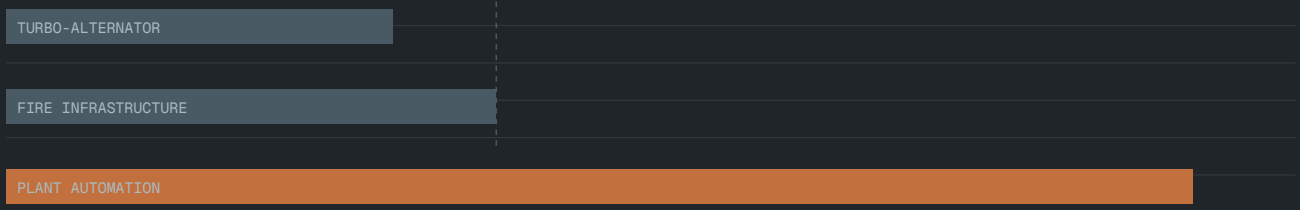
DIGITAL TWIN WHITE PAPER SERIES

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The Cables Were Never the Problem



Three electrical lots on a waste-to-energy build — turbo-alternator, fire infrastructure and plant automation — and why configuration, not construction, governed the schedule.

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The schedule risk was in the software

The argument in one line: this project had drawings of what the plant was made of long before it had a complete description of how the plant was meant to behave. The missing twin was not geometric. It was behavioural.

This edition is written from direct project experience rather than from the literature. The subject is a waste-to-energy plant and three electrical lots delivered within it: the turbo-alternator, the fire infrastructure, and the plant automation. Vendors are anonymised throughout and figures are given as ratios rather than absolutes, so that the structural lessons transfer without disclosing commercial detail.

Across the three lots, the physical works progressed broadly as planned. Cable routes, switchgear, detection heads and terminations were procured and installed close to expectation. Schedule pressure emerged instead in plant-specific functional engineering and in the definition of behaviour across lot boundaries. Published research points the same way: a VDW study cited in Striffler and Voigt's 2023 review of virtual commissioning reports that up to 90 percent of commissioning time can be spent on electrical and control systems, with up to 70 percent of that associated with software errors.

FINDING 01

Installation estimates are mature; configuration estimates are not

Cable pulling, terminations and panel installation have decades of productivity data behind them and estimate reliably. Functional engineering has a far weaker estimating basis and is often priced as a lump and planned as a block, which conceals both its duration and its dependencies.

FINDING 02

The plant becomes specific in its behaviour

Standard function blocks configure quickly. The schedule exposure sits in what is specific to this plant: interlock philosophy, alarm rationalisation, operating modes, sequences and cross-system responses — much of it obvious to people who had built plants before, and written down nowhere.

FINDING 03

Interfaces lacked an assigned owner

Each lot had a clear internal scope and a competent vendor. The work that ran late lived between them — the fire system telling the crane where a hot spot is, the turbo-alternator handing status to the control room. In a separately contracted lot structure, technical interfaces become contractual boundaries unless interface ownership is explicitly assigned. On this project it was not.

FINDING 04

The behavioural model arrived last

Every physical item had a drawing, a quantity, an owner and a progress measure. Interlocks, modes, sequences and cross-system behaviours had no equivalent representation until late. A geometric description of the installation existed long before an executable description of its behaviour.

Scope and evidence

This is a practitioner account, not a controlled study. It describes one plant, one contract structure and one set of vendors, and the generalisations offered are hypotheses drawn from that experience rather than findings established across a sample. Where public technical sources support a point — particularly in the Engineering Zoom — they are cited. Where the claim rests on project experience alone, it is identified as such.

Why the functional scope keeps growing

Physical work is mature as an estimating discipline. The functional scope is not, and it keeps expanding.

up to 90%
OF COMMISSIONING TIME
Spent on electrical and control systems — VDW study cited in a 2023 review

up to 70%
OF THAT, SOFTWARE
Share of that commissioning effort attributable to control software errors

73%
IN ONE REPORTED STUDY
Cut in real commissioning time in a small-scale virtual-commissioning experiment

01 Systems became platforms

A modern control system is a configurable platform rather than a fixed-function device. That is a real gain in capability, and it moves effort from the factory to the project: as control systems have become more configurable, a larger share of plant behaviour is decided at project level rather than embedded in fixed-function hardware.

