ARKE

GUARDIANS OF EARTH

A Pore-Scale Microbial Adventure
Based on Real Science from CompLaB3D

INSTRUCTION BOOKLET

ARKE: Guardians of Earth is an educational tile-based game that teaches biogeochemical concepts through interactive microbial gameplay.

Based on research from the **University of Georgia**

CompLaB3D Pore-Scale Reactive Transport Framework

Game Engine: Godot 4.2+

Genre: Educational / Strategy / Tile-based

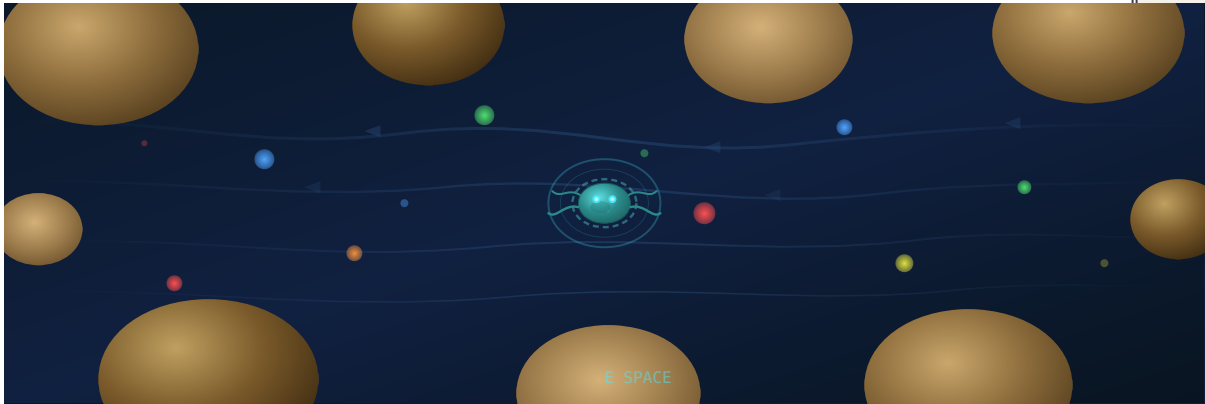**Players:** 1

Platform: PC / Web (itch.io)

All game art, music, and sound effects are procedurally generated. No external assets required.

This instruction booklet contains important information about gameplay mechanics, characters, worlds, and the real science behind the game. Please read it thoroughly before beginning your mission.

THE STORY

Deep beneath the surface of the Earth, between grains of rock and soil, there exists a hidden world. In the microscopic spaces called **pores**, water flows carrying dissolved chemicals—the fuel of life itself.

For billions of years, tiny organisms called **archaea** have lived here in the dark, feeding on chemicals that seep up from deep underground. They are Earth's invisible guardians— consuming **methane (CH$_4$)**, a greenhouse gas **80 times** more potent than CO$_2$, and **nitrate (NO$_3^-$)**, which would otherwise become **nitrous oxide (N$_2$O)**, a gas **300 times** more potent than CO$_2$.

Without these microbes, Earth's climate would spiral out of control.

> YOUR MISSION
>
> You are **ARKE**—a young methanotrophic archaeon, newly awakened in the pore space. Guided by the ancient **Elder Archaeon Prime**, you must navigate through five increasingly hostile environments:
>
> 1. Eat **substrates** (dissolved chemicals) to survive and grow
> 2. Manage your **Health**, **Energy**, and **Growth**
> 3. Place **biofilm colonies** to secure territory and protect the planet
> 4. Outcompete **rival microbes** who hunt for the same food
> 5. Survive **toxic zones**, starvation, and hostile environments

THE AWAKENING

Elder Archaeon Prime:

"Wake up, young one. You're deep in the subsurface now, between the grains. This is your home—the pore space."

ARKE:

"Where... where am I? Everything is so dark..."

Elder:

"Look around you. See those brown walls? Those are rock grains. The dark blue space between them is water—your world. And those glowing particles? That's your food."

Elder:

"There's methane rising from below—CH_4. It's a greenhouse gas, 80 times more potent than CO_2. And nitrous oxide seeping from thawing soil above—300 times more potent! If these gases reach the atmosphere... the planet warms."

ARKE:

"What can I do? I'm just one microbe..."

Elder:

"One microbe can become billions. Eat substrates, grow your biomass, and when you're ready—divide! Place biofilm colonies across the pore space. Each colony is a sentinel, consuming greenhouse gases. You are Earth's climate shield. Now go, young one. The Soil Frontier awaits."

OBJECT OF THE GAME

Navigate through **10 levels** across **5 unique environments**, each inspired by real subsurface ecosystems. In each level, you must place a target number of **biofilm colonies** by eating substrates and growing your biomass to the division threshold.

To Win Each Level:

- Eat substrates to fill your Growth bar
- Press **SPACE** when Growth reaches 100 to divide
- Place the required number of colonies
- Advance to the next level

You Lose If:

- Your Health drops to 0 (starvation)
- Toxic zones drain your Health too fast
- Rivals consume all available food
- (You can always retry the level!)

HOW STARVATION WORKS

Your Health (HP) drains constantly at **1.5 points per second** due to basal metabolic costs—the energy your cell needs just to stay alive. Starting from full health (100 HP), you have approximately **67 seconds** before death if you eat absolutely nothing. This timer is unforgiving: even a few seconds of not finding food will noticeably chip away at your HP.

Warning indicators: When HP drops below **30**, the screen edges begin flashing red and the text **"STARVING!"** appears on screen as an urgent warning. This gives you roughly 20 seconds to find food before death.

HOW SUBSTRATES SPAWN

New substrate particles appear every **1.2 seconds** near the **INLET** edge of the map (typically the top or left side, depending on the level's flow direction). Once spawned, substrates **drift with the water flow** across the pore space, following the flow field at a speed determined by the local velocity.

Substrates do not appear uniformly across the map. They concentrate along flow paths and accumulate in low-velocity zones where water slows down. Understanding flow patterns is key to finding reliable food sources. In later levels, the spawn rate may feel slower because rivals consume substrates before they reach you.
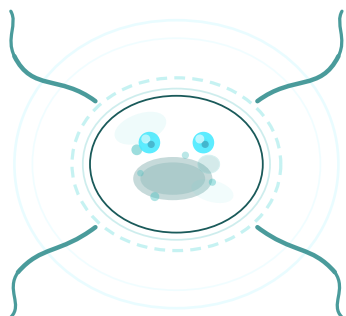
When your HP reaches 0, ARKE's body fades and a **"GAME OVER"** screen appears. After a **2-second delay**, you are prompted to press **ENTER** to retry the current level from the beginning. All progress within that level (colonies placed, growth accumulated) is reset, but your overall game progress (completed levels) is preserved. You can retry any level as many times as needed.

REMEMBER

Every molecule of methane (CH_4) you eat prevents greenhouse warming. Every nitrate (NO_3^-) you consume prevents nitrous oxide release. **You are playing for the planet!**

CHARACTERS

ARKE

A young **methanotrophic archaeon**—a single-celled organism that feeds on dissolved chemicals in underground water. ARKE is Earth's front-line defender against greenhouse gas emissions, capable of consuming methane and other substrates to grow biomass and reproduce through binary fission (division). With translucent double membranes, internal ribosomes, and sensitive chemotactic receptors, ARKE navigates the dark pore spaces guided by chemical gradients.

TYPE: Player Character • SIZE: 32×32px • SPEED: 2.5 tiles/sec (5.0 in planktonic mode)
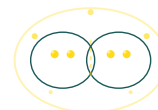
ARKE Directional Sprites

UP	DOWN	LEFT	RIGHT	EATING	DIVIDE!

ARKE'S VITAL STATS

HP   100

Health — Drains at **1.5 per second** constantly due to cellular maintenance costs (basal metabolism). At full health (100), you have approximately **67 seconds** before death if you eat nothing. When HP drops below **30**, screen edges flash red and **"STARVING!"** text appears. At 0, game over.

