

LANDRY INDUSTRIES INC.

MITLINITE

*Hemp-Derived Carbon Nanosheets
from Supercapacitors to Composites*

A THEORETICAL TREATISE · TRL 1-2

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MITLINITE: HEMP-DERIVED CARBON NANOSHEETS FROM SUPERCAPACITORS TO COMPOSITES

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Status. This is a theoretical work at Technology Readiness Level 1–2. The energy-storage chapters report published, peer-reviewed results. Every composite property in this book is a projected design target reasoned from published analogues, not a measured value for Mitlinitite.

On the name. “Mitlinitite” is the author’s eponym honouring Dr. David Mitlin’s work on hemp-derived carbon nanosheets. It is not a term used by Mitlin or in the scientific literature, and its use implies no endorsement by him.

Claim markers. **Published** peer-reviewed and cited **Inferred** engineering inference from analogues
Proposed (Landry) the author’s untested hypothesis

Facts were verified by live web search on 11–12 October 2026 in keeping with the author’s Seshat’s Axiom (retrieve = store = cite). Nothing in this book is engineering, legal, regulatory or occupational-safety advice.

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ABOUT THIS BOOK

A theoretical treatise on hemp-derived carbon nanosheets: their proven role in supercapacitors, their proposed conversion to graphene oxide, and their proposed use as a filler in epoxy, bio-epoxy, polymer, metal, ceramic and cementitious composites.

Mitlinitite is the author's name for the interconnected, partially graphitic carbon nanosheets that David Mitlin's group made from hemp bast fibre and published in *ACS Nano* in 2013. The energy-storage chapters report published, peer-reviewed results. Every composite chapter is theory: to the author's knowledge, as of October 2026 no composite using these nanosheets as a filler has been made and reported.

Status: Technology Readiness Level (TRL) 1–2. All composite property figures in this book are projected design targets, reasoned from published data on comparable two-dimensional carbon fillers (graphene, graphene nanoplatelets, graphene oxide, reduced graphene oxide and carbon black). None is a measured value for Mitlinitite.

■ On the name

"Mitlinitite" is an eponym coined by Marie-Soleil Seshat Landry to honour Mitlin's work. It is not a term used by Mitlin or in the scientific literature, and its use here implies no endorsement by him. Despite the "-ite" suffix, Mitlinitite is a synthetic carbon, not a mineral.

■ How claims are marked

Marker	What it means	Example
Published	Reported in peer-reviewed literature and cited	2,287 m ² /g surface area (Mitlin group, 2013)
Inferred	Engineering inference from published analogues	Percolation threshold estimated from other porous 2D carbons
Proposed (Landry)	The author's original hypothesis, untested	Mitlinitite as a filler in bio-epoxy vitrimers; the hemp-to-GO/rGO pathway

■ How to read it

1. Chapters 1–4 cover what is established: where Mitlinitite came from, what it is, how it is made and what it has been proven to do.
2. Chapter 5 sets out the author's hemp → Mitlinitite → graphene oxide → reduced graphene oxide pathway.

3. Chapters 6–11 build the composite theory, matrix by matrix, and the technologies it could enable.
4. Chapters 12–14 say how to test the theory, what it could cost or harm, and what remains unknown.

Every factual claim was checked by live web search while writing, in keeping with the author's Seshat's Axiom (retrieve = store = cite). Sources are listed at the end.

CHAPTER 1

ORIGINS: MITLIN'S HEMP NANOSHEETS AND THE NAMING OF MITLINITE

Mitlinitite begins with one paper: Wang, Mitlin and twelve co-authors at the University of Alberta reported in *ACS Nano* in 2013 that hemp bast fibre could be turned into graphene-like carbon nanosheets (Wang et al., *ACS Nano* 7(6):5131–5141, doi:10.1021/nn400731g). **Published.**

■ The 2013 discovery

The team, led by first author Huanlei Wang with David Mitlin as senior author, set out to make stacking-free, graphene-like carbon from a cheap biomass precursor. Their earlier work had turned eggshell membranes into electrode carbon; hemp was the next step (Nanowerk, May 2013).

The key idea was to let the plant do the templating. Hemp bast — the fibre from the inner bark around the stalk — has a layered cell wall whose middle layer is mostly crystalline cellulose built from microfibrils 10–30 nm across. Hydrothermal treatment stripped the outer layers and loosened the microfibrils; a hot potassium hydroxide (KOH) step then split them into sheets and activated them (Nanowerk). The result was a three-dimensional network of 10–30 nm sheets with surface area up to 2,287 m²/g (Wang et al. abstract).

The research was funded by Alberta Innovates Technology Futures, Canada's National Institute for Nanotechnology and the Alberta Livestock and Meat Agency (renewable-carbon.eu, Aug 2014).

■ From paper to press to start-up

Date	Event	Source
Today	Mitlin is an endowed professor in the Walker Department of Mechanical Engineering, University of Texas at Austin; his group now centres on beyond-lithium metal and all-solid-state batteries	UT Austin, Mitlin group
Jan 2016	CQuest Partners LLC, co-founded by Mitlin with Gary and David Charboneau, receives a US\$229,000 New York State grant to make hemp-fibre carbon nanosheets near Potsdam, NY	NorthCountryNow
Aug 2014	Mitlin, now at Clarkson University, presents the work at the 248th ACS National Meeting in San Francisco; a spin-off then called Alta Supercaps targets high-temperature storage for oil and gas	phys.org, NBC News
May 2013	ACS Nano paper published from the University of Alberta	Nanowerk

At the 2014 meeting Mitlin said the devices performed on par with or better than graphene-based devices, and that the advantage was cost: the electrodes came from biowaste by a simple process (phys.org). He told NBC News the hemp carbon was a little better than graphene but "1,000 times cheaper" ([NBC News](http://NBCNews.com)). Press figures like this are the inventor's estimates, not peer-reviewed cost analyses.

■ The bridge to composites

CQuest's stated first product was a hemp-fibre carbon nanosheet for supercapacitors, batteries, and water and air purification. Mitlin framed the business as graphene-class performance at activated-carbon prices, and said the nanosheets could substitute wherever graphene is wanted but too costly ([NorthCountryNow](http://NorthCountryNow.com)). Composites are the largest such market. That is the gap this book addresses: the material was positioned as a cheap graphene substitute, yet its composite potential was never published.

■ Why give it a name

"Hemp-derived carbon nanosheets" describes dozens of unrelated materials made by different routes. The author proposes **Mitlinite** for one specific class, so that composite work can specify it precisely. **Proposed (Landry)** working definition:

Mitlinite — interconnected, partially graphitic carbon nanosheets, nominally 10–30 nm thick, made from *Cannabis sativa* bast fibre by hydrothermal carbonization followed by chemical activation or high-temperature carbonization, in which the fibre's native cellulose microfibril layering templates the sheet morphology.

Carbons from hemp hurd (the woody core), from whole-stalk pyrolysis, or from routes that destroy the bast layering are excluded. They may be useful, but they are not Mitlinite. Chapter 2 defines grades within the class.

CHAPTER 2

WHAT MITLINITE IS: STRUCTURE, CHEMISTRY AND MEASURED PROPERTIES

Mitlinite is a porous, partially graphitic carbon whose sheets contain stacks of only three to four graphene layers, surrounded by disordered carbon. Pressed into a pellet it conducts at about 220 S/m — close to commercial graphene nanoplatelets measured the same way (294 S/m) and several times higher than commercial activated carbon (about 33 S/m). **Published** ([US 2014/0328006 A1](#)).

■ A structure inherited from the plant

The hemp bast fibre is a hollow tube 10–30 μm across. Its wall has three layers; the middle (S2) layer is about 70 wt% crystalline cellulose and makes up over 85% of the wall thickness. S2 is itself built from 10–30 nm microfibrils, each a bundle of roughly 2 nm cellulose elementary fibrils ([patent description](#)).

Mitlinite keeps an echo of every one of these levels:

1. **Sheets** — 10–100 nm thick depending on activation temperature, interconnected into a 3D network.
2. **Graphitic domains** — X-ray diffraction gives an interlayer spacing of 0.39–0.40 nm and stacks 1.4–1.5 nm tall: three to four graphene layers per domain. Raman gives an in-plane domain width (L_a) of about 4 nm.
3. **Pores** — micropores under 2 nm, mesopores of 2–5 nm, and macroporous voids of 1–2 μm between sheets.

For comparison, the interlayer spacing in crystalline graphite is about 0.335 nm. The wider 0.39–0.40 nm spacing in Mitlinite signals turbostratic, defect-rich stacking. **Inferred.**

■ Measured properties by activation temperature

The three published samples are named CNS-700, CNS-750 and CNS-800 after their KOH activation temperature in $^{\circ}\text{C}$. The same study measured a commercial activated carbon (AC) and commercial graphene nanoplatelets (GNP) as baselines.