02 The standard library never quite fits

Vendors supply extensive function libraries, and they cover the generic cases well. A waste-to-energy plant is not generic — fuel is heterogeneous and uncharacterised, combustion control is continuous adaptation, and the interlock philosophy reflects a specific regulatory and operational context.

03 The literature knows, but the project plan does not

Research on virtual commissioning has documented the scale of the problem for years: one VDW study, cited in a 2023 review, reported up to 90 percent of commissioning time spent on electrical and control systems, with up to 70 percent of that associated with software errors. Control code errors surface only when components are functionally integrated. We did not locate a benchmark separating plant-specific functional engineering from installation for comparable waste-to-energy electrical packages.

04 Lot-based contracting fragments the interfaces

Splitting electrical scope into lots gives commercial clarity and competitive tension within each. Unless interface ownership is explicitly assigned — to the EPC, to an integrator, or through an interface matrix — technical boundaries also become contractual ones, and specification gaps accumulate there.

Sources: Striffler, N. and Voigt, T., “Concepts and trends of virtual commissioning – a comprehensive review,” Journal of Manufacturing Systems 71 (2023) 664-680, citing a VDW study · Schamp, M. et al., “Virtual Commissioning of Industrial Control Systems – a 3D Digital Model Approach,” Procedia Manufacturing 39 (2019) 66-73, which reports the 73% figure from an earlier small-scale experiment.

Four kinds of work inside one lot

An electrical lot is usually priced and planned as a single scope. It contains four kinds of work whose estimating behaviour differs sharply.

TYPE 01

SUPPLY — estimates well

Switchgear, cable, detection heads, controllers. Lead times are known, quantities are countable from drawings, and vendors are accountable for delivery dates. This is the part of the lot that behaves the way the programme assumes all of it behaves.

TYPE 02

INSTALLATION — estimates well

Routing, pulling, terminating, mounting, panel placement. Decades of productivity data support the estimate, progress is physically visible, and a delay announces itself immediately because you can walk the site and see it.

TYPE 03

CONFIGURATION — estimable once scope is defined

Implementing known requirements on the vendor platform: I/O mapping, loop configuration, graphics, standard blocks. Bounded in principle and estimable when the requirement is settled, though progress is invisible from the site and the unit of work is not countable the way cable metres are.

TYPE 04

FUNCTIONAL ENGINEERING — as mature as the decisions behind it

Defining this plant's modes, interlocks, alarms, sequences and cross-system behaviour. It can be estimated using reference classes and complexity drivers, but only once its inputs are sufficiently defined. On this project they were not.

THE LADDER OF SCHEDULE CONTROL

01 Count the physical

Metres, terminations, panels. Reliable, and the part everyone already does well.

02 Separate the functional

Break it out of the lump sum so it has its own duration and its own owner.

03 Name the interfaces

List every signal crossing a lot boundary, with an owner on each side, before award.

04 Freeze the philosophy

Agree interlock and alarm philosophy early; it is the input functional engineering consumes.

05 Verify the specification

Design reviews discover assumptions; FAT demonstrates the agreed behaviour was built.

The strategic read

The two categories that estimate well are also the two that are easy to see. Cable on a drum is visible; an unwritten interlock philosophy is not. Programme reporting is therefore structurally biased toward the work that carries least risk, and a project can be reported as on track on everything measurable while the item determining the commissioning date goes unmeasured.

04 / LOT 01

Turbo-alternator: the lot that behaved

Where conventional estimating works, and why

It is worth starting with the lot that went broadly to plan, because the contrast explains the others. The turbo-alternator electrical scope is mature, standardised and tightly specified, and it estimated accordingly.

THE STRUCTURE

Why it estimates well

Generator protection, excitation, synchronisation and the associated switchgear are governed by long-established practice and standards. The functional requirements are largely determined by the machine and the grid connection rather than by local preference, so the configuration space is narrow and the vendor's standard solution fits closely.

THE VERIFICATION

The discipline that comes with it

Protection settings are calculated, reviewed and witnessed. Synchronisation is proven against defined criteria. There is an established testing and acceptance sequence with recognised documentation. The work is not easy, but it is legible — everyone involved agrees in advance what done looks like.