EN   100

Energy — Drains at **0.8 per second**. Powers planktonic mode (SHIFT key). Each flow-riding move costs **0.5 additional energy**. When EN reaches 0, you cannot ride flow and are stuck at normal speed (**2.5 tiles/sec** instead of **5.0**).
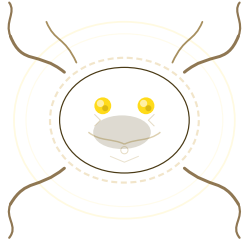
GR   100

Growth — Does **NOT** decay! This is key—every substrate you eat permanently increases GR. When GR reaches exactly **100**, your body glows yellow and you can press **SPACE** to divide. Growth persists even if your HP is critically low, so a clutch division is always possible.
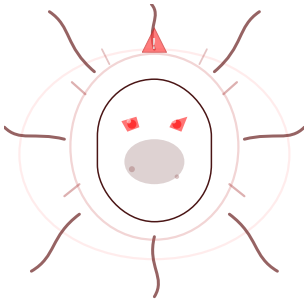
ELDER ARCHAEON PRIME

ELDER ARCHAEON PRIME

An ancient archaeon who has guarded the subsurface for eons. The Elder's body bears the marks of countless generations—ornate membrane patterns that tell the story of deep-Earth survival. The Elder serves as your mentor, providing mission briefings before each level and teaching you the science behind your abilities. Appears during cutscenes and narrative sequences.

TYPE: Mentor / NPC • APPEARS: Cutscenes & Briefings

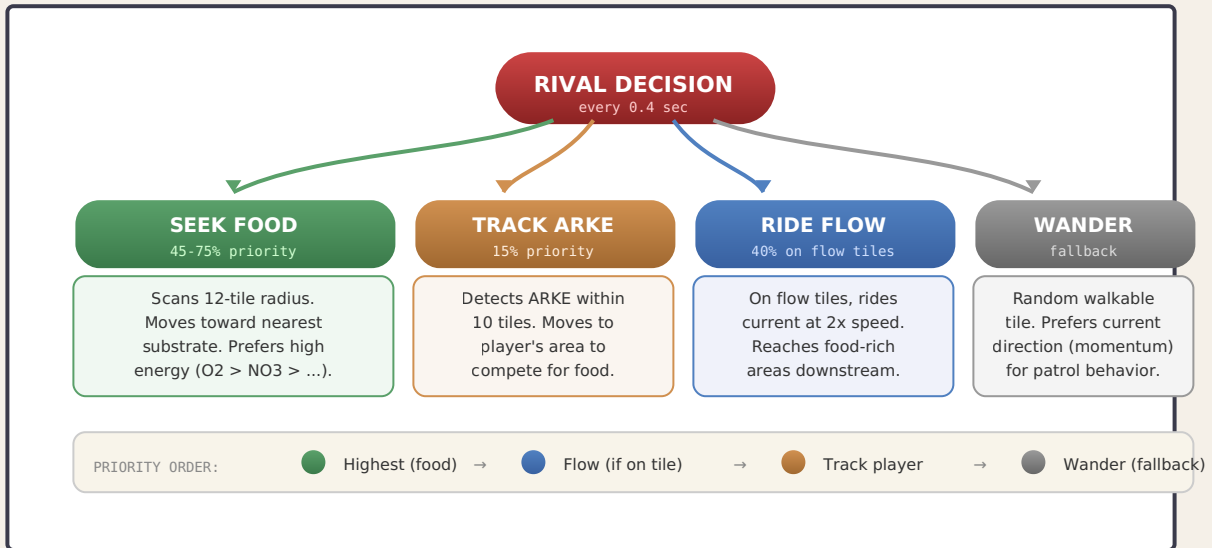## RIVAL MICROBES

RIVAL MICROBE

Competing bacteria that hunt for the same substrates as you. Rivals are **invulnerable**—you cannot kill or damage them. They don't attack you directly, but they consume food aggressively, creating deadly scarcity. With their rod-shaped bodies and multiple flagella, they are efficient hunters that use sophisticated decision-making algorithms to find food. The more rivals in a level, the harder it becomes to survive.

TYPE: Enemy (Competitor) • SIZE: 10×10px • SPEED: 2.5 tiles/sec • SENSE: 12 tiles

HOW RIVALS SENSE AND HUNT

Every **0.4 seconds** (the decision interval), each rival microbe evaluates its surroundings and chooses an action from its decision tree. Understanding this algorithm is critical to outmaneuvering them.

RIVAL DECISION
every 0.4 sec

SEEK FOOD 45-75% priority	**TRACK ARKE** 15% priority	**RIDE FLOW** 40% on flow tiles	**WANDER** fallback
Scans 12-tile radius. Moves toward nearest substrate. Prefers high energy (O2 > NO3 > ...).	Detects ARKE within 10 tiles. Moves to player's area to compete for food.	On flow tiles, rides current at 2x speed. Reaches food-rich areas downstream.	Random walkable tile. Prefers current direction (momentum) for patrol behavior.

PRIORITY ORDER: ● Highest (food) → ● Flow (if on tile) → ● Track player → ● Wander (fallback)

1. Seek Food (45-75% Priority)

The rival calculates **Manhattan distance** to every substrate within **12 tiles**. It moves one tile toward the nearest substrate. If multiple substrates are equidistant, it prefers the one with the highest energy value ($O_2 > NO_3^- > Mn > Fe > SO_4^{2-} > CH_4$). The seek probability increases when the rival hasn't eaten recently, rising from 45% to 75% after several seconds without food.

2. Track Player (15% Priority)

If ARKE is within **10 tiles**, the rival has a **15% chance** per decision cycle to move toward the player's position. This doesn't mean they attack you—they move to *your area* because you're likely near food. This creates intense **competition zones** where you and rivals are racing for the same substrates.

3. Ride Flow (40% on Flow Tiles)

When standing on a tile with water flow, rivals have a **40% chance** to enter planktonic mode, traveling at **2x speed** along the flow direction. This lets them quickly reach substrate-rich areas downstream. Rivals on flow tiles can cover large distances rapidly, often beating you to fresh substrate spawns.
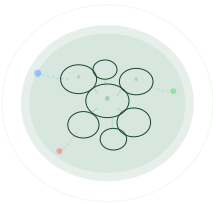
4. Wander (Fallback)

If no food is detected, no player nearby, and not on a flow tile, the rival picks a random walkable adjacent tile and moves there. They tend to **prefer their current direction** (momentum), which creates patrol-like behavior across the map.

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KEY FACTS ABOUT RIVALS

Invulnerable	Rivals are **INVULNERABLE**—you cannot kill, damage, or block them. There is no combat mechanic. Your only strategy is to outmaneuver them.
Instant Consumption	Rivals consume substrates **instantly on contact**, just like you. If a rival reaches a substrate first, it's gone permanently.
Equal Speed	Rivals move at **2.5 tiles/sec**—the same speed as you in normal (benthic) mode. Your only speed advantage is planktonic mode (SHIFT).
Toxic Immunity	Rivals do **NOT** take damage from toxic zones. This is unfair but realistic—different species have different chemical tolerances.
Scaling Count	Each level has **0-5 rivals**. Level 1: 0 rivals. Level 10: 5 rivals. The count increases by approximately one rival every two levels.
Food Competition	Rivals effectively reduce your food supply. With **5 rivals**, you get roughly **1/6** of all food that spawns (assuming equal efficiency).

BIOFILM COLONIES

BIOFILM COLONY

When ARKE divides, a permanent biofilm colony is placed on the map. Colonies are clusters of daughter cells embedded in a protective extracellular matrix—the biofilm. They are stationary sentinels that **passively consume** nearby substrates. Each colony placed earns **+100 points** and counts toward the level goal.

TYPE: Stationary Ally • SIZE: 12×12px • FEED RANGE: 1.5 tiles •
PERMANENT • INDESTRUCTIBLE

COLONY MECHANICS IN DETAIL

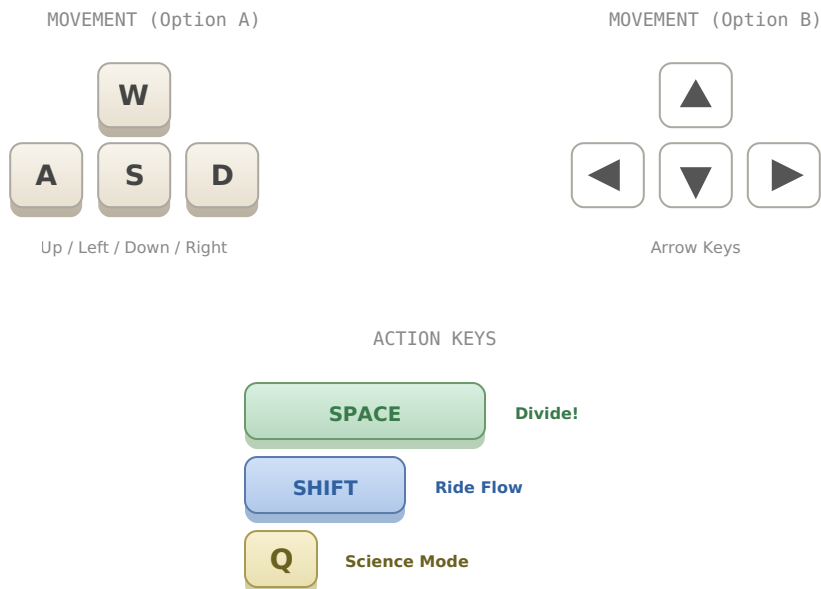|	
Placement	Colonies are placed **automatically** on the best adjacent pore tile when you press SPACE at GR=100. The game selects the tile furthest from grain walls, preferring open space with good flow exposure.
Feeding Radius	Each colony has a passive feeding radius of **1.5 tiles**. Any substrate particle that drifts within this zone has a chance to be consumed.
Consumption Rate	Colonies consume substrates with **2% probability per frame** for any substrate within range. This is a slow, steady drain—not as fast as active eating.
Permanence	Colonies are **permanent and indestructible**. Once placed, they remain for the entire level. Rivals cannot destroy or interact with them.
Strategic Note	Colony passive feeding does **NOT** benefit you directly—it removes food from the map. However, this also **reduces rival food**, creating zones of scarcity that hinder your competitors. Place colonies strategically along rival patrol routes to starve them out.