Property	CNS-700	CNS-750	CNS-800	Activated carbon	Graphene nanoplatelets
Sheet thickness (nm)	50–100	40–70	10–30	particulate	—
BET surface area (m^2/g)	1,690	2,287	1,505	2,050	726
Total pore volume (cm^3/g)	1.08	1.45	1.26	1.17	1.37
Pore volume in pores > 2 nm (%)	40.4	43.8	58.2	38.3	82.0

Property	CNS-700	CNS-750	CNS-800	Activated carbon	Graphene nanoplatelets
Pellet conductivity (S/m)	217	211	226	~33 (literature)	294
Raman IG/ID	0.89	0.85	0.93	0.52	1.55
Graphitic domain width La (nm)	3.92	3.74	4.09	2.29	6.82
Oxygen (at%, XPS)	5.41	5.6	4.19	4.65	6.03
Nitrogen (at%, XPS)	0.90	1.01	1.48	—	—

Source: Table 1 and description of [US 2014/0328006 A1](#), which reproduces the 2013 *ACS Nano* data. Conductivity was measured by four-point probe on pellets pressed at 20 MPa.

Three patterns matter for composites. Hotter activation makes thinner sheets: only CNS-800 reaches the 10–30 nm range quoted in the abstract. Surface area peaks at 750 °C and then falls as pores widen. And KOH, which usually destroys graphitic order, leaves Mitlinitite unusually ordered, because the crystalline cellulose template resists it ([patent](#)).

■ Surface chemistry

The hydrothermal biochar is oxygen-rich (24.7 at% O). Activation strips most of it, leaving 4–6 at% oxygen and about 1–1.5 at% nitrogen. That residual oxygen — hydroxyl, carbonyl and carboxyl groups on sheet edges and pore walls — is the handle composite chemists will need for bonding to a matrix. **Inferred:** at 4–6 at% O, Mitlinitite sits between pristine graphene (near zero) and graphene oxide (typically 20–35 at%), a useful middle ground for epoxy reactivity without GO's loss of conductivity.

■ Proposed grades

Proposed (Landry). Electrode-grade Mitlinitite is optimized for surface area. Composites need other trade-offs, so the author proposes four grades:

Grade	Purpose	How it differs from the 2013 recipe	Target
Mitlinitite-E (electrode)	Supercapacitors, sorbents	As published (CNS-750 / CNS-800)	1,500–2,300 m ² /g
Mitlinitite-S (structural)	Stiffness and toughness in matrices	Milder or no activation; exfoliation by sonication, which the patent predicts may give thinner sheets	< 30 nm thick, < 500 m ² /g, few pores to soak up resin
Mitlinitite-F (functional)	Strong matrix bonding; feedstock for GO	Controlled surface oxidation after activation	8–15 at% O, tunable
Mitlinitite-C (conductive)	EMI shielding, antistatic, de-icing	High-temperature anneal under inert gas	Higher La and conductivity than as-made

A caveat on Mitlinitite-C: cellulose-derived carbons are generally classed as "hard", non-graphitizing carbons, so annealing may raise conductivity only modestly. This must be measured, not assumed.

■ What is not yet known

These gaps decide whether the composite chapters hold up. Each is a first experiment, not a reason for doubt.

- Modulus and strength of a single Mitlinitite sheet: porous few-layer carbon will be far below graphene's, but by how much?
- Intrinsic sheet conductivity, as opposed to pellet conductivity that includes contact resistance.
- Lateral sheet size and aspect ratio after milling and dispersion.
- Skeletal and bulk density, thermal conductivity, and oxidation onset in air.
- Residual potassium and ash after washing, which matter for metals and ceramics.
- Whether resin, molten metal or cement paste enters the pores — and whether that helps (interlocking) or hurts (viscosity, voids).

CHAPTER 3

MAKING MITLINITE: PROCESS, VARIABLES AND SCALE-UP

The published recipe has two hot steps — a 24-hour hydrothermal soak at 180 °C, then KOH activation at 700–800 °C — and the first step is the one that makes sheets. When the group carbonized hemp directly and then activated it with KOH under the same conditions, no layered structure formed ([US 2014/0328006 A1](#)). **Published.**

■ The laboratory recipe

As disclosed in the patent's methods section:

1. **Hydrothermal carbonization (HTC).** Seal 3.0 g of hemp bast fibre with 50 mL of dilute sulfuric acid in a 120 mL stainless-steel autoclave. Heat at 180 °C for 24 h, then cool. The acid catalyses breakdown of hemicellulose and part of the lignin.
2. **Recover the biochar.** Filter, wash with distilled water and dry.
3. **Mix with KOH.** Grind biochar and potassium hydroxide together at a 1:1 mass ratio.
4. **Activate.** Heat to 700, 750 or 800 °C at 3 °C/min under argon and hold for 1 h. KOH melt wedges between the loosened microfibrils, splits them into sheets, and etches pores.
5. **Wash.** Rinse with 10 wt% hydrochloric acid, then distilled water, to remove potassium compounds.
6. **Dry.** 100 °C for 12 h.

The feedstock fibre had 81.98 wt% volatile matter and 2.95 wt% ash. The patent does not report a mass yield, which is the first number any scale-up needs.

■ Process variables and what they control

Variable	Published value	What it controls	Direction for composite grades
Feedstock	Hemp bast fibre	Native microfibril layering = sheet template	Keep bast; exclude hurd
HTC temperature and time	180 °C, 24 h	Exfoliation and pre-carbonization	Explore shorter times for throughput
HTC catalyst	Dilute H ₂ SO ₄	Speed of hemicellulose and lignin removal	Patent says iron oxide or chloride catalysts may also work

Variable	Published value	What it controls	Direction for composite grades
Activating agent	KOH, 1:1 by mass	Thinning and pore creation	Lower ratio or none for Mitlinite-S
Activation temperature	700–800 °C	Thickness (thinner when hotter), surface area (peak at 750 °C)	800 °C for thinnest sheets
Atmosphere	Argon	Prevents burn-off	Nitrogen is the usual industrial substitute
Wash	10 wt% HCl, water	Residual potassium and ash	Tighter limits for metal and ceramic matrices

The patent also predicts, without demonstrating, that NaOH, ZnCl₂, H₃PO₄, CO₂ or steam could replace KOH, and that sonicating the fibre before carbonization might give thinner sheets ([patent](#)). These are the inventors' predictions, not results.

■ The scale-up problem is KOH

KOH activation works superbly in the lab and badly in plants. At activation temperatures KOH is reduced to metallic potassium, which corrodes furnaces, condenses in cooler pipework and can contaminate the carbon ([US 8,252,716](#), [US 8,927,103](#)). Potassium recovery rates are low, and alkali-activated carbon can be highly flammable ([US 11,584,651](#)). A review from Spain's INCAR-CSIC argues that replacing KOH is mandatory because its industrial use is unrealistic ([Sevilla, Díez and Fuertes, summary](#)).

This matters less for composites than for electrodes. **Proposed (Landry):** a structural grade (Mitlinite-S) wants thin sheets with few pores, so it can skip KOH altogether — HTC, mechanical or ultrasonic exfoliation, then inert-gas carbonization. Whether that route still yields sheets rather than particles is the decisive first experiment, given the group's finding that the hydrothermal step is essential.

■ Feedstock supply

Canada planted 15,380 hectares of hemp in 2025, of which 12,859 ha were for grain and only 933 ha were designated for fibre; Alberta led with 6,999 ha ([HempToday](#), citing [Health Canada](#)). Grain crops still leave stalks, and every stalk carries bast. Mitlin himself described bast fibre piling up unused at an Alberta processor ([Digital Trends](#), quoting [BBC](#)). **Inferred:** feedstock is limited by decortication capacity, not by the crop.

■ Fitting Mitlinite into a hemp biorefinery

Proposed (Landry): In the author's Hemp Refinery architecture, Mitlinite becomes one more unit operation on the bast stream:

1. Decorticate stalks into bast and hurd; hurd continues to bio-based resin and fuel streams.
2. Run bast through HTC; route the organic-rich process liquor to the refinery's liquid-fuel or biogas stream rather than to waste.
3. Activate or carbonize the biochar by grade (E, S, F or C).
4. Recover and recycle the washing acid and, where used, potassium.

