

Intracellular Organelles

Compartmentalization, biosynthesis, turnover and cellular organization

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Learning outcomes

- Explain why cells separate housekeeping reactions into specialized compartments.
- Match organelles with their major synthetic, metabolic and degradative functions.
- Trace protein production, intracellular cargo routing and organelle turnover.
- Relate cytoskeletal organization and epithelial polarity to function.
- Distinguish membrane-bound organelles from biomolecular condensates.

Housekeeping sustains cellular viability

Nutrient acquisition	Metabolism	Communication
Supplies material for metabolism	Supports energy and synthesis	Coordinates cellular responses
Movement	Renewal	Stress protection
Positions cells and their components	Replaces senescent molecules	Maintains intracellular homeostasis

Source context: Cellular housekeeping includes these recurring requirements.

Compartmentalization permits specialization

- Many housekeeping functions take place inside membrane-bound organelles.
- Physical separation allows different reactions to occur in the same cell.
- An organelle creates a regulated local environment, rather than a homogeneous cytosol.

A boundary can improve both safety and reaction efficiency.

Separating degradative reactions protects the cell



An intracellular membrane helps contain potentially injurious activities.

Compartments establish distinct environments

Chemical conditions

- Low pH can support selected reactions.
- High local calcium can support selected functions.

Consequences

- Enzymes operate under more favorable conditions.
- Metabolic pathways gain spatial control.

A distinct local chemical environment can favor a specific reaction.

Compartmentalization improves efficiency



Organelles divide the work of cell maintenance

Mitochondria

ATP • intermediates • damage response

RER + Golgi

Membrane and secreted proteins

SER

Steroids • lipoproteins • compound modification

Proteasome / lysosome

Protein and macromolecule breakdown

Peroxisome

Oxidative breakdown of very-long-chain fatty acids

Vesicles + cytoskeleton

Transport • architecture • polarity

Synthesis and degradation are coupled

Anabolism

- Generates new cellular macromolecules.
- Depends on energy and building blocks.

Catabolism

- Processes endocytosed material.
- Removes the cell's own spent components.

Homeostasis requires both directions of molecular turnover.

Growth requires energy and building blocks

- Cell growth requires a sustained supply of energy.
- Macromolecule synthesis also needs metabolic precursors.
- Mitochondria contribute to both needs.

Energy production and anabolic metabolism are linked.

Mitochondria carry several responsibilities

Energy

Most cellular ATP arises from oxidative phosphorylation.

Anabolic inputs

Metabolic intermediates support synthesis.

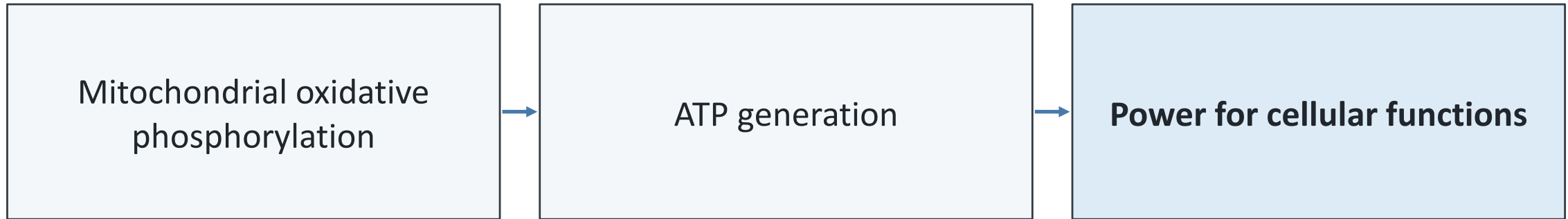
Specialized synthesis

Mitochondria contribute to heme production.