CONTROLS & MOVEMENT

Keyboard Controls

MOVEMENT (Option A)

W
A S D

Up / Left / Down / Right

MOVEMENT (Option B)

▲
◀ ▼ ▶

Arrow Keys

ACTION KEYS

SPACE **Divide!**

SHIFT **Ride Flow**

Q **Science Mode**

System Keys

Key	Function
ESC / P	Pause game — opens pause menu (Resume / Mute / Quit)
M	Toggle sound on/off (mute all audio)
ENTER	Advance dialogue, confirm menu selection, start level

HOW ARKE MOVES

Normal Movement

ARKE moves tile-by-tile at **2.5 tiles per second** in 4 directions (up, down, left, right). No diagonal movement is possible. Movement is smooth — ARKE animates between tiles over 0.4 seconds. You can queue the next direction

Planktonic Mode (SHIFT)

Hold **SHIFT** while pressing a direction key to enter planktonic mode. This doubles your speed to **5.0 tiles/sec** but **ONLY works on tiles that have water flow**. The flow direction is shown in
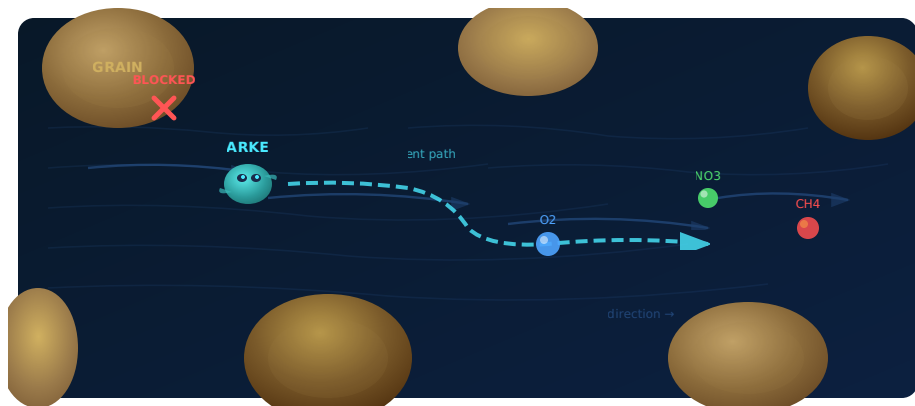
while moving, so skilled players can navigate winding pore channels without pause.

- ARKE **cannot** pass through **GRAIN** tiles (solid rock) or **VOID** tiles (map boundary).
- ARKE **can** walk through **BIOFILM** tiles (your own colonies) freely.
- ARKE **can** walk through **TOXIC** tiles, but you will take **-20 HP/sec** damage while on them. Move through quickly!
- ARKE **can** walk through **PORE**, **FAST_FLOW**, **INLET**, and **OUTLET** tiles normally.

Science Mode (Q). Each planktonic move costs **0.5 Energy** points.

- When Energy reaches 0, planktonic mode is disabled and you are stuck at normal speed until you eat more substrates.
- Planktonic mode shows a **blue glow** around ARKE, making it easy to tell when you are flow-riding.
- You can only ride in the direction of the local flow vector — you cannot flow-ride upstream.
- Essential for intercepting fast-moving substrates in later levels!

Movement Through Pore Space

ARKE navigates tile-by-tile through pore space between grain particles. Brown grains block movement. Glowing orbs are substrate particles consumed on contact.
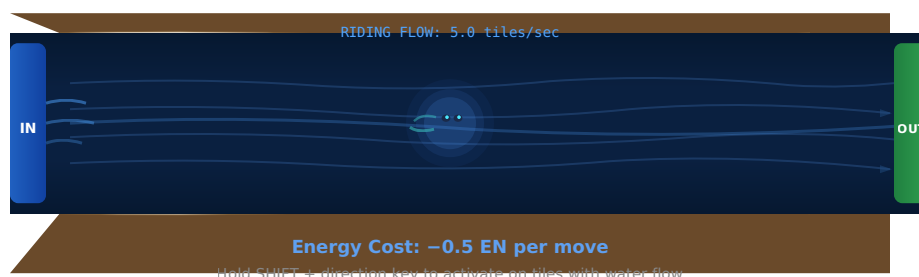
FLOW MECHANICS

Water flows from **INLET** (left side, blue) to **OUTLET** (right side, green). The flow field is computed by the game's physics engine based on the pore geometry of each level. **Narrow channels** have faster flow speeds, while **wide-open areas** have slower flow. **FAST_FLOW** tiles provide a 2.5x speed bonus when flow-riding. The flow carries substrates from the inlet toward the outlet, so food is freshest near the inlet and becomes sparser near the outlet.

PLANKTONIC FLOW-RIDING

Planktonic mode is ARKE's fastest traversal method. By releasing from surfaces and floating freely in the water column, ARKE can ride the current at double speed. This is essential for intercepting fast-moving substrates and escaping danger zones.

How Flow Riding Works

RIDING FLOW: 5.0 tiles/sec

IN

OUT

Energy Cost: −0.5 EN per move

Hold SHIFT + direction key to activate on tiles with water flow

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FLOW RIDING TIPS

- Flow moves from **INLET** (left, blue) to **OUTLET** (right, green).
- Not all tiles have flow — check the **Science Mode (Q)** overlay to see flow directions and speeds.
- Flow speed varies: some channels are **FAST FLOW** (2.5× speed bonus). These are the express lanes!
- Essential in Chapters 4-5 where substrates move very quickly through narrow channels.
- Watch your Energy bar! Running out strands you at normal speed — eat O_2 (+10 EN) or NO_3 (+7.5 EN) to refuel.
- Narrow channels concentrate flow — use them as highways to cross the map fast.

TILE TYPES YOU'LL ENCOUNTER

PORE	GRAIN	BIOFILM	TOXIC
Dark blue water with subtle flow	Solid rock with mineral texture	Green organic cell clusters	−20 HP/sec!

FAST FLOW	INLET	OUTLET	VOID

| 2.5× speed current | Water & food enters here | Water exits the level | Map boundary (impassable) |

EATING MECHANICS

AUTOMATIC CONSUMPTION

Eating is **automatic** — simply move ARKE onto a tile containing a substrate particle and it will be consumed instantly. There is no "eat" button. On contact, the substrate disappears and your **HP**, **EN**, and **GR** bars update immediately. A chiptune sound effect plays and ARKE briefly flashes green to confirm the consumption.

Eating Rules

- **Multiple substrates** can exist on the same tile. Moving onto it eats **only one per step** — you must step off and back on (or pause briefly) to eat the next one.
- Substrates have a **limited lifetime** of approximately 30 seconds. If nobody eats them, they despawn and are lost.
- **Rival organisms** also eat on contact with the same instant mechanics. They will compete for the same food!
- Eating does **not slow you down** — you maintain full movement speed while consuming substrates.

Substrate Values Quick Reference

Substrate	HP	EN	GR
O2	+20	+10	+15
NO3	+15	+7.5	+18
Mn(IV)	+12	+6	+12
Fe(III)	+10	+5	+10
SO4	+6	+3	+8
CH4	+5	+2.5	+25

PRO TIP: SUBSTRATE INTERCEPTION

Since substrates drift with the water flow from INLET to OUTLET, the best strategy is to position ARKE **in the path of incoming substrates** rather than chasing after them. Use Science Mode (Q) to see flow lines, then park in a high-flow channel and let the food come to you. In fast-flow levels, use planktonic mode to ride alongside drifting substrates and scoop them up.