THE PRINCIPLE

The transferable lesson

This lot behaved because much of its specification was externally determined. Standards, machine characteristics and grid requirements constrain the solution space tightly, reducing the number of unresolved discretionary decisions — though protection settings, excitation tuning and auxiliary interfaces still involve project-specific engineering. The principle transfers: the more philosophy fixed externally and early, the less schedule is exposed to discovery.

So what

When a project manager reviews a lot and finds it is estimating confidently, the useful question is why. If the answer is that the requirement is externally fixed by standard or by machine, the confidence is earned. If the answer is that nobody has yet examined the requirement closely, the same confident number means the opposite thing — and the two are indistinguishable in a programme report.

Practitioner account. Vendors and commercial terms anonymised; figures given as ratios rather than absolutes throughout this edition.

04 / LOT 02

Fire infrastructure: the lot with a physics problem

Where the standard product meets a non-standard building

Fire detection and suppression is a mature discipline with clear standards. What makes it interesting on a waste-to-energy plant is that the largest single risk area — the waste bunker — is an environment most fire detection technology was not designed for.

THE SPLIT

Two buildings in one

Most of the plant is conventional: offices, workshops, switchrooms, cable galleries, all served by standard detection and suppression to established codes. The bunker is a different problem entirely, and it is where the engineering attention concentrates, out of proportion to its share of the detection head count.

THE CONSTRAINT

Why the bunker defeats conventional detection

Conventional point smoke detection can perform poorly in a large, dusty bunker with cranes moving and substantial air movement, where smoke transport and stratification are hard to predict and nuisance conditions are significant. Self-heating can develop beneath the visible surface of bulk waste, where insulating material delays the appearance of a measurable anomaly at any ceiling-mounted device.

THE REAL WORK

The interface that made it a schedule item

The detection technology itself was available and proven. What took the time was defining what happens when it fires: which alarm goes where, who decides, whether the crane responds automatically, how a coordinate reaches the crane control system. All of that lives between the fire lot and the automation lot — in the interface neither contract fully owned.

So what

The physical scope of the fire lot was unremarkable and delivered as expected. The demanding part was a specification question about cross-system behaviour, which appeared in no bill of quantities, had no unit rate, and belonged to no single vendor. Where interface ownership is unassigned, that is where schedule risk concentrates.

Practitioner account, with the bunker detection constraint corroborated by public technical sources cited in the Engineering Zoom.

04 / LOT 03

Plant automation: the twin that was missing

The lot whose physical scope was smallest, whose duration was longest, and whose real deliverable was a description of behaviour

The automation lot is where the finding is sharpest. Its physical content — controllers, panels, network, workstations — was modest against the other two. Its duration was not.

THE EASY HALF

What configured quickly

Standard function blocks, I/O mapping, loop configuration and generic graphics proceeded broadly at the rate the vendor's estimate assumed. Where the plant looked like the library, the library worked, and modern engineering tools genuinely do compress this work.

THE HARD HALF

What did not

The plant-specific layer: combustion control philosophy for a fuel with no consistent calorific value, interlock logic reflecting this plant's operating and regulatory context, alarm rationalisation, mode transitions, start-up and shutdown sequences, and the behaviour expected at every boundary with another lot. None of it is exotic engineering. All of it required decisions that had not yet been made.

THE DIAGNOSIS

Coding was not late. Decisions were.

The vendor estimated the work it could see: its own scope, against its own library. Duration depended on how quickly the operator, the EPC and three vendors converged on decisions that were nobody's deliverable. The implementation effort ran broadly as predicted; its inputs arrived late. That is a question the contract structure did not ask anyone.

So what

Here is the observation that reframes the whole project. Every physical item had a drawing, a quantity, an owner and a progress measure. The plant's behaviour — its modes, interlocks, sequences and cross-system responses — had no equivalent representation until it was written directly into controller code. We possessed a geometric description of what the plant was made of long before we possessed an executable description of how it was meant to act. The missing twin was not geometric. It was behavioural. The practical consequence: separate implementation from functional definition in the contract, and give the second an owner with authority to decide.

Practitioner account. The quantitative split between configuration and functional engineering effort on this project is held with the author and available on request under appropriate terms.