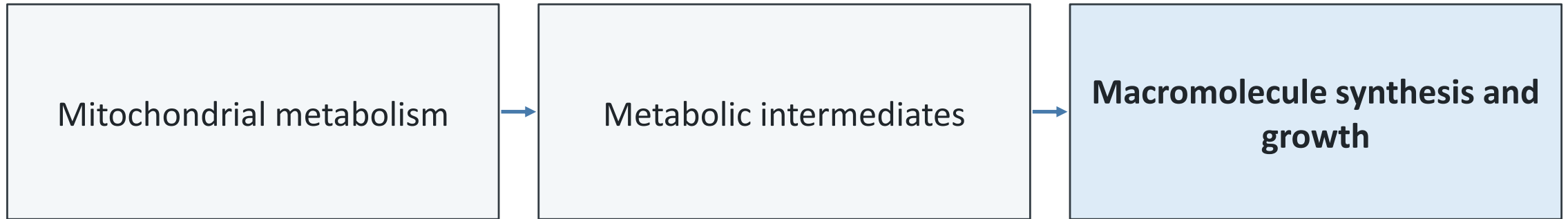
Cell fate

Damage sensors can regulate apoptosis.

Oxidative phosphorylation produces most ATP



Mitochondrial intermediates support anabolism

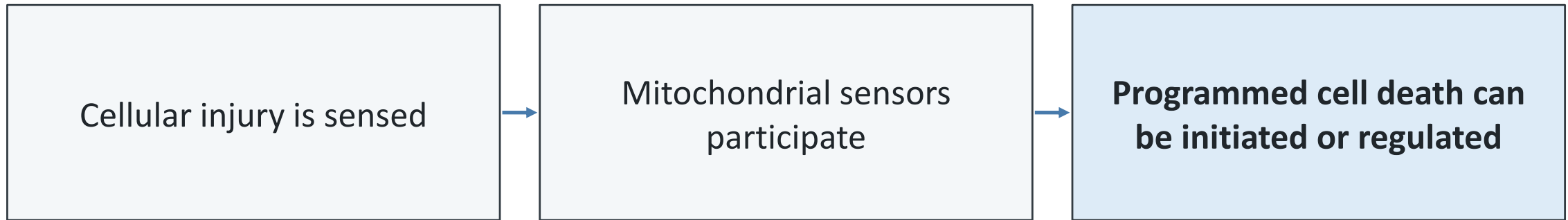


Heme synthesis illustrates a biosynthetic role

- Mitochondria are not solely ATP-generating compartments.
- Heme synthesis includes a mitochondrial contribution.
- This example links organelle function to specialized biosynthesis.

Avoid reducing mitochondrial biology to “the powerhouse of the cell.”

Mitochondria participate in cell-damage responses



Apoptosis is the example given; Detailed apoptotic pathways are outside this topic.

Mitochondrial functions have different endpoints

Function	Mitochondrial contribution	Cell-level relevance
Energy metabolism	Oxidative phosphorylation	ATP supply
Biosynthesis	Metabolic intermediates	Anabolic pathways
Specialized synthesis	Heme synthesis	Heme production
Damage response	Apoptosis regulation	Cell fate

Application: Connect an organelle to its functions

A researcher disrupts a cell compartment responsible for most ATP production. Which two additional roles may also be affected?

A. Production of metabolic intermediates and apoptotic signaling

B. Sorting of internalized cargo and lysosomal digestion

C. Apical-basolateral polarization and actin polymerization

Discuss the justification before advancing to the explanation.

Mitochondria: Integrated interpretation

- The compartment in the question is the mitochondrion.
- Mitochondria contribute to ATP generation, anabolic intermediates, heme synthesis and apoptosis.
- The example illustrates why single-function labels for organelles are incomplete.

Mitochondria connect energy supply, biosynthesis and the response to injury.

Protein destination shapes its site of synthesis

Rough ER / Golgi route

- New secreted proteins.
- New proteins destined for plasma membrane.

Free-ribosome route

- New proteins intended to remain in the cytosol.
- Translation occurs on free ribosomes.

Different destinations engage different protein-synthesis locations.

Rough ER supports export and membrane proteins

- The rough endoplasmic reticulum (RER) is part of a secretory production route.
- New proteins intended for secretion are assembled in the RER–Golgi system.
- The same system handles proteins destined for the plasma membrane.

Protein destination is central to the division of biosynthetic labor.

RER and Golgi form a functional partnership



Free ribosomes produce cytosolic proteins

- Not every new protein enters the RER–Golgi route.
- Proteins intended for the cytosol are synthesized on free ribosomes.
- This distinction is determined by intended subcellular destination.

Free-ribosome translation is not synonymous with secretion.