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SUBSTRATES — YOUR FOOD

Substrates are dissolved chemicals carried by water flow through the pore space. They are your food, energy, and building material. Each substrate provides different amounts of **Health**, **Energy**, and **Growth**. Understanding the Redox Ladder is the key to mastering ARKE's feeding strategy.

> ### THE REDOX LADDER (Real Science!)
>
> In real microbiology, organisms use chemicals in a specific thermodynamic order called the **Redox Ladder**. Oxygen provides the most energy per reaction; methane provides the least. However, nature has a twist: **low-energy substrates often support the highest growth rates** because organisms that use them face less competition and have evolved efficient metabolisms. The game faithfully represents this hierarchy — energy and growth are inversely related!

The Redox Ladder — Energy & Growth Hierarchy

HIGH

ENERGY YIELD

GROWTH YIELD

OXYGEN
O_2 — Aerobic Respiration
HP +20 | EN +10 | GR +15
-818 kJ/mol
MOST ENERGY
GR: 15
Low growth

NITRATE
NO_3^- — Denitrification
HP +15 | EN +7.5 | GR +18
-649 kJ/mol
GR: 18

MANGANESE
Mn(IV) — Mn Reduction
HP +12 | EN +6 | GR +12
-558 kJ/mol
GR: 12

IRON
Fe(III) — Iron Reduction
HP +10 | EN +5 | GR +10
-334 kJ/mol
GR: 10

SULFATE
SO_4^{2-} — Sulfate Reduction
HP +6 | EN +3 | GR +8
-152 kJ/mol
GR: 8

METHANE
CH_4 — Methanotrophy
HP +5 | EN +2.5 | GR +25
-31 kJ/mol
LEAST ENERGY
GR: 25
HIGHEST GROWTH!

LOW

SUBSTRATE DETAILS

O2 — OXYGEN

Aerobic respiration. Highest energy yield in nature. Available in surface soils and thawing permafrost. Best for emergency HP recovery.

+20 HP | +10 EN | +15 GR | +10 PTS
Levels: 1, 2, 7

NO3 — NITRATE

Denitrification. Prevents N_2O (300× CO_2) from forming. The best all-around substrate — strong in every stat.

+15 HP | +7.5 EN | +18 GR | +25 PTS
Levels: 1-4, 7-10 | CLIMATE BONUS!

Mn(IV) — MANGANESE

Manganese reduction. Crystalline purple particles. Mid-range energy and growth. Found in mineral-rich sediments.

+12 HP | +6 EN | +12 GR | +10 PTS
Levels: 4, 9, 10

Fe(III) — IRON

Iron reduction. Moderate energy and growth. Found in deep sediments and hydrothermal vents. Rusty metallic sheen.

+10 HP | +5 EN | +10 GR | +10 PTS
Levels: 3, 4, 6, 9, 10

SO4 — SULFATE

Sulfate reduction. Produces H_2S (creates toxic zones!). Low energy but necessary in deep anaerobic environments.

+6 HP | +3 EN | +8 GR | +10 PTS
Levels: 5-10

CH4 — METHANE

Methanotrophy! Lowest energy but **HIGHEST GROWTH** (+25 GR!). Prevents greenhouse warming (80× CO_2). ARKE's signature food!

+5 HP | +2.5 EN | +25 GR | +35 PTS
ALL LEVELS | CLIMATE BONUS!

FEEDING STRATEGY — WHEN TO EAT WHAT

Choosing the right substrate at the right time is the difference between winning and losing. Your three stats — HP (Health), EN (Energy), and GR (Growth) — each have different urgency levels. Use this decision framework to maximize your efficiency:

CRITICAL: HP < 30 — EMERGENCY MODE

When your Health drops below 30, you are in danger of dying. **Eat the nearest ANYTHING** — do not be selective! O_2 gives the best recovery at **+20 HP**, followed by NO_3 at **+15 HP**. If neither is nearby, grab whatever substrate is closest. A dead microbe does not grow. Survival comes first, always.

HP 30-60: RECOVERY PRIORITY

Eat **NO_3** (Nitrate) as your priority substrate. It provides **+15 HP** (good recovery), **+7.5 EN** (keeps flow-riding available), AND **+18 GR** (excellent growth). It is the best balanced substrate in the game. If NO_3 is not available, eat O_2 for the superior +20 HP recovery.

HP > 60: GROWTH MODE

Focus on **CH_4** (Methane) for maximum growth. Each CH_4 gives **+25 GR** — only 4 methane particles fill your entire Growth bar and trigger cell division! This is the **speed run strategy**: stay healthy, then gorge on methane to divide as fast as possible.

ENERGY MANAGEMENT: EN < 20

When your Energy drops below 20, you are about to lose flow-riding ability. Without planktonic mode, you cannot keep up with fast-moving substrates in later levels. Eat **O_2** (+10 EN) or **NO_3** (+7.5 EN) to restore your Energy reserves. Avoid CH_4 (+2.5 EN) and SO_4 (+3 EN) when low on energy — they barely help.

SUBSTRATE SPAWN MECHANICS

Understanding how and when substrates appear is crucial for positioning and interception strategy.

Spawn Timing & Location

- Substrates spawn every **1.2 seconds** in a batch near the **INLET** (left edge of the map).
- Each batch contains **2–6 particles** depending on the level's spawn density setting.
- After spawning, substrates **drift with the water flow** toward the OUTLET (right edge).

- In fast-flow levels, substrates move quickly — you must **intercept them** or use flow riding to keep up.
- Each level has a specific **mix of substrate types** based on its geochemical environment.
- Substrates that reach the OUTLET or go uneaten for approximately **30 seconds** will despawn and are lost forever.

Level 3	**3** per cycle	Level 8	**5** per cycle
Level 4	**2** per cycle	Level 9	**4** per cycle
Level 5	**5** per cycle	Level 10	**6** per cycle

Note: Level 4 has the lowest density (2) — food is scarce! Levels 7 and 10 have the highest density (6) — a feast, but so are the rivals.

POSITIONING STRATEGY

The smartest players do not chase substrates — they **position themselves in the flow path** and let the food come to them. Camp near the INLET in early levels when flow is slow. In fast-flow levels, use Science Mode (Q) to find the main flow channels, then ride alongside drifting substrate batches using planktonic mode. Remember: every 1.2 seconds a new batch appears, so timing your sweeps through high-flow channels is the key to staying fed and growing fast.

GROWTH & DIVISION

Growth is the core mechanic of ARKE. Every substrate you eat adds to your Growth bar (GR). When GR reaches **100**, you can **divide**—placing a permanent biofilm colony on the map. This is how you win each level!

The Growth Cycle

1. EAT	2. GROW	3. READY!	4. DIVIDE!
Move over food	GR: 70/100 — GR bar fills up	SPACE! — Press SPACE	ARKE (GR=0) COLONY +100 PTS

Repeat this cycle to place enough colonies and complete each level!

DIVISION MECHANICS

Trigger: When GR reaches exactly 100, ARKE glows bright yellow. The GR bar flashes to alert you.

Action: Press SPACE to trigger binary fission (division). ARKE's body stretches and splits.

Animation: The division animation takes approximately 0.5 seconds to complete.

After Split: Your GR resets to 0, but HP and EN remain unchanged. You immediately continue.

Colony: A biofilm colony is automatically placed on the best available adjacent tile.

Score: +100 points per colony placed. Colony counts toward the level's completion goal.