The fire that starts where you cannot look

Early detection in a waste bunker — a surface instrument and a buried source

THE CHALLENGE

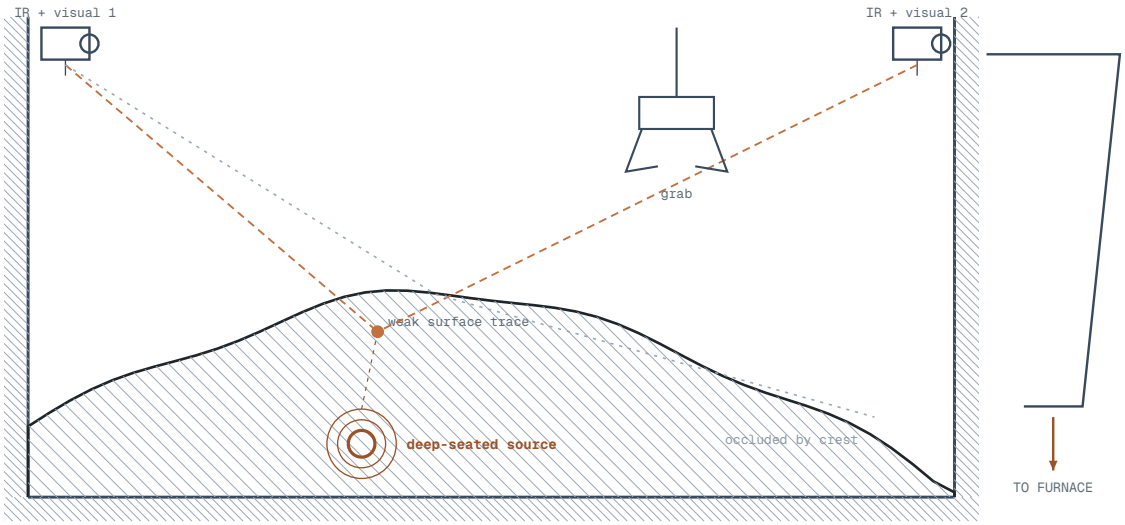
A waste bunker holds thousands of tonnes of heterogeneous municipal waste in a deep concrete pit. Paper, plastics and organics compact under their own weight, biological activity generates heat, and the pile insulates itself. Self-heating can develop beneath the visible surface, where insulating material delays the appearance of a measurable surface anomaly.

Thermography is a widely used early-warning technique for waste bunkers, and it is a surface and line-of-sight measurement. An infrared camera reads radiation leaving the face of the pile; it cannot see three metres into it. The system is therefore looking for the faint surface trace of a source that may be developing below — and a fire protection specialist's published assessment of the method states the limit plainly: deep-seated fires can build up heat energy without being detected.

Why the obvious solutions fail

Full-area water application carries significant operational consequences: contaminated firewater requiring containment and disposal, and saturation of fuel feeding a boiler that depends on calorific consistency. It may still be the correct or mandated response depending on fire development, plant design and the approved fire strategy — but for a localised incipient hotspot, plants often prefer a targeted option. Conventional point smoke detection performs poorly in a large, dusty bunker with cranes moving and unpredictable smoke transport. And line of sight constrains everything: the pile crest occludes part of the bunker, while vehicle exhausts and legitimately warm delivered waste generate nuisance alarms that erode operator trust.

FIG. 01 — WASTE BUNKER, SECTION: BURIED SOURCE AND SURFACE INSTRUMENT



1 Self-heating may develop below the surface
2 Thermography reads surface, line of sight
3 Pile geometry may create occlusion
4 Two-view architecture shown: triangulation
5 Location passed to the response system
6 Targeted removal or suppression per strategy

Give the crane a coordinate

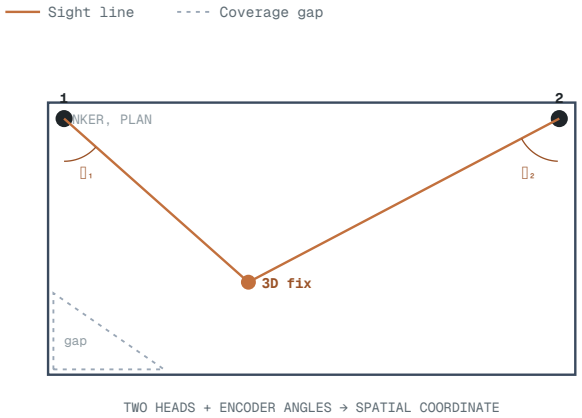
The design move, the interface it creates, and the trade accepted