Protein synthesis: Compare the two routes

Protein destination	Principal synthesis context	Expected destination
Secreted protein	RER–Golgi system	Outside the cell
Plasma-membrane protein	RER–Golgi system	Cell surface
Cytosolic protein	Free ribosomes	Cytosol

Smooth ER specializes in selected biosynthesis

Steroids

Participates in steroid hormone synthesis.

Lipoproteins

Participates in lipoprotein synthesis.

Hydrophobic compounds

Converts or modifies them for aqueous export.

Smooth ER (SER) differs functionally from the rough ER.

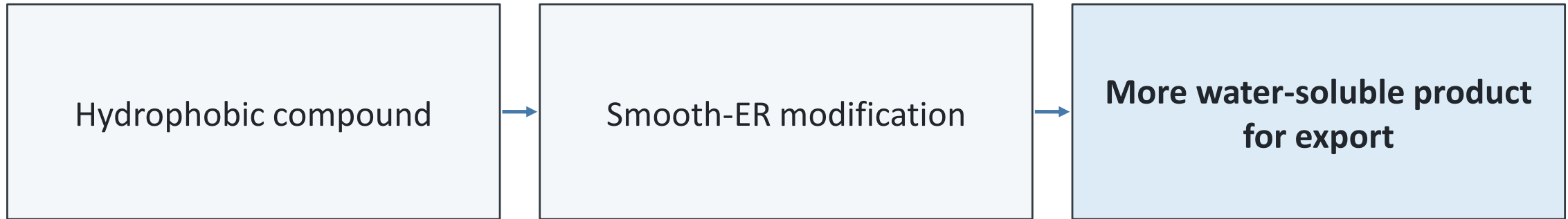
Smooth ER supports steroid synthesis

- The smooth endoplasmic reticulum (SER) is involved in steroid hormone production.
- This is a distinct output from the RER's synthesis of secreted and surface proteins.
- Organelle specialization aligns the chemistry of synthesis with cellular needs.

Smooth ER contributes to lipoprotein production

- Lipoprotein synthesis among SER functions.
- The organelle therefore participates in synthesis beyond steroid hormones.
- SER activity belongs to the cell's anabolic housekeeping repertoire.

SER modifies hydrophobic compounds for export



Rough ER and smooth ER are functionally distinct

Feature	Rough ER	Smooth ER
Core emphasis	New secretory and membrane proteins	Selected lipid synthesis and modification
Representative products	Secreted / membrane-bound proteins	Steroids and lipoproteins
Additional task	Works with Golgi apparatus	Hydrophobic-compound processing

Application: Identify the synthetic route

A newly made protein will remain in the cytosol. Which option best matches its site of synthesis?

A. Free ribosomes

B. Rough ER and Golgi

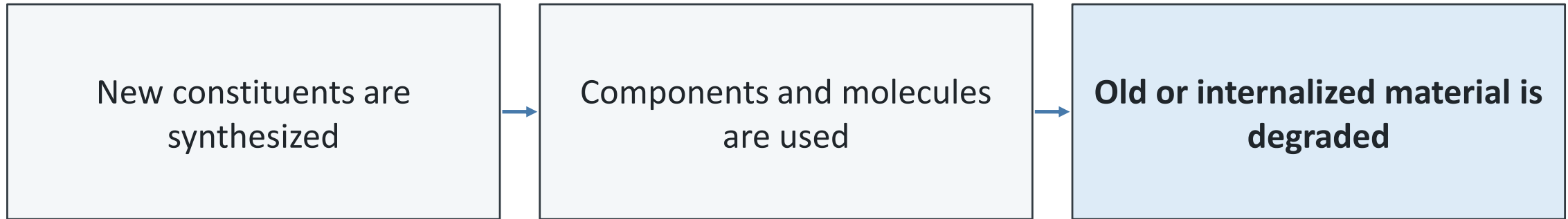
C. Smooth ER

Discuss the justification before advancing to the explanation.

Protein destination determines the answer

- Cytosolic proteins are synthesized on free ribosomes.
- RER–Golgi activity is linked to secreted and membrane-destined proteins.
- SER is highlighted for steroid, lipoprotein and hydrophobic-compound functions.