SUBSTRATES NEEDED TO DIVIDE

Substrate	Growth/Eat	Eats to Divide	Efficiency Rating
CH4 (Methane)	+25 GR	**4 eats**	BEST for growth
NO3 (Nitrate)	+18 GR	6 eats	Great balanced option
O2 (Oxygen)	+15 GR	7 eats	Good energy, decent growth
Mn(IV)	+12 GR	9 eats	Mid-range
Fe(III) (Iron)	+10 GR	10 eats	Mid-range
SO4 (Sulfate)	+8 GR	13 eats	Slowest growth

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COLONY PLACEMENT MECHANICS

When you press SPACE to divide, the game must decide *where* to place the new biofilm colony. The placement algorithm follows a precise set of rules to find the optimal location:

Step 1 — Scan Adjacent Tiles: The game scans all 4 adjacent tiles (up, down, left, right) from ARKE's current position.
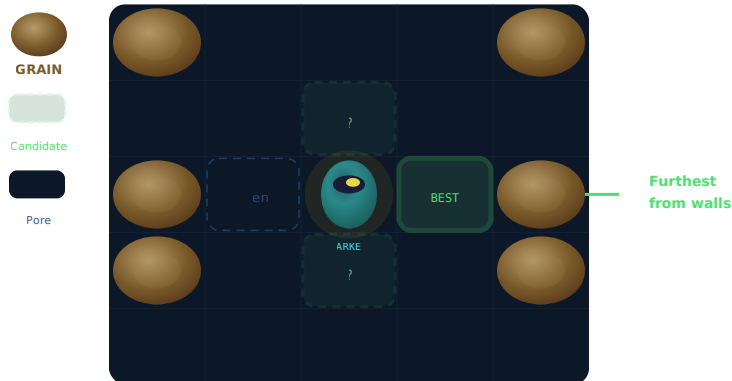
Step 2 — Filter Candidates: Only PORE tiles (walkable water tiles) are candidates for colony placement. Tiles occupied by grains, existing colonies, rivals, or toxic zones are excluded.

Step 3 — Rank by Openness: If multiple PORE tiles are available, the game picks the one that is furthest from any GRAIN tile walls, preferring open space. This maximizes the colony's feeding radius coverage.

Step 4 — Diagonal Fallback: If no adjacent PORE tile is available (all blocked by grains or existing colonies), the search extends to diagonal neighbors (up-left, up-right, down-left, down-right).

Step 5 — Edge Case: If absolutely no valid tile exists within 2 tiles, division still happens but no colony is placed (rare edge case). Your GR still resets to 0 and you still score points.

Where Does the Colony Go?

COLONY PASSIVE FEEDING

Once placed, each colony becomes a permanent structure that passively feeds on nearby substrates. Understanding colony feeding mechanics is essential for strategic placement:

Detection Radius: Each colony has a circular detection radius of **1.5 tiles** around it.
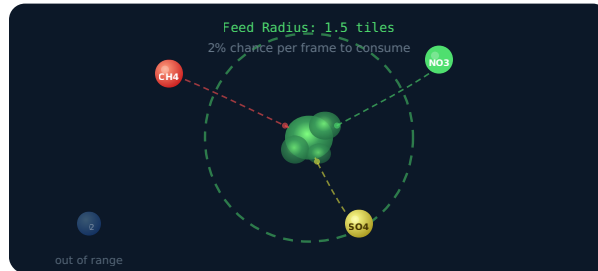
Consumption Chance: Every game frame, for each substrate particle within range, there is a **2% probability** the colony will consume it.

Average Time: A substrate sitting next to a colony will be eaten within about 50 frames (~0.8 seconds at 60 FPS).

No Personal Benefit: Colony feeding does NOT restore your HP/EN/GR — it simply removes substrates from the map.

Area Denial: Strategic colony placement near food-rich areas denies food to rivals (area denial strategy).

Inlet Control: Colonies placed near the INLET intercept substrates before they spread across the map.

LEVEL COMPLETION

```
EAT  →  GROW  →  DIVIDE  →  COLONY  →  REPEAT ×N
```

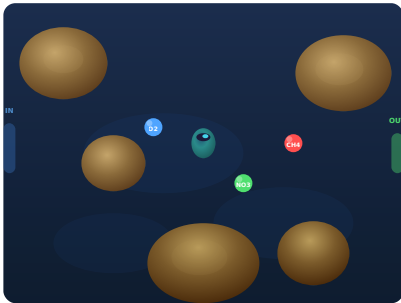| Level	Goal	Level	Goal
1. First Breath	**3** colonies	6. Vent Guardians	**8** colonies
2. Roots of Life	**5** colonies	7. Thawing Grounds	**6** colonies
3. Into the Depths	**4** colonies	8. The Great Thaw	**8** colonies
4. The Hungry Dark	**6** colonies	9. The Abyss	**8** colonies
5. The Methane Vents	**5** colonies	10. Earth's Last Stand	**12** colonies

SCORING

+10 pts per substrate eaten • **+25 bonus** for CH_4 • **+15 bonus** for NO_3 • **+100 pts** per colony placed • **+1,000 pts** per level completed

WORLDS & ENVIRONMENTS

ARKE's journey spans **5 unique environments** across **10 levels**, each inspired by real subsurface ecosystems studied by the CompLaB3D research team. Each environment has its own color palette, pore geometry, procedural generation algorithm, and challenges.

CHAPTER 1: THE SOIL FRONTIER

Levels 1-2 • Environment 0

Shallow soil with wide-open pore spaces between rounded rock grains. Water flows gently, carrying abundant nutrients including **oxygen**. The safest environment— perfect for learning the basics of movement, feeding, and division.
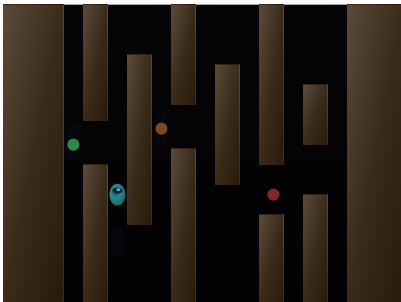
Porosity: 65-70% (very open — ample room to maneuver)
Generation: Circle-packing algorithm (random radii, no overlap)
Substrates: O_2, NO_3, CH_4
Hazards: None (Lv1) / 1 rival (Lv2)
Flow Speed: 0.3× (gentle current)

CHAPTER 2: THE DEEP SEDIMENT

Levels 3-4 • Environment 1

Deep beneath the ocean floor. No oxygen here! Narrow, maze-like corridors carved through compacted sediment. Flow is sluggish and food is scarce. **Navigation skill** becomes critical as dead ends can trap you.

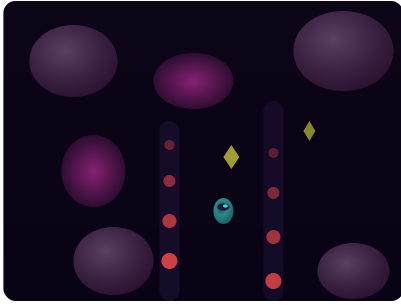**Porosity:** 45-50% (tight — many dead ends and chokepoints)
Generation: Recursive maze algorithm (binary subdivision)
Substrates: NO_3, Fe(III), Mn(IV), CH_4 (no O_2!)
Hazards: 2-3 rivals, slow flow, claustrophobic corridors
Flow Speed: 0.4× (sluggish, stagnant current)

CHAPTER 3: THE METHANE SEEPS

Levels 5-6 • Environment 2

Methane bubbles up through vertical vent channels. **Toxic H_2S zones** appear for the first time! Purple-tinted world with abundant CH_4 but dangerous terrain. This is where ARKE truly becomes Earth's climate shield.
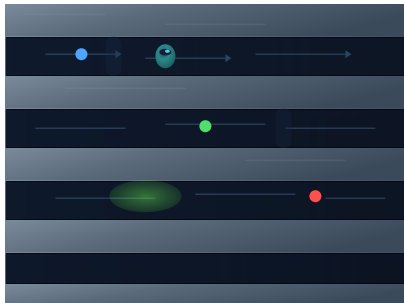
Porosity: 55-60% (moderate — open areas between vents)
Generation: Circle-packing + vertical vent channel overlay
Substrates: SO_4, CH_4, Fe(III)
Hazards: 15-20% toxic zones, 2-3 rivals
Flow Speed: 0.5× (moderate with upward vent drafts)

CHAPTER 4: THE PERMAFROST EDGE

Levels 7-8 • Environment 3

Thawing permafrost releases ancient carbon. **Fast horizontal flow channels** between ice layers demand mastery of **SHIFT (flow riding)**. Substrates race past at high speed. Oxygen returns briefly in Level 7!
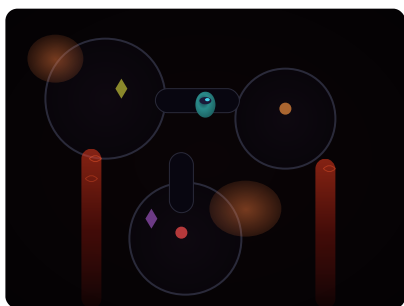
Porosity: 50-55% (layered — wide horizontal, narrow vertical)
Generation: Horizontal layer stacking + vertical connector cuts
Substrates: O_2 (Lv7), NO_3, SO_4, CH_4
Hazards: 10-15% toxic zones, 3-4 rivals, fast flow
Flow Speed: 0.8-1.0× (rapid horizontal currents)