5. Ship graded Mitlinite to electrode, sorbent and composite customers, and to the GO line in Chapter 5.

■ Release tests for every batch

A composite maker needs a datasheet. The minimum set, matching the 2013 characterization plus composite needs:

- Surface area and pore size distribution (N₂ adsorption, BET and DFT)
- Sheet thickness (TEM or AFM) and lateral size (laser diffraction after dispersion)
- Raman IG/ID and XRD interlayer spacing
- Oxygen, nitrogen and potassium content (XPS, ICP)
- Pressed-pellet conductivity (four-point probe at a stated pressure)
- Oxidation onset in air and ash (thermogravimetric analysis)

CHAPTER 4

THE PROVEN APPLICATION: SUPERCAPACITORS AND ELECTROCHEMICAL STORAGE

Mitlinit's one demonstrated use is as a supercapacitor electrode, where it delivered 19 Wh/kg at 20 kW/kg at room temperature (active-material basis) and kept 96% of its capacitance after 10,000 cycles. Packaged, the device reached an estimated 12 Wh/kg — above commercial supercapacitors of the time (Wang et al. abstract via [phys.org](#); US 2014/0328006 A1). **Published.**

■ How the device was built

Electrodes were 80 wt% Mitlinit, 10 wt% carbon black and 10 wt% PVDF binder, coated at about 2 mg/cm² on stainless steel. Two identical electrodes faced each other in a coin cell with an ionic-liquid electrolyte (BMPY TFSI) at 3.0 V (patent methods). Ionic liquids are non-flammable and allow higher voltage than organic electrolytes, but they are viscous and usually perform poorly below about 60 °C. Mitlinit's achievement was to make them work from 0 °C.

■ Headline results

Measure	Result	Condition
Specific capacitance	106 F/g	0 °C, 10 A/g
Specific capacitance	113 / 144 / 142 F/g	20 / 60 / 100 °C at 100 A/g
Rate retention	72–92%	at 100 A/g, 60–100 °C
Energy density (active mass)	19 / 34 / 40 Wh/kg	at 20 kW/kg, 20 / 60 / 100 °C
Max power (whole device)	28 / 49 / 77 kW/kg	20 / 60 / 100 °C
Packaged energy density	~12 Wh/kg (estimated)	3.0 V, whole device
Full recharge	< 6 s	at 8–10 Wh/kg, whole device
Cycle life	96% retained	10,000 cycles at 10 A/g
Equivalent series resistance	~6 Ω	vs ~30 Ω for commercial activated carbon

Sources: [phys.org abstract](#) and [patent](#). Packaged figures were extrapolated from active-mass data with a factor of four, because carbon was about 30% of the packaged cell mass.

■ Why it works

The inventors trace the performance to four structural features: interconnected, partially graphitic sheets for electron flow; 1–2 μm voids that act as electrolyte reservoirs; sheets only 10–30 nm thick, so ions travel 5–15 nm at most; and a high share of mesopores large enough for the bulky ionic-liquid ions (up to 1.1 nm) ([patent](#)). Each of these features reappears in the composite chapters — sometimes as an asset, sometimes as a liability.

■ The wider family

Mitlin's group applied the same idea — let a plant's architecture template the carbon — to other biomass. Peanut-skin carbon nanosheets, down to 20 nm thick and up to 2,070 m^2/g , served as both electrodes of a hybrid sodium-ion capacitor that kept 85% capacity over 3,000 cycles (*J. Mater. Chem. A*, 2016). Wood-cellulose carbon nanosheets hosted selenium in a sodium–selenium cell (*BEST Magazine*). Mitlin also filed a "supercapattery" application using carbon nanosheets in both electrodes ([US 2018/0083331 A1](#)).

Others have since used hemp for sodium-ion anodes by different routes, including hemp-hurd hard carbon from the University of Zaragoza ([Antorán et al.](#)) and hemp-stem carbon hybrids with cobalt chalcogenides (*Sustainable Energy & Fuels*, 2026). By the definition in Chapter 1, these are hemp carbons but not Mitlinite.

■ What the electrode results tell a composite designer

Inferred. Three lessons transfer directly:

- **The network conducts.** A pressed powder with only 10 wt% carbon black already gives low resistance, so Mitlinite sheets touch and pass current readily — a good sign for electrical percolation in a matrix.
- **The surface is accessible.** Viscous liquids with 1 nm ions wet the pores within cycles. Uncured epoxy and polymer melts are far more viscous, so resin will coat the outer sheet surfaces quickly but fill the micropores slowly, if at all.
- **It tolerates heat.** Stable operation to 100 °C in the cell says nothing yet about oxidation in air, but suggests the carbon itself is not the weak link in mid-temperature composites.

CHAPTER 5

FROM MITLINITE TO GRAPHENE OXIDE AND REDUCED GRAPHENE OXIDE: THE LANDRY PATHWAY

The author proposes that Mitlinitite can serve as the feedstock for graphene oxide (GO) and reduced graphene oxide (rGO): oxidize it as graphite is oxidized in the Hummers method, exfoliate it in water, then reduce it. **Proposed (Landry) – untested.** The rationale is that Mitlinitite already arrives as thin, few-layer, partly graphitic sheets, so it may need less oxidant and less exfoliation energy than mined graphite.

Published · Mitlin group, 2013

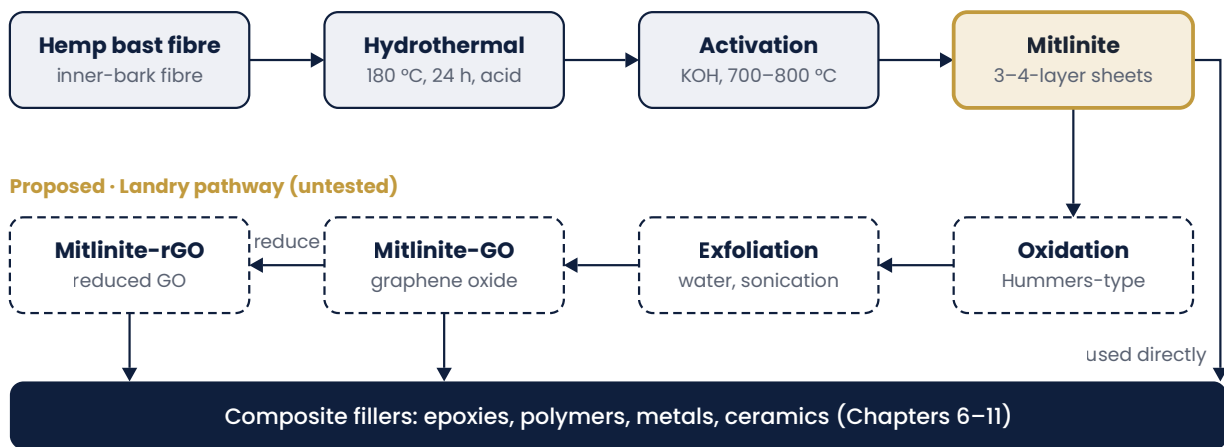


Figure 5.1 The Landry pathway. Solid boxes are the published steps (Mitlin group, 2013); dashed boxes are the author's proposed, untested steps. All three products feed the composite chapters.

The top row is Mitlin's published route; the dashed lower row is the author's proposed extension, and all three products — Mitlinitite, Mitlinitite-GO and Mitlinitite-rGO — feed the composite chapters.

■ Graphene oxide in one page

GO is graphene decorated with oxygen groups (epoxy, hydroxyl, carboxyl) that make it disperse in water; removing most of that oxygen gives rGO, a chemically derived graphene (Ramli and Hidayat, *IntechOpen* 2022). The standard route is Hummers and Offeman's 1958 oxidation of graphite with potassium permanganate in sulfuric acid, now mostly run in modified forms. Older chlorate routes exist; Hofmann's version, for example, gave GO with a carbon-to-oxygen ratio of about 2.5 (*Materials* review, PMC).

Modern variants drop sodium nitrate, which releases toxic nitrogen oxides, and raise the permanganate dose instead (*Materials* 2022, PMC). Permanganate must be added slowly with cooling because a fast temperature rise risks explosion (Ramli and Hidayat).

■ Why Mitlinitite might be a better GO feedstock

Inferred from the Chapter 2 data:

- **Already few-layer.** XRD shows 3–4-layer graphitic stacks, so less intercalation is needed than for bulk graphite.
- **Already thin and open.** 10–30 nm sheets with 1–2 μm voids give the oxidant short paths in.
- **Renewable and local.** It replaces mined or synthetic graphite; the Fazi study notes graphite is on the European critical raw materials list (Fazi et al., *Chem. Eng. Trans.* 118, 2025).

■ The main risk: small graphitic domains

Mitlinitite's graphitic domains are only about 4 nm wide (La, Chapter 2), against micrometre-scale crystals in graphite. GO inherits the domain size of its parent, so Mitlinitite-GO is likely to be small-domained and defect-rich, and its rGO less conductive than graphite-derived rGO. Biochar-to-GO researchers likewise stress that the carbon must be graphite-like, with extended conjugated domains (Fazi et al.). **Proposed mitigations:** start from CNS-800 (the highest La of the published samples), anneal first (Mitlinitite-C), and test milder oxidation to preserve what order exists.