THE RESOLUTION

Two moves resolve it. The first is geometric: a hot spot you cannot locate is one you cannot act on. Two camera heads mounted apart, each on a pan-tilt with angle encoders and viewing the same region, give the spatial coordinates of the warm area by triangulation — the architecture in US Patent 5,592,151, which notes that because only location is required, the sensitivity demanded of each camera falls. Stereo is not the only route: a calibrated single scanning camera can also map a surface hotspot where geometry and camera pose are known. Commercial bunker monitoring is deployed in both configurations; that evidence is separate from the patent and does not show which architecture any given installation uses.

The second move reconsiders the response. In a plant whose purpose is burning waste, a developing hot spot may be fuel that is ready early. One documented response to a localised incipient hotspot is for the crane operator to remove the affected material and, where procedures permit, transfer it to the furnace; targeted suppression is another. Either way the most valuable output is a coordinate delivered to the control system, not an alarm bell.

FIG. 02 — TRIANGULATION, PLAN VIEW



TWO HEADS + ENCODER ANGLES → SPATIAL COORDINATE

DETECTION CHAIN — ARCHITECTURE SHOWN

Detection principle	**IR thermography**
Measurement domain	**Surface, line of sight**
Localisation, this arch.	**Stereo + encoders**
Output required	**3D coordinate**
Typical first response	**Targeted removal**
Full-area water	**Per fire strategy**

Detection principle and localisation method from public technical and patent literature. Intervention hierarchy reflects both that literature and project practice. Figures are schematic geometry, not measurements.

The trade-off accepted — and the interface it created

You accept that you detect only what reaches the surface, so the system is a strong early-warning layer rather than a guarantee, and must be paired with discipline about pile turnover. The schedule consequence was second-order: making the crane the primary response means the fire system writes a coordinate into the crane control system, in a defined frame, with agreed authority over who moves the grab. That sentence sits across two contracts, and defining it took materially longer than installing either.

THE OUTCOME — WHERE THE ENGINEERING EFFORT ACTUALLY WENT

2
CAMERA HEADS
In the referenced stereoscopic architecture; calibrated single-camera systems also exist

1
COORDINATE FRAME
Which had to be agreed between the fire lot and the automation lot

0
LINE ITEMS
Number of bills of quantity in which that agreement appeared as scope

Sources: US 5,592,151 · US 10,694,107 · Picton, Blazequel · InfraTec WASTE-SCAN. Full citations on page 12. Drawings are schematic.

How I would structure it next time

Offered as practitioner recommendations rather than established method. Durations are indicative and depend on plant type, contract structure and client capability.

BEFORE AWARD

Separate configuration from functional engineering in the contract

Price and schedule them as distinct scopes with distinct owners. Configuration is implementation against known requirements and estimates reasonably as a vendor deliverable. Functional engineering depends on decisions about plant behaviour and needs an owner with authority to resolve them, because a vendor cannot manage a risk whose driver is somebody else's decision-making speed.

BEFORE AWARD

Write the interface register first

For every signal, command and status crossing a lot boundary, record: source and destination system; data object, type and engineering units; update or event behaviour; fail-safe state; command authority; acknowledgement, timeouts and watchdogs; reference frame where relevant; safety classification; cybersecurity trust boundary; owner; interface version and change authority; and the acceptance evidence that will close it. The last of those matters as much as the first: the recurring problem is not only defining an interface but controlling changes to it. Do this before award, while it still carries commercial leverage.

EARLY EXECUTION

Freeze the operating philosophy before configuration starts

Interlock philosophy, alarm rationalisation and operating modes are the inputs functional engineering consumes. Starting configuration before they are settled means configuring against assumptions, and every assumption that proves wrong is rework at the least convenient moment.

EXECUTION

Measure configuration by evidence, not percentage

Physical progress is self-reporting because you can walk the site. Configuration progress is a claim. Replace percentage-complete with testable completion evidence: approved logic, tested sequences, closed assumptions and signed-off interfaces.