Anabolism must be balanced by catabolism



The cell clears external and endogenous material

Incoming cargo

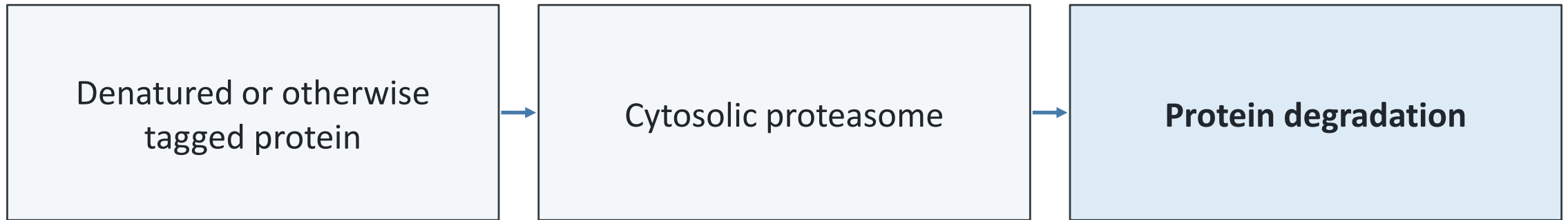
- A wide variety of molecules enter through uptake.
- Internalized cargo requires intracellular processing.

The cell's own components

- Proteins undergo replacement.
- Organelles also have finite functional lifetimes.

Both streams contribute to the cell's degradative workload.

Proteasomes target selected cytosolic proteins



Proteasomes are not general organelle digestors

- They are complexes that degrade selected cytosolic proteins.
- Denaturation or a degradation tag identifies relevant substrates.
- This role from organelle digestion in lysosomes.

Substrate and cellular location distinguish catabolic pathways.

Lysosomes digest diverse macromolecules

Proteins

Digestive substrates

Polysaccharides

Digestive substrates

Lipids

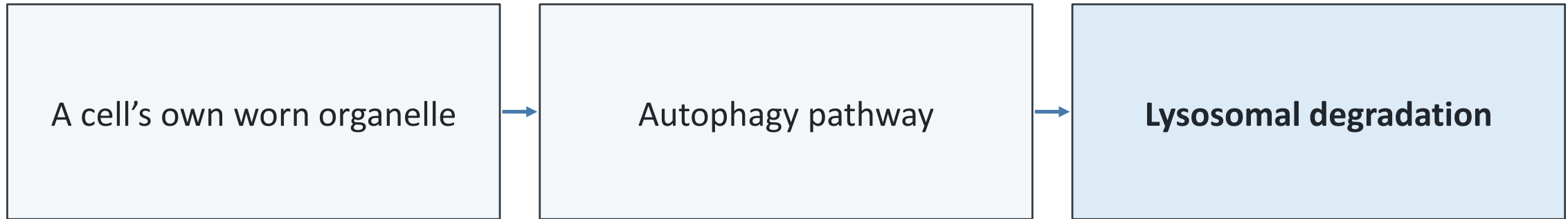
Digestive substrates

Nucleic acids

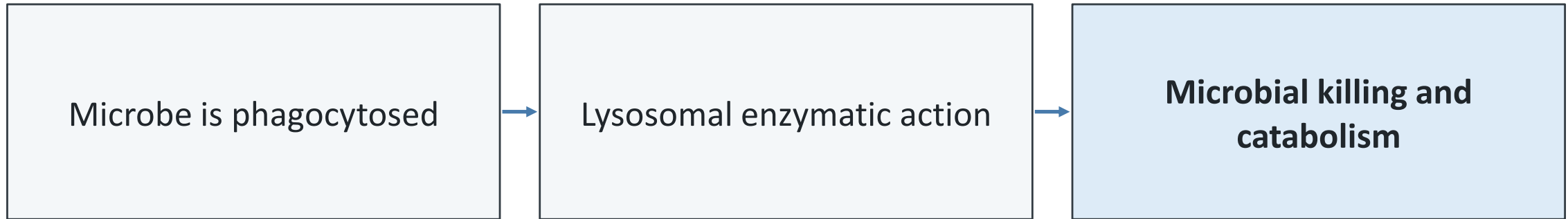
Digestive substrates

Lysosomes contain degradative enzymes able to process multiple classes.