■ A starting laboratory protocol

Proposed (Landry). Quantities are a starting point scaled from a published biomass-carbon Hummers recipe (rice-husk carbon), not an optimized method (Ramli and Hidayat):

1. Mill and sieve 1 g of Mitlinitite (CNS-800 or annealed grade).
2. Stir into about 23 mL concentrated sulfuric acid in an ice bath; omit sodium nitrate.
3. Add about 3 g potassium permanganate slowly, keeping the mixture below 20 °C; then hold at 35 °C for about 30 min.
4. Dilute carefully with water, then quench with dilute hydrogen peroxide until the colour turns yellow; this also strips manganese residues.
5. Wash to neutral pH, exfoliate by sonication, and centrifuge to keep the few-layer fraction: this is Mitlinitite-GO.

6. Reduce by heating under inert gas or with a chemical reductant to obtain Mitlinitite-rGO — or reduce in situ inside a composite.

Signs of success to measure: the XRD peak moving from about 23° toward about 10° 2θ (rice-husk GO showed 10° , an 8.8 Å spacing, in the same chapter); a C/O ratio near 2–3 by XPS; stable dispersion in water; and, after reduction, recovery of the D and G Raman bands and of electrical conductivity.

■ Prior and neighbouring work

The searches for this book found several routes near the author's, but none that oxidizes Mitlin-type hemp nanosheets into GO and reduces it to rGO.

Year	Work	What it did	How the Landry pathway differs
2025	Fazi et al.	Slow-pyrolysis agricultural biochar → GO by Hummers	Feedstock is templated hemp nanosheets, not generic biochar
2022	Ramli and Hidayat	Activated carbon from palm bunches, rice husk and coconut shell → GO by modified Hummers	Hemp bast; few-layer sheets before oxidation
2022	Hossain et al., J. Sci. Res. 14(2)	Hemp bast → HTC + KOH "hemp-derived graphene" (a Mitlin variant, up to 1,410 m ² /g)	No oxidation to GO, no rGO
2021	US 11,760,638 (China priority March 2021)	Carbonized hemp skin, stem or root → laser-induced graphene	Laser graphitization, not oxidation–reduction
2017	US 2019/0248655 A1 (CannGraph LLC; granted as US 10,611,641)	"Graphene" from carbon plus hemp-derived dicarboxylic acids in water	Not a GO route; no nanosheet feedstock
2013	Wang et al. / US 9,478,365	Hemp bast → carbon nanosheets (Mitlinitite)	Stops at the nanosheet; no oxidation
1958	Hummers and Offeman, <i>JACS</i> 80:1339 (cited in Ramli and Hidayat)	Graphite → GO	Graphite feedstock

The author states that she was the first to map the hemp → Mitlinitite → GO → rGO sequence. The searches for this book did not find an earlier publication of that specific sequence, though they cannot prove a negative. Priority rests on the author's earliest dated public record of the pathway, which should be cited here. *(Add DOI of the author's first dated record.)*

■ Testable predictions

- **P5.1** Mitlinitite oxidizes to GO with less permanganate per gram than flake graphite.
- **P5.2** Mitlinitite-GO sheets are smaller in lateral size and more defective than graphite GO; annealing first narrows the gap.
- **P5.3** Mitlinitite-rGO is less conductive than graphite-derived rGO but more conductive than as-made Mitlinitite.
- **P5.4** Mitlinitite-GO disperses in water and in epoxy hardeners well enough for the composite routes in Chapter 7.

COMPOSITE DESIGN PRINCIPLES FOR 2D CARBON FILLERS

Whether Mitlinite works as a filler hinges on three numbers nobody has measured yet: the stiffness of a single sheet, its aspect ratio after dispersion, and the strength of its bond to the matrix. Standard micromechanics shows how much each matters. At 2 vol% in epoxy, the projected stiffness gain ranges from +10% to +34% depending on sheet modulus alone. **Inferred — a design target, not a result.**

■ What graphene-family fillers have delivered

These published results set realistic expectations for any 2D carbon in a matrix.

Filler and matrix	Loading	Reported effect	Source
Graphene platelets in epoxy	0.1 wt%	Mode I fracture toughness up ~53%, vs ~20% for multi-walled nanotubes	Rafiee et al., <i>ACS Nano</i> 3, 3884 (2009) (summary)
Multi-layer graphene in epoxy	0.1 wt%	Young's modulus +26%, fracture toughness +41%	Atif, Shyha and Inam, <i>J. Compos. Mater.</i> 51(2), 2017
Graphene nanoplatelets in aerospace epoxy	6 wt% (3.7 vol%)	Tensile modulus 2.72 → 3.36 GPa (+23.5%)	King et al., <i>J. Appl. Polym. Sci.</i> 128(6), 2013
Reduced GO sheets in polystyrene	~0.1 vol%	Electrical percolation threshold; ~0.1 S/m at 1 vol%	Stankovich et al., <i>Nature</i> 442, 282 (2006)

Two lessons stand out. Toughness responds at tiny loadings, and Rafiee's group linked part of that to the wrinkled, rough surface of the platelets interlocking with the resin. Stiffness gains come more slowly and need volume.

■ Stiffness: the Halpin–Tsai estimate

For aligned platelets in a matrix, the Halpin–Tsai equations give the composite modulus E from the matrix modulus E_m , filler modulus E_f and filler volume fraction ϕ :

$$\frac{E}{E_m} = \frac{1 + \zeta\eta\phi}{1 - \eta\phi}, \quad \eta = \frac{E_f/E_m - 1}{E_f/E_m + \zeta}$$

The shape factor ζ carries the geometry. Van Es showed Halpin–Tsai matches the more rigorous Mori–Tanaka model for platelets when $\zeta = (2/3)(l/t)$, where l/t is the sheet's length-to-thickness ratio ([van Es](#), as summarized in [CRC Press](#), ch. 20). Some authors use $\zeta = 2(l/t)$, which predicts more.

The chart applies the conservative form with three assumptions, each marked: epoxy at 3.0 GPa, $l/t = 50$ (a 1 μm sheet 20 nm thick), and sheet moduli of 20, 50 or 100 GPa — a deliberately wide range, because Mitlinite's porous, few-layer sheets will be far softer than graphene's ~ 1 TPa.

Modulus gain over neat epoxy

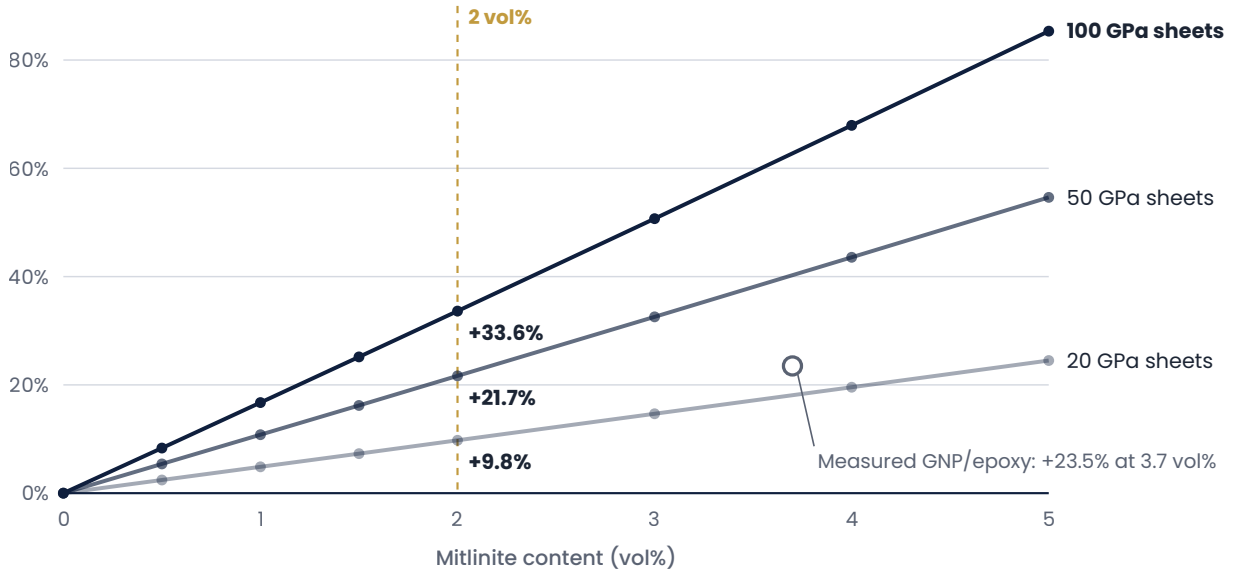


Figure 6.1 At 2 vol%, projected stiffness gain spans +10% to +34%. Halpin–Tsai, aligned sheets, aspect ratio 50, epoxy at 3.0 GPa; each line assumes a different, unmeasured sheet modulus. Reference point: King et al., J. Appl. Polym. Sci. 128(6), 2013. Projection computed for this book.

