires five things. **First**, fix what is fixable before deciding, and say so: the demand inputs must be rebuilt to reflect required electrification rather than extrapolated from a record of the system being replaced, since a line sized on an invalid series is indefensible whichever way it errs, and this is cheap and quick compared with the works. **Second**, make the evidence contestable: publish Bramwold's assumptions, weather years and sensitivities, disclose that Pendlemoor commissioned it, commission independent review, and require the undergrounding and Quilverton configurations to be modelled on identical assumptions so the community can see what its preference costs and who bears it. **Third**, run the consent processes in **parallel** with technical design rather than after it, so that the Heritage Association's evaluation and the Alliance's knowledge of soils, flood paths and fire behaviour can change the alignment instead of merely reviewing a settled one — which is also the only way the timetable and the standing can both be respected. **Fourth**, allocate the residual risks explicitly and separately: who carries the **reliability** risk if the line is late against a 2031 closure, who carries the **cost** risk if Quilverton would have been cheaper, and who carries the **transition** risk for Harrowfen's 620 employees — with the hosting payments and the Community Energy Fund stated as what they are, compensation and benefit-sharing, not consent. **Fifth**, build in review: staged approvals, published monitoring of the delivery dependencies, and trigger points that commit the parties in advance to revising the configuration — including revisiting the closure date under the notice-of-closure provisions — if the capacity is not on track. **However**, none of this dissolves the tensions, and a response claiming it does has misread the dot point: the woodland is still fragmented or the target still missed, and the decision-maker must choose and say why. ∴ the decision is responsible if the tensions are named rather than concealed behind the modelling, finding is kept apart from judgement, the demand evidence is rebuilt rather than inherited, the residual risks are allocated on the record, those with a stake and no power are given standing before the design is settled, and the strategy is built to be revised — and it may be responsible on those terms even if it later proves to have been wrong. *(Full marks require: at least three interconnections named with direction and mechanism; at least three tensions named with the factors in opposition and at least two sustainability principles correctly attached; correct identification of at least two regulatory instruments and who decides under them; identification of the historical demand-data problem; and a justified conclusion about responsibility framed as a property of the process, not the outcome.)*