CHAPTER 5: THE HYDROTHERMAL REALM

Levels 9-10 • Environment 4

The deepest, most extreme environment. Chaotic chamber-and-tunnel geology near hydrothermal vents. **Maximum toxic coverage (25%)**, extreme flow speeds, and **5 rivals**. The full redox ladder (minus O_2) is available. **This is the final challenge.**

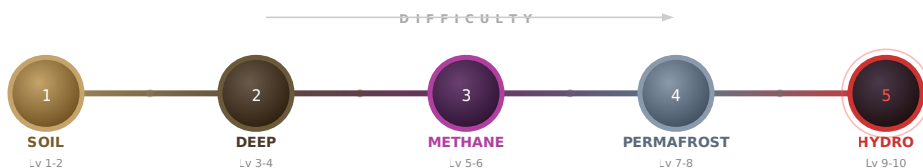**Porosity:** 40-50% (chambers connected by narrow tunnels)
Generation: Random chambers + tunnel connections + vent columns
Substrates: SO_4, Fe(III), Mn(IV), CH_4, NO_3 (Lv10)
Hazards: 20-25% toxic, 4-5 rivals, extreme flow
Flow Speed: 1.2-1.5× (violent currents near vents)

JOURNEY OVERVIEW

DIFFICULTY

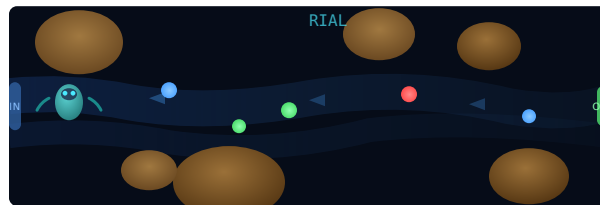| 1 | 2 | 3 | 4 | 5 |
| SOIL | DEEP | METHANE | PERMAFROST | HYDRO |
| Lv 1-2 | Lv 3-4 | Lv 5-6 | Lv 7-8 | Lv 9-10 |

Each world is **procedurally generated** from its own algorithm, meaning no two playthroughs are identical. Porosity determines how much open space you have to maneuver: higher porosity = easier navigation, lower porosity = tighter corridors and more dead ends. Flow speed affects how fast substrates move through pore channels and how effective the SHIFT (flow riding) ability is. Toxic zone coverage increases steadily from 0% in the Soil Frontier to 25% in the Hydrothermal Realm.

LEVEL GUIDE

LEVEL 1: FIRST BREATH
Chapter 1 — The Soil Frontier

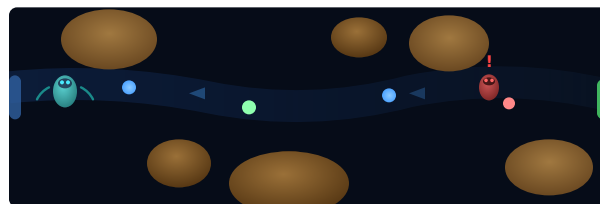| GOAL	MAP	RIVALS	TOXIC
3 colonies	**30×20**	**0**	**None**

Strategy: Pure tutorial level. No enemies, no hazards. Wide open pore space with 70% porosity means tons of room to move. O_2, NO_3, and CH_4 are all available. Learn the basics: WASD/Arrow movement, eating on contact, watching GR bar fill, pressing SPACE to divide. Food density is 4 (moderate). Take your time learning — there is no pressure.

LEVEL 2: ROOTS OF LIFE
Chapter 1 — The Soil Frontier

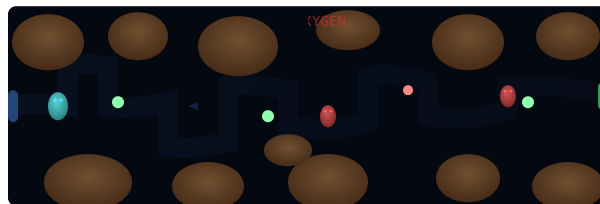| GOAL	MAP	RIVALS	TOXIC
5 colonies	**35×22**	**1**	**None**

Strategy: Your first rival appears! It wanders the map seeking substrates. Move quickly to eat before it does. Larger map (35×22) requires better navigation. Try using SHIFT on flow tiles to outpace the rival. Still O_2-rich environment. The rival has 12-tile sense range — if you see food, it probably does too. **Strategy: race to food clusters near the INLET where substrates spawn fresh.**

LEVEL 3: INTO THE DEPTHS

Chapter 2 — The Deep Sediment

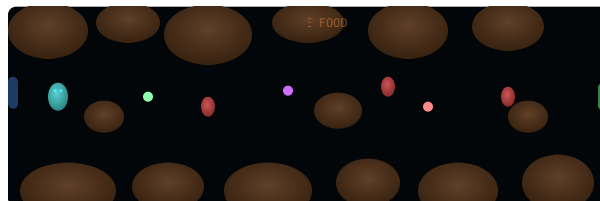| GOAL	MAP	RIVALS	TOXIC
4 colonies	35×25	2	None

Strategy: No oxygen available! This is a shock after O_2-rich soil. Tight maze corridors with only 50% porosity. Slow flow (0.3×). Food is scarce (density 3). NO_3 becomes your best friend: +15 HP and +18 GR is the best balanced substrate. Two rivals compete for limited food. Navigate carefully — dead ends waste precious time while starvation continues at −1.5 HP/sec.

LEVEL 4: THE HUNGRY DARK

Chapter 2 — The Deep Sediment

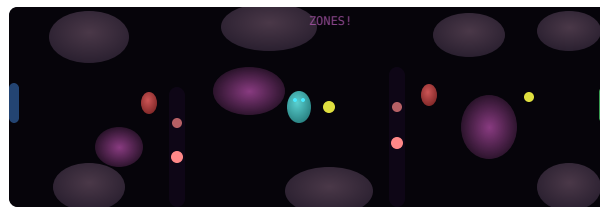| GOAL	MAP	RIVALS	FLOW
6 colonies	40×28	3	0.25× (crawl)

Strategy: The hardest early-game level. Absolute minimum food density (2 per spawn cycle). Tightest porosity (45%). Three rivals fight for scraps. Crawling flow (0.25×). Manganese Mn(IV) appears (purple, +12 GR). Must be surgical with every substrate — eat CH_4 for growth when safe, NO_3/Fe when HP drops. This level teaches resource management.

LEVEL 5: THE METHANE VENTS

GOAL	MAP	RIVALS	TOXIC
5 colonies	**35×22**	**2**	**15%**

Strategy: TOXIC ZONES APPEAR! Purple H_2S tiles deal −20 HP/sec on contact. Combined with starvation (−1.5), that is −21.5 HP/sec — you will die in under 5 seconds in toxic! Check minimap for purple patches. Only SO_4 and CH_4 available (no O_2/NO_3). Abundant food (density 5) compensates for toxins. CH_4 is your primary growth source (+25 GR). Sulfate keeps energy up. Navigate around toxic zones.

LEVEL 6: VENT GUARDIANS

Chapter 3 — The Methane Seeps

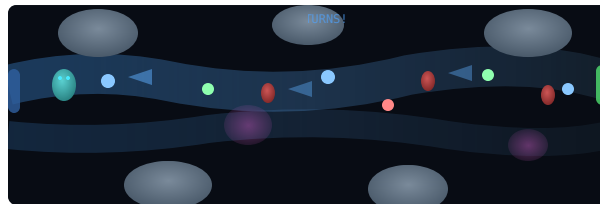| GOAL	MAP	RIVALS	TOXIC
8 colonies	**40×25**	**3**	**20%**

Strategy: Double the colonies of Level 5! Fe(III) now available for +10 HP recovery. Toxic zones now cover 20% of tiles — 1 in 5 tiles is dangerous. Three rivals compete aggressively. Balance toxin avoidance with food access. Plan colony locations near food-rich safe zones. Long level requiring 8 complete eat-grow-divide cycles.

LEVEL 7: THAWING GROUNDS

Chapter 4 — The Permafrost Edge

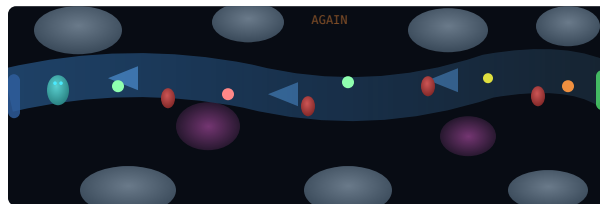| GOAL	MAP	RIVALS	FLOW
6 colonies	**40×25**	**3**	**0.8× (fast!)**

Strategy: OXYGEN RETURNS! Fast flow (0.8×) makes SHIFT essential. Substrates race past at high speed. O_2 provides +20 HP (best recovery). Abundant food (density 6 — highest yet!). Only 10% toxic. Master flow-riding here — position at INLET and intercept food as it flows past. This level rewards aggressive play.