The measured graphene-nanoplatelet point sits between the 20 and 50 GPa curves, a reminder that real dispersions lose aspect ratio to stacking and folding. Halpin–Tsai also assumes alignment; randomly oriented sheets give less, and the PET-graphene literature notes the model overpredicts when the filler is hundreds of times stiffer than the matrix ([US 10,087,302](#)).

■ Conductivity: percolation

Above a critical volume fraction ϕ_c , conductive sheets touch through the matrix and conductivity follows a power law, with σ_f the filler conductivity and t near 2 in three dimensions ([US 7,914,844](#)):

$$\sigma_c = \sigma_f \left(\frac{\phi - \phi_c}{1 - \phi_c} \right)^t$$

Randomly oriented discs with an aspect ratio of 1,000 percolate near 0.1 vol% ([US 7,914,844](#)). Because the geometric threshold of thin discs scales roughly with thickness over diameter, **inferred:** Mitlinites at $l/t = 50$ would percolate near 2 vol%, and at $l/t = 100$ near 1 vol%. Its pellet conductivity of ~ 220 S/m is three to four orders below graphene's, so expect antistatic to static-dissipative composites, not metallic ones, unless the Mitlinites-C or rGO grades deliver more.

■ Toughness: why porous sheets might help

Cracks in brittle matrices are slowed by fillers that deflect, pin and bridge them. **Proposed (Landry):** Mitlinites' rough, porous, interconnected sheets may toughen better than smooth graphene per unit stiffness, because resin entering surface pores creates mechanical interlock — the same mechanism Rafiee's group credited to wrinkled platelets. This is the composite property most likely to show a benefit at low loadings, and the cheapest to test.

■ Porosity cuts both ways

Electrode-grade Mitlinites holds $1.08\text{--}1.45\text{ cm}^3$ of pore volume per gram (Chapter 2). **Inferred:** one gram can therefore soak up more than a cubic centimetre of liquid resin, thickening the mix and starving the matrix of free resin. This is why the structural grade (Mitlinites-S) targets low porosity, and why every Mitlinites datasheet must state pore volume.

■ Interface and dispersion

Graphene's own pioneers found pristine sheets agglomerate in polymers and need chemical modification to disperse ([Stankovich et al. 2006](#)). Mitlinites starts with 4–6 at% oxygen, a modest handle. Routes to stronger bonding, all **proposed:** amine or silane grafting onto edge groups; the oxidized Mitlinites-F grade; or Mitlinites-GO dispersed in water or hardener, then reduced in place.

■ Design rules for Mitlinites composites

1. Specify the grade, sheet thickness, lateral size and pore volume, not just "hemp carbon".
2. Convert weight to volume fraction with measured skeletal density; until measured, assume about 2 g/cm^3 and say so.
3. Test fracture toughness first: it responds at 0.1–0.5 wt% in graphene systems.
4. For stiffness, measure sheet modulus (AFM nanoindentation) before promising numbers.
5. For conductivity, aim above the estimated 1–2 vol% threshold and report the measured φ_c .
6. Report dispersion quality (optical microscopy, SEM fracture surfaces) with every result.

THERMOSET MATRICES: EPOXIES AND BIO-EPOXIES (HEMPOXIES)

Epoxy is the right first matrix for Mitlinit: it is processed as a liquid, its amine cure chemistry reacts with oxygen groups on carbon, and graphene-epoxy is the best-documented 2D-carbon composite. The first experiment should target fracture toughness at 0.1–0.5 wt%, where graphene platelets have raised epoxy toughness by roughly 40–55% (Chapter 6). **Proposed (Landry).**

■ Three ways to get Mitlinit into epoxy

1. **Disperse in the hardener.** Amine hardeners are less viscous than resin and interact with carbon surface groups; graphene studies commonly disperse the filler in the hardener first, then mix in the resin ([RSC Advances author version](#)).
2. **Three-roll milling or high-shear mixing.** Breaks agglomerates without the sheet damage that long sonication causes. Best for Mitlinit-S and Mitlinit-C powders.
3. **Carry Mitlinit-GO in water or solvent, exchange into resin, reduce in place.** Gives the best dispersion but changes the cure chemistry, as below.

■ The stoichiometry trap with oxidized grades

GO's own epoxide groups consume amine hardener and push the resin off its ideal epoxy-to-amine ratio. Southampton researchers found T_g falling as GO content rose; post-curing recovered much of it, as hydroxyl groups on GO reacted with excess epoxide. Post-curing also partly reduced the GO, raising the composite's electrical conductivity ([Vryonis et al., *J. Mater. Sci.* 54, 3035–3051, 2019](#)).

Inferred for Mitlinit: the as-made grades (4–6 at% O) will barely disturb stoichiometry. Mitlinit-F and Mitlinit-GO will, so their formulations need extra hardener or a post-cure — and that post-cure doubles as an in-situ reduction step.

■ Bio-based epoxies: the hemp-on-hemp idea

Epoxidized hemp seed oil (EHO) is a working bio-resin. In jute-fibre composites, EHO resins were marginally better than commercial epoxidized soybean oil, though still below a petroleum epoxy control, and bioresin content was kept below 30% ([Manthey et al., *J. Reinf. Plast. Compos.* 32\(19\), 2013](#)).

Proposed (Landry): an **all-hemp composite** — hemp-oil resin from the seed, Mitlinitite filler from the bast, and hemp fibre or hurd reinforcement from the stalk. One crop supplies matrix, nanofiller and reinforcement. This extends the author's Hempoxies platform, which is itself at TRL 1–2 with projected, not validated, performance targets.

Plant-oil resins are softer and more ductile than bisphenol-A epoxies. **Inferred:** a stiff, conductive nanofiller may recover part of the stiffness gap, so Mitlinitite could matter more in bio-epoxies than in petroleum ones.

■ Vitrimers: Mitlinitite as a built-in heater

Vitrimers are cross-linked resins whose bonds exchange when heated, so they can be healed, reshaped and re-cycled. Carbon fillers make that heat easy to deliver:

- A fully plant-oil epoxy vitrimer (soybean and tung oil) filled with graphene self-healed when triggered by electricity, heat, electromagnetic waves or infrared light (Hu et al., *Compos. B* 259, 110704, 2023).
- An epoxy vitrimer with 0.2 wt% GO kept 89% of its flexural strength after remoulding, and its glass-fibre composites could be chemically unbuilt to recover the fibres (Sharma et al., *J. Reinf. Plast. Compos.*, 2024).

Proposed (Landry): Mitlinitite in a Hempoxies vitrimer as the photothermal and Joule-heating trigger. Black, conductive and cheap, it could let a part be healed with a lamp or a current instead of an oven.

■ Projected design targets

All values are **proposed design targets** for TRL 1–2 planning, anchored to the graphene benchmarks in Chapter 6. None has been measured for Mitlinitite.

System	Grade and loading	Target	Benchmark it is anchored to
DGEBA epoxy, amine cure	Mitlinitite-S, 0.1–0.5 wt%	K_{IC} +20–40%	Graphene platelets +41–53% at 0.1 wt%
DGEBA epoxy, amine cure	Mitlinitite-S, 1–2 vol%	Modulus +10–20%	Halpin–Tsai, 20–50 GPa sheets
DGEBA epoxy	Mitlinitite-C or -rGO, 3–5 vol%	Conductivity approaching 0.1 S/m	rGO in polystyrene, ~0.1 S/m at 1 vol%
EHO-based bio-epoxy	Mitlinitite-S, 1–2 wt%	Recover part of the stiffness gap to petroleum epoxy	EHO below petroleum control
Hempoxies vitrimer	Mitlinitite-C, 0.2–1 wt%	≥ 85% property retention over ≥ 4 reprocessing cycles; light- or current-triggered healing	GO vitrimer 89% after remoulding

■ Failure modes to watch

- Viscosity climbing out of the processing window, from porosity soaking up resin.
- Agglomerates acting as crack starters, which turns a toughener into an embrittler.
- T_g loss with oxidized grades if stoichiometry is not corrected.
- Moisture carried into the resin by hygroscopic, high-surface-area carbon: dry at 100–120 °C before mixing.

THERMOPLASTICS, ELASTOMERS AND FIBRES

In thermoplastics Mitlinitite competes with three incumbents — carbon black, ordinary biochar and graphene nanoplatelets — and its likely niche is a renewable filler that adds stiffness, static dissipation and flame resistance at 2–10 wt%, compounded in the melt. **Proposed (Landry).**

■ What carbon fillers already do in thermoplastics

- **Biochar in polyolefins.** In polypropylene, tensile and flexural modulus rose steadily with biochar content, while cone-calorimeter peak heat release, smoke and CO/CO₂ output fell; rice-husk biochar did similar things in recycled HDPE. The flame-retardant action works in the condensed phase, through a protective char layer ([Plastics Engineering](#), Mar 2026).
- **Graphene nanoplatelets in PLA.** Mixed in the melt and hot-pressed, GNPs made PLA electrically conductive at 7 wt%; modulus and thermal stability rose while tensile strength and elongation fell ([Cheong et al., Chem. Eng. Technol. 47\(11\), 2024](#)).