Autophagy delivers cellular material for breakdown



Lysosomes help destroy ingested microbes



Microbial breakdown is one stated function of lysosomes.

Proteasomes and lysosomes have different substrates

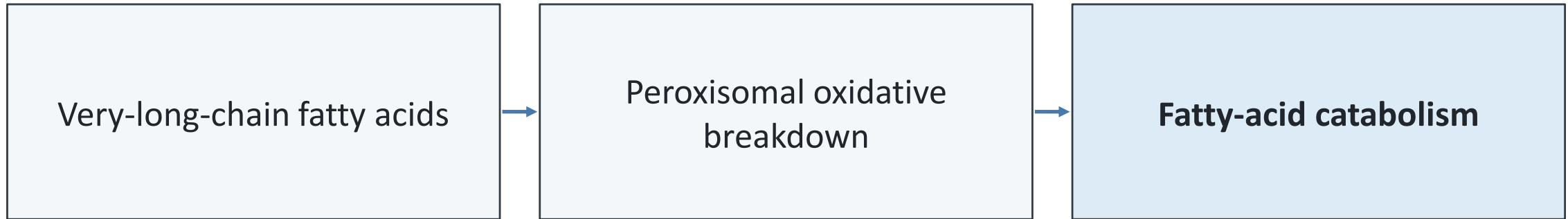
Feature	Proteasome	Lysosome
Typical target	Denatured / tagged cytosolic proteins	Broad macromolecules
Organelle recycling	Not its role in this summary	Autophagy
Ingested microbes	Not its role in this summary	Killing and catabolism

Peroxisomes contain oxidative enzymes

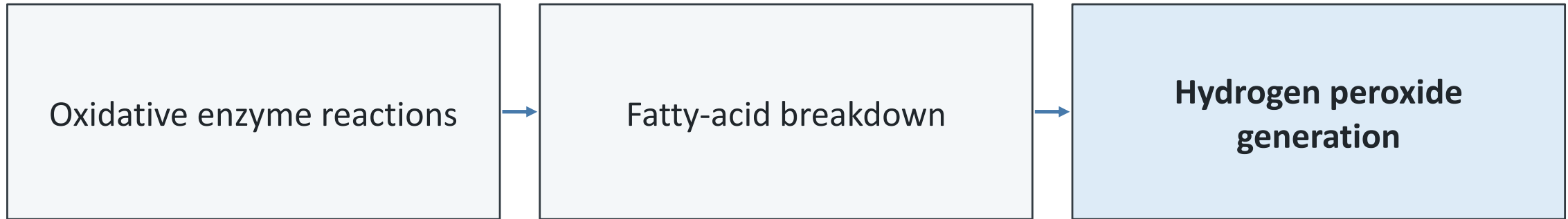
- Peroxisomes are membrane-bound organelles with oxidative activities.
- The source specifically names catalase and peroxidase.
- Peroxisomal chemistry differs from proteasomal and lysosomal degradation.

Peroxisomes are a distinct catabolic compartment.

Peroxisomes break down very-long-chain fatty acids



Peroxisomal catabolism generates hydrogen peroxide



Three routes to molecular disposal

Compartment	Principal substrate or task	Distinctive feature
Proteasome	Selected cytosolic proteins	Denatured or tagged
Lysosome	Macromolecules, organelles, microbes	Degradative enzymes; autophagy
Peroxisome	Very-long-chain fatty acids	Oxidative enzymes; H ₂ O ₂ produced

Application: Choose the degradative compartment

A cell must dismantle one of its own aging organelles. Which compartment is associated with the relevant process?