LEVEL 8: THE GREAT THAW

Chapter 4 — The Permafrost Edge

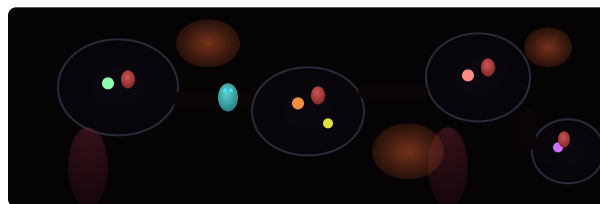| GOAL	MAP	RIVALS	FLOW
8 colonies	45×28	4	1.0× (very fast!)

Strategy: No oxygen again — thaw accelerates. Fastest flow yet (1.0×). Largest map so far (45×28 = 1,260 tiles). FOUR rivals! Must constantly ride flow with SHIFT. NO_3 is critical (+15 HP, +18 GR). Very difficult — requires expert navigation. Food density 5 is good but 4 rivals eating means intense competition.

LEVEL 9: THE ABYSS

Chapter 5 — The Hydrothermal Realm

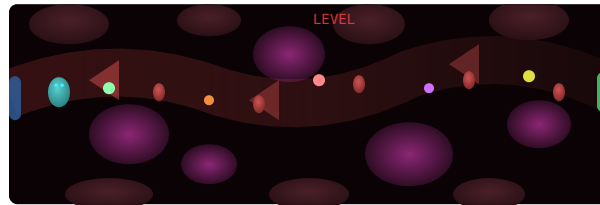| GOAL	MAP	RIVALS	TOXIC
8 colonies	45×25	4	20%

Strategy: Deep-sea hydrothermal vents. Full redox ladder minus O_2: NO_3, Fe(III), Mn(IV), SO_4, CH_4. Extreme flow (1.2×). Toxic everywhere (20%). Chamber-based topology — connected rooms with tunnels. Food density 4 (scarce with 4 rivals). Requires mastery of all mechanics: efficient eating, toxic avoidance, flow riding, strategic colony placement.

LEVEL 10: EARTH'S LAST STAND   *FINAL LEVEL*

GOAL	MAP	RIVALS	TOXIC
12 colonies!	**50×30**	**5 (MAX)**	**25% (MAX)**

THE ULTIMATE TEST. Everything at maximum intensity. Largest map (50×30 = 1,500 tiles). Most colonies needed (12 — twelve full eat-grow-divide cycles!). Fastest flow (1.5×). Most toxic (1 in 4 tiles!). Most rivals (5 — you get roughly 1/6 of all food). All substrates except O_2. Victory requires COMPLETE mastery. **Completing this level triggers the VICTORY screen showing total score and climate impact. You have saved the planet!**
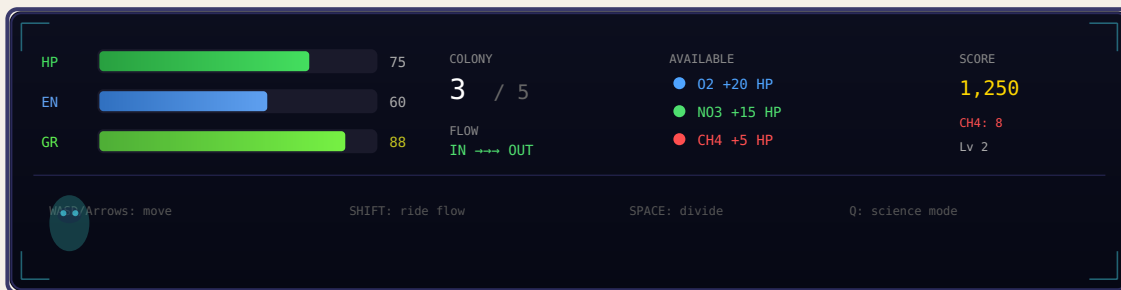

GAME OVER

If your Health reaches 0, you die. Do not panic! Press **ENTER** after 2 seconds to retry the same level. Your score for that level resets, but you keep your global progress.
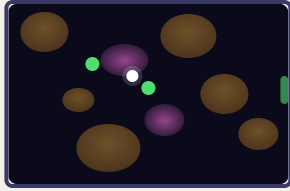
THE HUD & INTERFACE

The Heads-Up Display (HUD) shows everything you need to survive. Learn to read it at a glance — in the heat of gameplay, every second spent looking away from threats is a second closer to starvation.

```
HP  ████████████████▓▓▓▓    75        COLONY              AVAILABLE                    SCORE
EN  ██████████████▓▓▓▓▓▓    60        3  / 5            ● O2 +20 HP                  1,250
                                                         ● NO3 +15 HP                CH4: 8
GR  ██████████████████▓▓    88        FLOW              ● CH4 +5 HP                  Lv 2
                                      IN →→→ OUT

       Arrows: move          SHIFT: ride flow          SPACE: divide          Q: science mode
```

Element	Location	What It Shows
HP Bar	Bottom-left	Health points. Color-coded: Green (>60), Yellow (35-60), Orange (15-35), Red (<15, FLASHING). When HP<30, screen edges pulse red and **"STARVING!"** text appears center-screen.
EN Bar	Bottom-left	Blue bar showing energy for flow riding. Drains passively at 0.8/sec. Each SHIFT move costs additional 0.5. When empty, planktonic mode is disabled and you cannot ride currents.
GR Bar	Bottom-left	Green bar, unique because it **NEVER decays**. Only increases when eating. Flashes bright yellow when full (100) — press SPACE immediately to divide!
Colony X/Y	Center-left	Current colonies placed / goal needed to win
Flow Compass	Center	IN → OUT shows flow direction; TOXIC warning if present
Redox List	Center-right	Available substrates and their energy values for this level
Score	Top-right	Accumulated points this level
CH4 Count	Right	Methane consumed (climate impact tracker)

THE MINIMAP

The minimap appears in the **top-right corner** during gameplay. It shows:

- **Brown ellipses** = Rock grains (impassable)
- **Purple glow** = Toxic zones (danger!)
- **Green dots** = Your colonies
- **White dot** = ARKE (you, pulsing)
- **Green edge** = Outlet

Use the minimap to plan routes, avoid toxic zones, and find open pore space for colonies.

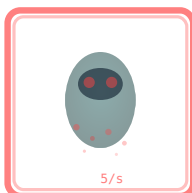## SCIENCE MODE (PRESS Q)

SCIENCE OVERLAY

Press **Q** to toggle the science overlay. It shows:

- **Flow direction arrows** on every tile with water current
- **Heat map**: Blue (slow) → Cyan → Green → Yellow (fast)
- **Speed labels** showing numeric flow values
- **Tile type labels** (PORE, FAST, TOXIC, INLET, etc.)

Use this to plan flow-riding routes and understand substrate delivery patterns!

18

HAZARDS & DANGERS

BEWARE! THE FOLLOWING ARE DEADLY:

STARVATION

HP drains at exactly **1.5 per second**, constantly, from the moment the level begins. This is basal metabolic cost — the energy your cell needs just to stay alive. From full HP (100), you have exactly 66.7 seconds before death if you eat absolutely nothing. But in practice, toxic zones and energy drain from flow-riding mean you have even less time. When HP drops below 30, the screen border flashes red. Below 15, the red border becomes intense and **"STARVING!"** appears on screen.
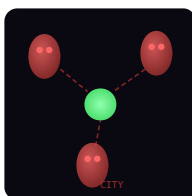
DAMAGE: -1.5 HP/sec (constant) • SCREEN: Red flash when HP < 30 • 66.7s from full to death

TOXIC ZONES (H_2S)

H_2S (hydrogen sulfide) is produced by sulfate-reducing bacteria in anaerobic environments. In the game, these purple/magenta tiles deal **20 HP per second** of ADDITIONAL damage while standing on them. Combined with the base 1.5 HP/sec starvation drain, you lose **21.5 HP/sec total**. At full health (100 HP), you can survive approximately 4.6 seconds in toxic. At half health (50 HP), only 2.3 seconds. **NEVER linger in toxic zones.** Cross them at maximum speed or find alternate routes.