BEFORE FAT

Rehearse the behaviour before the plant exists

Virtual commissioning exercises production or representative control logic against an executable model of the plant, so sequences and interlocks can be exercised before hardware is available. Published work reports material reductions in real commissioning time using this approach. It will not invent an operating philosophy — a digital twin cannot simulate a decision nobody has made — but it makes the absence of one visible months earlier, when it is cheap to resolve.

> **Organisational readiness**
>
> Every recommendation above reduces to one: give the invisible work an owner and a shape. On a lot-based contract the physical scope has both and the functional work often has neither. This is a structural property of how industrial electrical scope is customarily divided rather than a failure of any vendor on the project, and it can be corrected at contract stage for close to nothing.

What goes wrong, and what it costs

Ranked by how often it is missed rather than by severity.

RISK 01

Unbounded functional scope

Plant-specific engineering priced and planned as a single lump conceals both duration and dependency. It cannot be tracked or challenged, gives no early warning when it slips, and absorbs the consequences of every late decision upstream of it.

RISK 02

Interfaces without assigned ownership

Unless interface responsibility is explicitly allocated — to the EPC, an integrator, or through an interface matrix — signals crossing a lot boundary belong to neither scope and are discovered during integration rather than design.

RISK 03

Progress that cannot report bad news

Percentage-complete on functional engineering is an assertion. Without falsifiable completion evidence the reported figure rises smoothly until the week it stops, which is usually the week before commissioning.

RISK 04

Operating philosophy frozen too late

Interlock and alarm philosophy are inputs to configuration. Settling them during configuration converts implementation into rework, and no amount of engineering capacity compensates for a decision that has not been taken.

RISK 05

Technology coverage mistaken for system performance

Thermographic detection covers what reaches the pile surface; a control library covers generic cases. Treating either as complete coverage substitutes instrument or product capability for the operational and engineering work around it.

RISK 06

Structural risk misdiagnosed as vendor performance

When functional engineering overruns, the vendor is the visible party. Where the driver was client-side decision latency or unassigned interface ownership, replacing the vendor may leave the underlying cause untouched while adding substantial delay and transition cost.

08 / WHERE TO START

Five questions before you award

01 Are configuration and plant-specific functional engineering scoped separately?

02 Does an interface register exist, with a named owner on each side?

03 Is the operating philosophy frozen before configuration begins?

04 Can our configuration progress report show bad news?

05 Who owns the plant-specific functional decisions — by name?

All five cost nothing at contract stage and are close to unrecoverable afterwards.

NEXT IN THIS SERIES

Edition 04 — Operating the Asset

How machine learning and digital twins combine in plant exploitation: forecasting, dispatch and maintenance scheduling against a single objective function.

SOURCES & METHOD

Method note: this edition is a practitioner account of one waste-to-energy project on which the author was project manager for three electrical lots. It describes a single plant, contract structure and vendor set; the generalisations offered are hypotheses drawn from that experience, not findings established across a sample. All vendors and commercial terms are anonymised, and quantitative project figures are withheld or expressed as ratios.

Independently sourced — fire detection: US Patent 5,592,151, "Fire monitoring system", stereoscopic infrared localisation of waste-bunker hotspots · US Patent 10,694,107, "Method and device for eliminating thermal interference for infrared and video-based early fire detection" · Picton, K., "Thermal Fire Detection in the Waste Industry Application," Blazequel · InfraTec WASTE-SCAN thermographic bunker monitoring, with published deployments at ARC Amager, Copenhagen and EEW Energy from Waste Stapelfeld. Patent and commercial evidence are distinct: the deployments are not shown to use the patent architecture.

Independently sourced — commissioning effort: Striffler, N. and Voigt, T. (2023), "Concepts and trends of virtual commissioning – a comprehensive review," Journal of Manufacturing Systems 71, 664-680, doi:10.1016/j.jmsy.2023.10.013, citing a VDW study for the 90% and 70% figures · Schamp, M. et al. (2019), "Virtual Commissioning of Industrial Control Systems – a 3D Digital Model Approach," Procedia Manufacturing 39, 66-73, which reports the 73% reduction from an earlier small-scale experiment by the same group · Liu, Z., Diedrich, C. and Suchold, N. (2012), "Virtual Commissioning of Automated Systems," InTech. No benchmark separating plant-specific functional engineering from installation duration was located for comparable waste-to-energy electrical packages.

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