The pattern is consistent: stiffness and fire behaviour improve, ductility pays. Mitlinitite should be expected to follow it.

■ Where Mitlinitite should differ

Inferred from the Chapter 2 data:

- **More conductive than ordinary biochar.** Its pellet conductivity (~220 S/m) is close to the commercial GNPs Mitlin measured alongside it (294 S/m), and its sheets are already interconnected. Percolation in PLA may therefore land in the same region as GNP's 7 wt%, possibly lower.
- **Not a gas barrier.** Graphene blocks gases because its sheets are impermeable. Mitlinitite's sheets are riddled with micro- and mesopores, so barrier films are the wrong target.
- **A built-in char former.** Like biochar, Mitlinitite should support a protective carbon layer in a fire, with the advantage of a higher surface area to trap volatiles.

■ Processing

1. **Dry the powder** (hygroscopic, high surface area) before compounding.
2. **Make a masterbatch** at 15–25 wt% on a twin-screw extruder, then let it down to the target loading. This is how carbon black is usually handled.

3. **Keep shear moderate.** High shear breaks sheets and lowers aspect ratio — the property that sets percolation and stiffness.
4. **Watch melt viscosity.** Porosity absorbs polymer melt less readily than liquid resin, but high-surface-area carbon still thickens melts.

■ Elastomers

Carbon black has long been the standard reinforcing filler in rubber. **Proposed:** partial replacement of carbon black with Mitlinitite in natural or synthetic rubber, aiming for a bio-sourced filler fraction, and conductive elastomers whose resistance changes with stretch, for wearable strain sensors. Both are untested.

■ Fibres: Mitlinitite on hemp, in hemp

A Chinese-priority patent already coats hemp fibres with laser-induced graphene made from the fibre's own non-cellulose components (US 11,760,638). **Proposed (Landry):** two related routes using Mitlinitite instead:

- **Mitlinitite-GO sizing on hemp fibre** for natural-fibre composites. A thin GO coat could improve fibre-to-resin bonding and give the fibre a conductive skin after reduction.
- **Mitlinitite in spun fibres** — melt-spun PLA or wet-spun regenerated cellulose — for antistatic and heated textiles.

■ Candidate systems

Matrix	Process	Grade and loading	Purpose
PLA	Twin-screw, filament extrusion	Mitlinitite-C, 5–10 wt%	Bio-based conductive 3D-printing filament
Polypropylene, HDPE	Masterbatch, injection moulding	Mitlinitite-S, 2–10 wt%	Stiffness and lower heat release in automotive and building parts
Nylon (PA6)	Twin-screw	Mitlinitite-C, 3–8 wt%	Static-dissipative housings
Natural or SBR rubber	Internal mixer	Mitlinitite-S, partial carbon black swap	Bio-sourced reinforcing filler
Hemp fibre in bio-epoxy	Fibre sizing	Mitlinitite-GO, < 1 wt% on fibre	Stronger fibre-matrix interface

All rows are proposals for testing at TRL 1–2; loadings are starting ranges drawn from the biochar and GNP precedents above.

CHAPTER 9

METAL MATRIX COMPOSITES

Metals are the hardest matrix for Mitlinitite: aluminium reacts with carbon to form brittle aluminium carbide, copper barely wets carbon, and porous sheets trap gas during sintering. Yet graphene precedents show 20–60% strength gains at only 0.3–2 wt%, so the prize justifies the difficulty. **Inferred.**

■ What graphene has done in aluminium and copper

Matrix and filler	Route	Result	Source
Al + 0.3 wt% GNP	Vacuum hot pressing	UTS +62%	Ali et al. review, Rev. Adv. Mater. Sci., 2021
Al + 1 wt% GNP	Spark plasma sintering, 550 °C	Yield +84.5%, UTS +54.8%; no carbide detected	same review (Bisht et al.)
Al5083 + 1 wt% GNP	Powder metallurgy + extrusion	UTS +50%, to 470 MPa	same review
Al + 1 wt% rGO	Powder metallurgy + SPS	UTS +49%, to 320 MPa	same review
Al + 0.3 wt% GNP	Ball milling + sonication	Wear rate -76.7%, hardness +35.6%	same review (Baig et al.)
Cu + 0.5 wt% Cu-decorated graphene	GO reduced with Cu in situ, then powder metallurgy	UTS 221 MPa (+23%), hardness +59%, conductivity 93.96% IACS	Yang et al., Carbon Letters 34, 2024

The review identifies four strengthening mechanisms — Orowan looping, load transfer by shear lag, dislocations from thermal-expansion mismatch, and grain refinement — and an optimum loading, usually 0.3–1 wt%, beyond which agglomerates act as pores and cracks ([Ali et al.](#)).

■ Why Mitlinitite is harder than graphene here

Inferred:

- **Carbide risk is higher.** Al_4C_3 forms spontaneously (about -196 kJ/mol at 298 K) and preferentially at graphene defects and open edges ([Ali et al.](#)). Mitlinitite, with ~ 4 nm graphitic domains and abundant pore walls, is almost all edge and defect.
- **Pores trap gas.** Electrode-grade Mitlinitite's $1.1\text{--}1.5$ cm³/g of pore volume can hold moisture and gas that blister or weaken sintered parts.
- **Impurities matter.** Residual oxygen (4–6 at%) and any potassium left from activation can form oxide inclusions.

■ Mitigations

1. **Use Mitlinit-S or annealed Mitlinit-C**, not electrode grade: fewer pores, fewer reactive edges.
2. **Sinter fast and cool**. Spark plasma sintering at 550 °C with a short hold produced no detectable carbide with GNPs; carry that window over.
3. **Coat before consolidating**. **Proposed (Landry):** decorate Mitlinit-GO with copper or nickel by in-situ chemical reduction, as Yang et al. did with GO, so metal–metal contact replaces the poor carbon–metal wetting.
4. **Degas powders** under vacuum before pressing.

■ Proposed systems and targets

System	Grade and loading	Purpose	Design target (TRL 1–2)
Aluminium alloy, SPS or extrusion	Mitlinit-S, 0.3–1 wt%	Lightweight structural parts	UTS +20–40%, no detectable Al_4C_3
Aluminium or bronze bearings	Mitlinit-C, 0.3–2 wt%	Self-lubricating wear surfaces	Wear rate –30–60%
Copper, powder metallurgy	Cu-decorated Mitlinit-rGO, 0.3–0.5 wt%	Stronger electrical contacts and conductors	UTS +15–25% while keeping $\geq$ 90% IACS

These are planning targets set below the graphene benchmarks, because Mitlinit's softer, defect-rich sheets should transfer less load.

CERAMIC AND CEMENTITIOUS MATRIX COMPOSITES

Brittle matrices are where 2D carbon has shown its most dramatic gains: 1.5 vol% graphene platelets more than doubled the fracture toughness of silicon nitride, and 0.03% graphene oxide by cement weight raised mortar's flexural strength by about 40%. Both point to Mitlinitite as a crack-stopper in ceramics and concrete. **Inferred from published analogues.**

■ Technical ceramics

In silicon nitride sintered by spark plasma sintering at about 1,650 °C for 2 minutes, fracture toughness rose from 2.8 to 6.6 MPa·√m at 1.5 vol% graphene platelets. The platelets wrapped around grains, pulled out, bridged cracks and forced them to deflect in three dimensions ([US 8,962,504](#), priority July 2011; [ScienceDaily](#) on [Walker et al., *ACS Nano* 2011](#)).

Inferred for Mitlinitite:

- **Atmosphere is non-negotiable.** Carbon burns in air at ceramic sintering temperatures, so Mitlinitite suits non-oxide ceramics (silicon nitride, silicon carbide, boron carbide) or oxides sintered under vacuum or inert gas by SPS or hot pressing.
- **Rough sheets may wrap grains well.** Mitlinitite's interconnected, crumpled morphology could anchor at grain boundaries like the platelets did — or, if sheets are too porous, fracture before they pull out.
- **Use the cleanest grade.** Residual potassium and oxygen form glassy phases at grain boundaries that weaken ceramics at high temperature. Mitlinitite-C, annealed and acid-washed, is the candidate.

■ Cement, mortar and concrete

In cement mortar, 0.03% GO by weight of cement raised 28-day compressive strength by 21%, flexural by 40% and tensile by 54%; at 0.05% the gains fell back, which the authors put down to poorer dispersion and higher water demand. They found GO did not speed hydration; it acted as a barrier that stopped microcracks spreading ([Wang, Yang and Ouyang, *Materials* 12\(22\), 3753, 2019](#)).