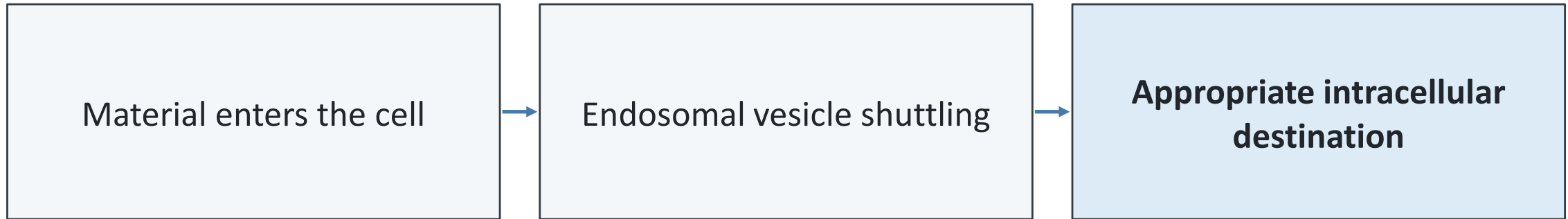
- A.** Lysosome, through autophagy
- B.** Free ribosome, through translation
- C.** Golgi apparatus, through secretion

Discuss the justification before advancing to the explanation.

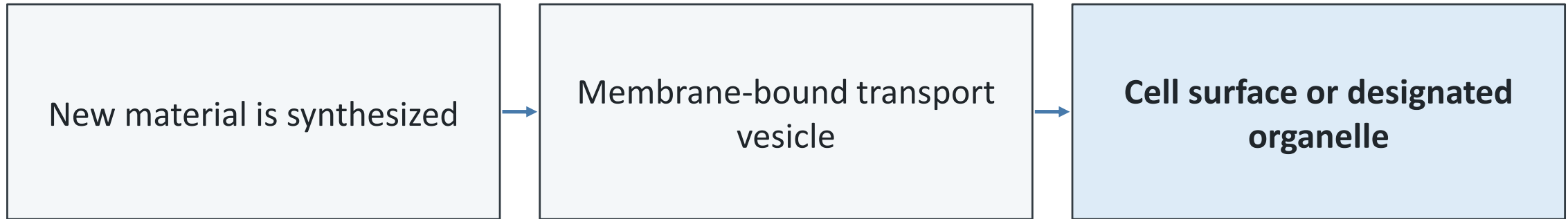
Organelle turnover is a lysosomal task

- Autophagy is the mechanism named for intracellular organelle breakdown.
- Lysosomes contain degradative enzymes for this process.
- Proteasomes instead remove selected cytosolic proteins in this framework.

Endosomes sort and route internalized cargo



Transport vesicles also deliver new products



Intracellular trafficking has two complementary directions

Cargo source	Transport component	Purpose
Internalized material	Endosomal vesicles	Route to appropriate location
Newly synthesized material	Other membrane-bound vesicles	Deliver to surface or organelles

The cytoskeleton organizes intracellular movement

- The cell moves internally and within its environment.
- Cytoskeletal structures support movement and spatial organization.
- They also maintain cellular shape and contribute to polarity.

Cell architecture is not independent of cell function.

Three cytoskeletal components are named

Component class	Example named in Robbins	Shared function in this overview
Microfilaments	Filamentous actin	Movement and organization
Intermediate filaments	Keratins	Shape and organization
Microtubules	Microtubule polymers	Movement and organization

Actin: A microfilament component

- Filamentous actin constitutes the microfilament system.
- As part of the cytoskeleton, it contributes to movement and cellular organization.
- Its activity participates in maintaining the cell's architecture.