DAMAGE: -20 HP/sec • LEVELS: 5-10 • COVERAGE: 10-25% • ~4.6s survival at full HP

FOOD COMPETITION (RIVALS)

Rivals consume substrates **instantly on contact**, just like you. They cannot be killed or stopped. They sense food from 12 tiles away and become more aggressive when hungry. The more rivals in a level, the less food available for you. Food competition follows a rough equal-share model: with N rivals, you get approximately 1/(N+1) of all food. Level 10 with 5 rivals means you get about **1/6 of spawned food**.

INDIRECT KILL • RIVALS: 0-5 per level • INVULNERABLE • SENSE: 12 tiles

DEAD-END PORES

Some corridors lead nowhere! If you wander into a dead end, you waste precious time backtracking while starvation continues. **Use the minimap and Science Mode (Q)** to identify dead ends before entering. Tiles with no flow arrows are likely dead ends.

TIPS & STRATEGIES

SURVIVAL TIPS

Early Game (Levels 1-4)

- Learn the controls in Level 1 with no pressure
- Always keep HP above 50 as a safety margin
- Eat O_2 when available—it is the best energy source
- Mix CH_4 (growth) with NO_3 (balanced)
- Follow the flow arrows to find substrate-rich zones
- Use the minimap to plan your route ahead

Late Game (Levels 5-10)

- Master SHIFT (flow riding)—it is essential!
- Check minimap for toxic zones BEFORE moving
- Use Science Mode (Q) to see flow patterns
- Race rivals to substrate spawn points near INLET
- Place colonies strategically near food-rich areas
- Cross toxic zones only when HP is high (>70)

THE ART OF EFFICIENT EATING

HP CRITICAL (<30)	HP SAFE (30-60)	HP HIGH (>60)
Eat ANYTHING nearby!	**Balanced approach**	**CH4 for MAX growth!**
Priority: O2 > NO3 > Fe	NO3 for HP + Growth	4 CH4 = full GR bar
Survival first.	CH4 when HP > 50	Sprint for division.
Growth can wait.	Keep building GR bar.	Fastest colony path.
You have ~20 sec to live!	NO3 = best all-rounder	240 pts per cycle!

SCORING GUIDE

Action	Points	Notes
Eat any substrate	+10	Base score for all types
Eat CH_4 (methane)	+35	+10 base +25 climate bonus
Eat NO_3 (nitrate)	+25	+10 base +15 climate bonus
Place colony	+100	Each division
Complete level	+1,000	Reach colony goal

CH_4 gives the most points per eat (35 pts) AND the most growth (+25 GR). Eating 4 methane to divide gives 140 pts from eating + 100 pts from colony = **240 pts per division cycle**. That is the fastest score per cycle in the game!

THE SCIENCE BEHIND ARKE

REAL SCIENCE, REAL IMPACT

Every mechanic in ARKE is based on real biogeochemistry studied by the CompLaB3D research team at the University of Georgia. Here are the science facts you unlock after completing each level:

LEVEL 1: THE REDOX LADDER

Microbes use electron acceptors in a strict thermodynamic order: $O_2 \rightarrow NO_3 \rightarrow Mn(IV) \rightarrow Fe(III) \rightarrow SO_4 \rightarrow CH_4$. Each step yields progressively less free energy per mole of substrate oxidized. This "redox ladder" governs all subsurface biogeochemistry and determines which microbes dominate at each depth in the sediment column. The game reproduces this hierarchy in every level through substrate availability.

LEVEL 2: METHANOTROPHY

Methanotrophic archaea like ARKE consume methane (CH_4) before it reaches the atmosphere. In ocean sediments, anaerobic methanotrophs prevent approximately 90% of seafloor methane from escaping to the water column. Without these microscopic guardians, atmospheric methane concentrations would be dramatically higher, and global temperatures could be 3-5°C warmer than today. Every CH_4 you eat in the game represents this real climate-protecting process.

LEVEL 3: DENITRIFICATION

Denitrifying microbes convert $NO_3 \rightarrow N_2$ (harmless nitrogen gas). Without denitrifiers, excess nitrate would be converted to N_2O (nitrous oxide), a greenhouse gas that is 300× more potent than CO_2 molecule-for-molecule, and that also catalyzes destruction of stratospheric ozone. Denitrification is a critical ecosystem service that prevents both climate warming and ozone depletion simultaneously.

LEVEL 4: DIFFUSION vs ADVECTION

The Péclet number ($Pe = vL/D$) determines whether dissolved chemicals move primarily by diffusion (random molecular motion, $Pe < 1$) or advection (bulk water flow, $Pe > 1$). In tight pores with slow flow, diffusion dominates and substrates spread slowly in all directions. In wider channels with fast flow, advection carries substrates rapidly downstream. The game's flow mechanics model this directly — SHIFT riding uses advection, while normal movement represents diffusion-scale transport.

LEVEL 5: MONOD KINETICS

Microbial growth follows Monod kinetics: $\mu = \mu_{max} \times S/(K_S+S)$. When substrate concentration S is much greater than the half-saturation constant K_S, growth approaches its maximum rate μ_{max}. When S drops below K_S, growth rate plummets. This is why abundant food levels feel generous while scarce food levels are brutal — the relationship between food availability and growth is nonlinear.

LEVEL 6: BIOFILM FORMATION

Biofilms are structured communities of microorganisms embedded in a self-produced extracellular polymeric substance (EPS) matrix. In nature, biofilms form when planktonic cells attach to surfaces and begin producing EPS, creating a protected microenvironment. CompLaB3D models biofilm spreading using Cellular Automata (CA): when local biomass concentration exceeds a critical threshold, daughter cells spread to adjacent pore spaces — exactly the mechanic replicated by ARKE's colony placement system. Real biofilms can clog pores, redirect flow, and create chemical gradients.

LEVEL 7: ANAEROBIC METHANE OXIDATION

AOM (Anaerobic Oxidation of Methane) is performed by syntrophic consortia of anaerobic methanotrophic archaea (ANME) and sulfate-reducing bacteria (SRB). These organisms physically aggregate together, with ANME cells surrounded by SRB partners. Together they consume CH_4 using SO_4^{2-} as the terminal electron acceptor, without needing any molecular oxygen. This process occurs at the sulfate-methane transition zone (SMTZ) in marine sediments and is responsible for consuming vast quantities of methane that would otherwise reach the atmosphere.

LEVEL 8: PERMAFROST CARBON FEEDBACK

Arctic permafrost stores approximately 1,500 gigatons of organic carbon — nearly twice the amount currently in Earth's entire atmosphere. As global temperatures rise, this permanently frozen ground thaws, exposing ancient organic matter to microbial decomposition for the first time in thousands of years. Microbes rapidly convert this thawed carbon into CH_4 and CO_2, which enter the atmosphere and accelerate further warming in a positive feedback loop. Methanotrophic organisms like ARKE are the last biological line of defense against this massive carbon release.

LEVEL 9: HYDROTHERMAL CHEMISTRY

At ocean-floor hydrothermal vents, superheated water (up to 400°C) percolates through volcanic rock and dissolves metals (Fe, Mn), gases (H_2S, CH_4, H_2), and other reduced compounds. When this fluid meets cold, oxygenated seawater, chemical gradients form that support dense ecosystems of chemosynthetic microorganisms. These microbes thrive entirely without sunlight, powered by redox chemistry alone. Hydrothermal vent communities were among the first discovered ecosystems independent of photosynthesis, and they may represent conditions similar to where life first evolved on Earth.

LEVEL 10: YOU ARE EARTH'S CLIMATE SHIELD

Earth's subsurface biosphere contains an estimated $2\text{-}6 \times 10^{29}$ cells — potentially more microbial biomass than all surface life combined. These invisible organisms regulate atmospheric composition, filter groundwater, cycle nutrients between organic and inorganic forms, and mediate the global carbon cycle. Without subsurface microbes, greenhouse gases would accumulate unchecked, soils would lose fertility, and Earth's climate would be radically different. By playing as ARKE, you have experienced firsthand the vital role these organisms play. Every methane molecule consumed, every colony established, represents the tireless, essential work of Earth's tiniest guardians.

ABOUT CompLaB3D

CompLaB3D (Computational Laboratory for Biofilm Dynamics in 3D) is a pore-scale reactive transport research framework developed at the University of Georgia. It simulates fluid flow, chemical transport, and microbial growth within the complex three-dimensional geometry of real porous media. The game ARKE translates these computational models into interactive gameplay, allowing players to experience biogeochemical processes at the scale where they actually occur — the microscopic world of pores, grains, and flowing water.

"One microbe can become billions."

— *Elder Archaeon Prime*

CompLaB3D

University of Georgia • Pore-Scale Reactive Transport