Biochar is also being added to concrete, with reviews reporting contributions to strength, lower permeability, reduced shrinkage and long-term carbon storage, though long-term performance remains an open question ([Alghawnmeh et al., *J. Asian Concrete Fed.* 11\(2\), 2025](#)).

Proposed (Landry): Mitlinite sits between these two. As GO, Mitlinite-GO could be a crack shield at hundredths of a percent; as biochar, porous Mitlinite could store water for internal curing and lock carbon into the structure for its service life.

■ Smart concrete

Proposed (Landry): Above its percolation threshold, a conductive carbon network turns concrete into its own sensor and heater:

- **Self-sensing.** Electrical resistance changes as the network is strained or cracked, giving structural health monitoring without embedded gauges.
- **De-icing.** Passing current through the network warms slabs, bridge decks and ramps — relevant to Atlantic Canada's freeze–thaw winters.

These functions need far more filler than strength does (likely several percent, Chapter 6), so cost per cubic metre will decide them.

■ Hempcrete

Hempcrete — hemp hurd bound with lime — is a low-strength insulating wall material. **Proposed (Landry):** a small Mitlinite or Mitlinite-GO dose in the lime binder, aiming at binder toughness and carbonation behaviour, would make an all-hemp building material: hurd aggregate and bast-derived nanocarbon from the same stalk. Untested.

■ Proposed systems and targets

System	Grade and dose	Purpose	Design target (TRL 1–2)
Silicon nitride or SiC, SPS	Mitlinite-C, 0.5–1.5 vol%	Tougher cutting tools, bearings, armour	K_{IC} +50–100%
Portland cement mortar	Mitlinite-GO, 0.01–0.05% by cement weight	Crack resistance	Flexural strength +15–30% at 28 days
Concrete	Mitlinite-S, 0.5–2% by cement weight	Internal curing, carbon storage	No strength loss; lower autogenous shrinkage
Conductive concrete	Mitlinite-C, several %	Self-sensing, de-icing	Measured percolation; stable resistance over freeze–thaw cycles
Lime hempcrete binder	Mitlinite or -GO, < 0.5% of binder	All-hemp wall material	Binder toughness gain without loss of insulation

TECHNOLOGIES MITLINITE COMPOSITES COULD ENABLE

The single most distinctive opportunity is a **structural supercapacitor**: a load-bearing composite panel that also stores energy, built by uniting Mitlinit's proven electrode performance with an epoxy matrix. The nearer-term opportunities are humbler — antistatic bio-plastics, tougher adhesives, crack-resistant mortars — and they are the ones to pursue first. **Proposed (Landry)**, ranked by the author's estimate of technical distance.

■ The flagship: energy-storing structures

Structural energy storage replaces dead weight with material that carries load and holds charge. Chalmers University's carbon-fibre structural battery reached 24 Wh/kg and 25 GPa stiffness, with a next generation projected at 75 Wh/kg and 75 GPa (Chalmers, 2021).

Structural supercapacitors trade energy for power and cycle life, and a 2023 Imperial College review names their two bottlenecks precisely (Greenhalgh et al., *Compos. Sci. Technol.* 235, 109968, 2023):

- **Too little surface.** Plain carbon fibre offers about 0.2 m²/g, so it stores little charge. Carbon aerogel, nanotubes or graphene grown on the fibres help, usually at some mechanical cost.
- **Electrolytes that are either stiff or conductive, rarely both.** The target is above 1 GPa and above 1 mS/cm. Epoxy-ionic-liquid electrolytes reach 0.8–0.96 GPa but only 0.07–0.28 mS/cm.

Scale-up hurts too: one device fell from 1.75 to 0.83 Wh/kg going from a small cell to A4 size, mostly through current-collection losses (same review).

Proposed (Landry) — why Mitlinit fits:

1. It supplies 1,500–2,300 m²/g — roughly ten thousand times plain carbon fibre's area.
2. It is proven in exactly the electrolyte family structural designers use: ionic liquids, from 0 to 100 °C (Chapter 4).
3. Its interconnected sheets conduct without a separate binder network, easing current collection.
4. Its mesopores let viscous electrolytes in, which is why it outperformed activated carbon in ionic liquid.

The concept: carbon-fibre (or, longer term, hemp-derived carbon-fibre) fabric coated with Mitlinitite as each electrode, separated by glass fabric, and infused with a bicontinuous epoxy–ionic-liquid or Hempoxies–ionic-liquid electrolyte. The first milestone is a coupon that keeps both measurable capacitance and a modulus above 10 GPa.

■ Technology map

Sorted from nearest to furthest, in the author's estimate. Every row is untested with Mitlinitite.

Technology	Composite (chapter)	What Mitlinitite contributes	Depends on	Horizon
Antistatic and conductive bio-plastic parts, 3D-printing filament	PLA, PP, PA6 (8)	Conductive network, char-forming flame retardance	Percolation below ~10 wt%	Near
Toughened adhesives, coatings and tooling resins	Epoxy (7)	Crack deflection and pinning	Dispersion at 0.1–0.5 wt%	Near
Lower-heat-release building and vehicle plastics	PP, HDPE (8)	Condensed-phase char layer	Loading vs. ductility	Near
Crack-resistant mortars and repair grouts	Cement (10)	Microcrack shielding (GO grade)	Mitlinitite–GO dispersion in mix water	Near–mid
Self-healing, recyclable panels	Hempoxies vitrimer (7)	Photothermal and Joule-heating trigger	Vitrimer chemistry at TRL 1–2	Mid
All-hemp vehicle and building panels	Hemp-oil epoxy + hemp fibre + Mitlinitite (7, 8)	Stiffness, conductivity, one-crop supply chain	Bio-epoxy stiffness gap	Mid
Self-lubricating bearings, wear parts	Al, bronze (9)	Solid lubricant	Carbide control	Mid
Self-sensing, self-de-icing concrete	Cement (10)	Piezoresistive, heatable network	Cost at several % dosage	Mid
EMI-shielding enclosures	Epoxy, PA6 (7, 8)	Conductive, absorbing network	Conductivity well above percolation	Mid
Sorbent composites for water and air filters	Polymer binders, membranes	High-area adsorbent (a use CQuest named)	Pore access through the binder	Mid
Stronger conductive copper	Cu (9)	Strengthening with ≥ 90% IACS	Metal decoration of sheets	Mid–long
Toughened non-oxide ceramics	Si ₃ N ₄ , SiC (10)	Grain wrapping, crack bridging	Clean, annealed grade	Mid–long
Structural supercapacitors	Fibre/epoxy–ionic liquid (this chapter)	Electrode surface and conduction	Structural electrolyte	Long

■ A regional opportunity

Proposed (Landry). Atlantic Canada combines a hemp-growing region, freeze–thaw infrastructure and a cold-weather energy problem. Three Mitlinitite products answer local needs: de-icing concrete for ramps and decks, hemp-based building panels, and cold-tolerant energy storage — the original paper's distinguishing result was operation down to 0 °C.

CHAPTER 12

VALIDATION ROADMAP: CHARACTERIZATION, TEST PLAN AND TRL LADDER

Moving Mitlinitite composites from concept to laboratory proof takes four gated phases, and the decisive gate comes early: whether a low-porosity structural grade can be made as sheets without KOH. Everything in Chapters 6–11 is TRL 2 today — a concept formulated, with speculative applications (ISED TRL scale). **Proposed (Landry).**



Figure 12.1 Four gated phases take Mitlinitite composites from TRL 2 to TRL 5. A phase starts only when the gate above it is passed; the highlighted gate is decisive. No dates are set.

Phases are sequenced, not dated; each one is funded only when the gate above it is passed.

■ What the TRL steps mean here

Canada's scale defines TRL 3 as analytical and experimental proof of concept, TRL 4 as validation in a laboratory environment, and TRL 5 as validation in a relevant environment (ISED). For Mitlinitite that translates to: TRL 3 once the grades exist and their key properties are measured; TRL 4 once coupon composites beat their benchmarks; TRL 5 once a demonstrator works under realistic loads, temperatures and humidity.

■ Test matrix

What to measure	Method	Why it matters
Surface area, pore size distribution	N ₂ adsorption (BET, DFT)	Grade identity; resin uptake
Sheet thickness, lateral size	TEM or AFM; laser diffraction after dispersion	Aspect ratio for every model in Chapter 6
Single-sheet modulus	AFM nanoindentation	The largest unknown in stiffness projections
Graphitic order	Raman IG/ID, XRD interlayer spacing	Conductivity and GO feedstock quality
Oxygen, nitrogen, potassium	XPS, ICP	Bonding, stoichiometry, metal and ceramic purity
Oxidation onset, ash	Thermogravimetric analysis in air	Processing window for melts, metals, ceramics
Epoxy fracture toughness	ASTM D5045	The first composite gate
Tensile and flexural properties of plastics	ASTM D638, ASTM D790	Stiffness and ductility trade-offs
Glass transition of composites	DMA per ASTM D7028	Stoichiometry effects of oxidized grades
Volume and surface resistivity	ASTM D257	Percolation threshold
Heat release	Cone calorimetry, ISO 5660	Flame-retardant claims in Chapter 8
Mortar compressive and flexural strength	ASTM C109, ASTM C348	Cement claims in Chapter 10
Dispersion quality	Optical microscopy, SEM fracture surfaces	Required with every mechanical result

■ Kill criteria

A theory is only useful if it can fail. **Proposed (Landry):** the programme changes course if...