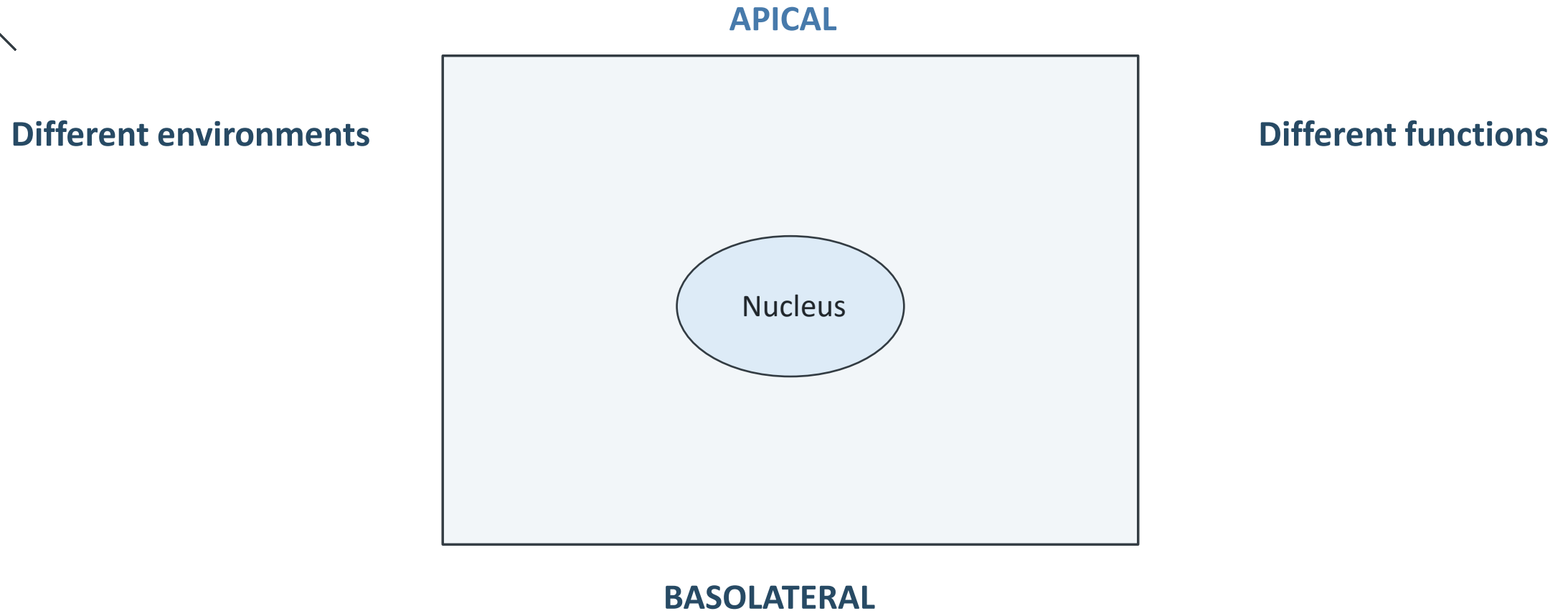
Keratins: Intermediate-filament examples

- Keratins are identified as intermediate-filament proteins.
- They contribute to the structural systems that preserve cell shape.
- The cytoskeletal scaffold is important for organized cellular compartments.

Cell shape and organelle position are regulated

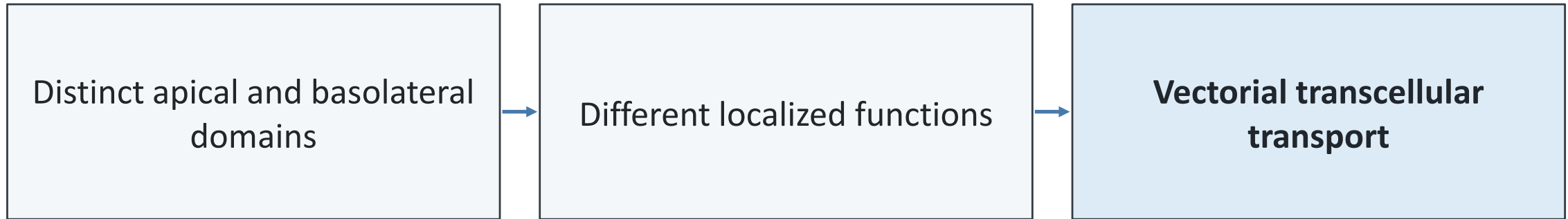
- Cellular constituents must occupy useful spatial positions.
- Cytoskeletal proteins support the organization of intracellular structures.
- Organized architecture enables the maintenance of specialized cell domains.

Epithelial cells have apical and basolateral domains



Apical: The top of an epithelial cell • Basolateral: The bottom and sides • The domains contact different environments and have different functions

Polarity supports directional epithelial transport



Loss of polarity threatens epithelial transport

Intestinal epithelium

- Directional movement across the lining requires organization.
- Disrupted polarity may impair vectorial transport.

Renal tubule

- Apical and basolateral differences support transport.
- Loss of polarity may disrupt directional movement.

Both intestinal and renal epithelia rely on correct cellular polarity.

Organelle biogenesis accompanies cell growth



Organelle biogenesis is a requirement for growth and division.

Cell division requires organelle partitioning

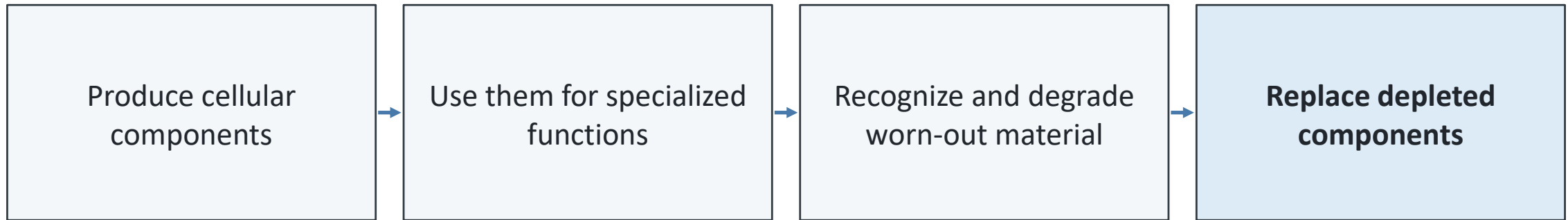


Organelles and proteins have finite lifespans

- Cells continually renew macromolecules and organelles.
- Recognition of worn-out components is essential to housekeeping.
- An approximate 10-day mitochondrial lifetime as an example, not a universal fixed lifespan.

Biogenesis and degradation must coexist.

Maintenance is a continuing lifecycle



This sequence synthesizes the text's discussions of biogenesis and turnover.

Not every intracellular compartment has a membrane

Membrane-bound organelles

- Enclosed by a limiting membrane.
- Maintain specialized local chemical conditions.

Biomolecular condensates

- Assemblies of proteins and nucleic acids.
- Dynamic compartments arising via phase separation.

Both forms of spatial organization contribute to intracellular housekeeping.

Phase separation creates biomolecular droplets



Examples of membraneless condensates

Stress granules	Processing bodies	Nucleoli
Named condensate example	P-bodies	Named condensate example

These are examples of biomolecular condensates, not membrane-bound organelles.

Two mechanisms of intracellular compartmentalization

Feature	Membrane-bound organelles	Biomolecular condensates
Boundary	Limiting membrane	No limiting membrane
Organization	Contained chemical milieu	Concentrated molecular assemblies
Formation	Organelle maintenance and biogenesis	Phase separation
Examples	Mitochondria, ER, lysosomes	Stress granules, P-bodies, nucleoli

Cell homeostasis requires coordinated compartments

Energy + precursors

Mitochondria

Macromolecule production

RER, Golgi and SER

Targeted degradation

Proteasomes, lysosomes and peroxisomes

Routing

Endosomes and transport vesicles

Shape + polarization

Cytoskeleton

Dynamic assembly

Biomolecular condensates

Integration: Trace internalized cargo

A cell takes up material that must be delivered to an appropriate intracellular location and then broken down. Which pairing best fits the functions described?

A. Endosomes for routing; Lysosomes for broad digestion

B. Free ribosomes for routing; SER for digestion

C. Mitochondria for routing; Microtubules for digestion

Discuss the justification before advancing to the explanation.

Why endosomes and lysosomes are paired

- The excerpt assigns trafficking of internalized cargo to endosomal vesicles.
- It assigns broad macromolecule digestion to lysosomes.
- Together they illustrate spatial coordination without equating the organelles.

Organelle functions: A compact reference

Function	Principal organelle or system
ATP and metabolic intermediates	Mitochondria
Secreted and membrane protein synthesis	RER + Golgi
Steroid / lipoprotein synthesis	SER
Protein and organelle breakdown	Proteasome / lysosome
Very-long-chain fatty-acid breakdown	Peroxisome
Routing, morphology and polarity	Vesicles + cytoskeleton

Primary source

Textbook reference

Robbins, Cotran & Kumar. Pathologic Basis of Disease. 11th edition (2026). Chapter 1, “The Cell as a Unit of Health and Disease,” pp. 5–7; section “Intracellular Organelles.”

Original, editable explanatory diagrams and tables. Source page mappings are retained in the PowerPoint presenter notes.