- **Mitlinitite-S comes out as particles, not sheets.** Fall back to activated grades and accept the porosity penalty in resin systems.
- **Single-sheet modulus is below about 10 GPa.** Drop stiffness claims; pursue toughness, conductivity and fire behaviour.
- **Epoxy toughness gains stay under 10% at the best loading.** Revisit surface chemistry before any other matrix.
- **Mitlinitite-GO cannot be exfoliated to few-layer sheets.** Keep the Landry pathway as a route to oxidized fillers, not to GO.

■ Reporting standard

Every Mitlinitite result should state the grade, the full release-test datasheet from Chapter 3, the matrix and its cure or processing schedule, loading by weight *and* volume, dispersion method, and dispersion evidence. Results without these cannot be compared — the same failure the structural-supercapacitor review identified across its field.

SAFETY, SUSTAINABILITY, ECONOMICS AND INTELLECTUAL PROPERTY

Mitlinit's three biggest non-technical risks are dust inhalation during handling, the chemical footprint of KOH activation and Hummers oxidation, and a patent family that covers the material itself in the United States until 2034. None is a reason to stop; each must be planned for from Phase 0.

■ Worker safety

A 2018 review of graphene-based materials found inhalation to be the main and best-studied occupational route. Short animal studies showed lung inflammation and fibrosis, some of it not fully reversible after 90 days, and persistent particles in lung macrophages and lymph nodes. Well-dispersed graphene caused milder effects than aggregated graphene. The authors concluded that no occupational exposure limit can yet be set ([Pelin et al., RSC, 2018](#)).

Inferred for Mitlinit: treat dry powder as a graphene-family material of unknown toxicity — enclosed transfer, local exhaust ventilation, HEPA-filtered vacuums rather than sweeping, and respiratory protection during open handling. Once Mitlinit is locked inside a cured or solidified matrix the inhalation risk falls, but sanding, machining and recycling of composites release it again.

Process chemicals carry their own hazards: KOH melts generate corrosive metallic potassium vapour (Chapter 3), and permanganate in sulfuric acid can run away if added too fast (Chapter 5).

■ Regulatory status in Canada

Under the Canadian Environmental Protection Act, a nanomaterial not on the Domestic Substances List is a new substance and must be notified before manufacture or import. Environment and Climate Change Canada lists inorganic carbon, including graphene and fullerenes, among the classes for which particle-size data will generally be requested ([ECCC advisory note, 2014](#)). Whether Mitlinit needs notification depends on how it is identified against the List — a question for a regulatory specialist before any sale or import.

■ Sustainability

Inferred: Mitlinit's case rests on three points and carries two burdens.

- **For:** it upgrades a by-product (bast from grain-hemp stalks), avoids mined or synthetic graphite, and stores plant carbon in durable products for their service life.

- **Against:** KOH activation uses about one kilogram of KOH per kilogram of biochar in the published recipe, plus acid washes; Hummers-type oxidation consumes concentrated sulfuric acid and permanganate and produces manganese-bearing waste.

A cradle-to-gate life-cycle assessment, comparing Mitlinitite with graphite-derived GO and with carbon black, is a Phase 1 deliverable. Claims of "green graphene" should wait for it.

■ Economics

No peer-reviewed cost analysis of Mitlinitite exists. The figures in circulation are the inventor's press remarks — that the hemp carbon was about "1,000 times cheaper" than graphene ([NBC News, 2014](#)) — and a garbled per-tonne figure repeated across secondary sites. Treat them as indications, not data.

The cost drivers are clear even without numbers:

1. Decortication and bast logistics.
2. Autoclave time (24 h at 180 °C in the lab recipe).
3. KOH consumption, potassium recovery and corrosion-resistant furnaces.
4. Washing, drying and waste treatment.
5. Yield per tonne of bast — the number the patent does not report.

Composite-grade Mitlinitite (S and C) may cost less than electrode grade, because it can skip or reduce KOH activation.

■ Intellectual property

The University of Alberta holds US 9,478,365 B2 (granted October 2016, adjusted expiry November 2034) and its continuation US 10,170,251 B2 (expiry June 2034), with a Canadian application CA 2,851,434 A1; inventors are Mitlin, Wang, Xu, Li and Holt ([Google Patents](#)). Their claims cover a carbon nanosheet comprising carbonized crystalline cellulose — the material itself, not only its use in capacitors.

Inferred, not legal advice: a composite containing Mitlinitite made, sold or imported in the United States before expiry may fall within those claims. A freedom-to-operate review and, where needed, a licence from the University of Alberta should precede any commercial product. The author's own contributions — the composite architectures, the grades, and the Mitlinitite → GO → rGO pathway — may be protectable in their own right, subject to the prior art listed in Chapter 5. The name "Mitlinitite" could also be checked for trademark availability before commercial use.

OPEN QUESTIONS AND RESEARCH AGENDA

Mitlinites stand or fall on a handful of measurable questions, and the first three can be answered with one batch of material and standard laboratory equipment. This chapter lists them in the order they should be asked, then collects every proposition in the book that is the author's own.

Ten open questions, in order

1. **Can Mitlin's 2013 datasheet be reproduced** from today's Canadian bast fibre, and what is the mass yield per kilogram of fibre?
2. **What is the Young's modulus of a single Mitlinites sheet?** This one number decides whether stiffness is a realistic goal (Chapter 6).
3. **Does Mitlinites-S stay sheet-like without KOH?** The patent says the hydrothermal step makes the sheets; if so, a low-porosity structural grade is possible.
4. **What lateral size and aspect ratio survive dispersion** in hardener, melt and mix water?
5. **How much does a 0.1–0.5 wt% dose toughen epoxy**, and does porosity help through interlock or hurt through voids?
6. **Where does Mitlinites percolate** in epoxy and PLA, and how close does it come to the inferred 1–2 vol%?
7. **Can Mitlinites be oxidized and exfoliated to few-layer GO**, with what yield, C/O ratio and sheet size — and how conductive is the rGO?
8. **How much aluminium carbide forms** with Mitlinites under fast, low-temperature sintering?
9. **Does Mitlinites survive and help** in silicon nitride sintered under inert gas?
10. **What are its cradle-to-gate footprint and cost** per kilogram, by grade?

The author's propositions

Collected here so that each can be cited, tested and credited. All are **Proposed (Landry)** and untested as of October 2026.

No.	Proposition	Chapter
L1	The name Mitlinites for bast-templated, hydrothermally made hemp carbon nanosheets, with a formal working definition	1
L2	Four composite-oriented grades: E (electrode), S (structural), F (functional), C (conductive)	2
L3	Mitlinites as a unit operation on the bast stream of an integrated hemp biorefinery	3

No.	Proposition	Chapter
L4	The hemp → Mitlinitite → GO → rGO pathway, with Mitlinitite-GO and Mitlinitite-rGO as products	5
L5	Porous Mitlinitite as a toughener through resin interlock	6
L6	An all-hemp composite: hemp-oil resin, Mitlinitite filler, hemp fibre reinforcement	7
L7	Mitlinitite as the photothermal and Joule-heating trigger in Hempoxies vitrimers	7
L8	Mitlinitite-GO sizing on hemp fibre for natural-fibre composites	8
L9	Copper- or nickel-decorated Mitlinitite-GO for metal matrices	9
L10	Mitlinitite in cement as crack shield, internal-curing reservoir and carbon store; self-sensing and de-icing concrete; Mitlinitite-modified hempcrete	10
L11	Mitlinitite-coated fibre electrodes in an epoxy- or Hempoxies-ionic-liquid structural supercapacitor	11
L12	A gated validation roadmap with explicit kill criteria	12

■ How to take this forward

Proposed (Landry). The fastest credible route is a small, open programme: reproduce Mitlinitite (Phase 0), publish the datasheet and the single-sheet modulus openly, then run the epoxy toughness coupon. A positive Gate 3 result would be the first measured Mitlinitite composite anywhere — and the point at which this book stops being theory.

Natural partners include the patent holder, the University of Alberta, for licensing and know-how; Mitlin's group, now at the University of Texas at Austin; and any Canadian lab with spark plasma sintering, nanoindentation and BET capability.

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