

CLEAN RESOURCES FINAL REPORT PACKAGE

Project proponents are required to submit a Final Report Package, consisting of a Final Public Report and a Final Financial Report. These reports are to be provided under separate cover at the conclusion of projects for review and approval by Alberta Innovates (AI) Clean Resources Division. Proponents will use the two templates that follow to report key results and outcomes achieved during the project and financial details. The information requested in the templates should be considered the minimum necessary to meet AI reporting requirements; proponents are highly encouraged to include other information that may provide additional value, including more detailed appendices. Proponents must work with the AI Project Advisor during preparation of the Final Report Package to ensure submissions are of the highest possible quality and thus reduce the time and effort necessary to address issues that may emerge through the review and approval process.

Final Public Report

The Final Public Report shall outline what the project achieved and provide conclusions and recommendations for further research inquiry or technology development, together with an overview of the performance of the project in terms of process, output, outcomes and impact measures. The report must delineate all project knowledge and/or technology developed and must be in sufficient detail to permit readers to use or adapt the results for research and analysis purposes and to understand how conclusions were arrived at. It is incumbent upon the proponent to ensure that the Final Public Report **is free of any confidential information or intellectual property requiring protection**. The Final Public Report will be released by Alberta Innovates after the confidentiality period has expired as described in the Investment Agreement.

Final Financial Report

The Final Financial Report shall provide complete and accurate accounting of all project expenditures and contributions over the life of the project pertaining to Alberta Innovates, the proponent, and any project partners. The Final Financial Report will not be publicly released.

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CLEAN RESOURCES FINAL PUBLIC REPORT TEMPLATE

1. PROJECT INFORMATION:

Project Title:	Elemental Carbon Market Assessment – Joint Industry Project
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AI Project Advisor:	David Van Den Assem

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3. PROJECT PARTNERS

InnoTech Alberta gratefully acknowledges funding for this project from Alberta Innovates (Hydrogen Centre of Excellence), Natural Resources Canada (Energy Innovation Program), Ekona Power Inc., FortisBC Energy Inc., Universal Matter Inc., and six other participating organizations. InnoTech Alberta further acknowledges the donation of methane pyrolysis carbon samples from several technology developers.

A. EXECUTIVE SUMMARY

Methane pyrolysis is an emerging technology producing hydrogen and solid elemental carbon from natural gas with relatively low GHG emissions and energy intensity, without needing carbon capture, utilization, and storage (CCUS). Methane pyrolysis solid carbon products comprise a wide range of elemental carbon forms with various properties and market values. Technology developers and end users see the development of solid carbon applications as a key challenge and opportunity to improve the economic viability of methane pyrolysis.

The objective of this Joint Industry Project (JIP) was to identify applications, evaluate market potential, and assess technoeconomic feasibility for elemental carbon products produced by or derived from methane pyrolysis technologies to support further development, adoption, and deployment of methane pyrolysis.

A market study, technoeconomic analysis, and greenhouse gas (GHG) emissions analysis evaluated various hypothetical methane pyrolysis and carbon processing commercial projects in Alberta and British Columbia. The analysis included eight methane pyrolysis process variations each modelled at three production scales, in which the use of methane pyrolysis carbon was analyzed in 20 use case scenarios. The market results indicated that there are several large, growing markets in which methane pyrolysis carbon can conceivably be used. However, market constraints including volumes, growth, and product sale prices may present both challenges and opportunities for development of products derived from methane pyrolysis.

The economics of methane pyrolysis were found to be most favourable at larger nominal production capacities above 50 tonnes of hydrogen per day (TPD H₂). At production scales above 50 TPD H₂, several methane pyrolysis process variations are commercially viable based only on the sale of hydrogen. At production scales below 50 TPD H₂, methane pyrolysis carbon needs to be processed and sold in specialized applications to make commercial projects viable. However, at all production scales, it is necessary to include methane pyrolysis carbon in GHG emissions allocation for the hydrogen product to qualify for federal clean hydrogen investment tax credits in Canada. This implies that methane pyrolysis carbon must be used or sold (valorized) rather than treated as a waste product. A key regulatory risk is the lack of registered emission quantification protocols allowing methane pyrolysis process GHG emissions allocation to carbon co-products.

Use of “raw” unprocessed methane pyrolysis carbon was deemed economically viable and technically feasible as a partial substitute or additive in asphalt, metallurgical coke (metcoke) or petroleum coke (petcoke) for anodes, and low-grade carbon black. However, the properties of actual methane pyrolysis carbon samples analyzed in the JIP only partially met product specifications for metcoke and low-grade carbon black, suggesting that further optimization to methane pyrolysis processes or carbon processing post-pyrolysis are required to meet product specifications. The analysis assessed the following upgraded products and applications to be the most economically favourable and technically feasible using methane pyrolysis carbon as a feedstock:

- Polymer Masterbatch
- Boron and Titanium Carbides
- Activated Carbon
- Coated Spherical Purified Graphite (CSPG)
- Turbostratic Graphene

Proof of concept and pilot projects conducted outside of this JIP have demonstrated the use of methane pyrolysis carbon in asphalt, metcoke, and carbon fibre. However, successful use of methane pyrolysis carbon for all other promising applications identified by this JIP has not yet been demonstrated. Further technology development projects are recommended as next steps. The JIP results provided guidance on which specific product pathways and applications are most economically favourable and technically feasible using methane pyrolysis carbon as an input material.

B. INTRODUCTION

The clean hydrogen production segment of the overall hydrogen value chain is expanding as jurisdictions seek low-carbon energy carriers that can support industrial decarbonization, clean fuels, and energy storage. Within this sector, methane pyrolysis offers a compelling pathway because it produces hydrogen with inherently low greenhouse gas (GHG) emissions while avoiding the need for carbon capture, utilization, and storage (CCUS). However, its commercial viability is thought to depend strongly on creating value from the solid carbon co-product. Identifying technically feasible and economically attractive applications for this carbon helps transform what could be a disposal liability into a revenue-generating asset. Revenue generation from the carbon co-product improves overall project economics, broadens the range of viable production scales, and supports market confidence in methane pyrolysis as a competitive clean hydrogen technology.

Methane pyrolysis offers several opportunities compared to other hydrogen production methods. A [2022 University of Alberta study](#) found that methane pyrolysis has the second lowest GHG emissions intensity (4.5 kgCO_{2e}/kgH₂) relative to other methane-derived hydrogen production processes (though the methane decomposition reaction produces no CO₂ emissions itself). Although the emissions intensity of

hydrogen production by electrolysis powered by renewable energy is significantly lower than methane pyrolysis (nominally on the order of 1 kgCO_{2e}/kgH₂), its energy intensity is much higher at 51 kWh/kgH₂ as compared to a range of 5 – 20 kWh/kgH₂ for methane pyrolysis. Another key opportunity for methane pyrolysis is that the process does not require water – a crucial consideration in regions with scarce freshwater resources. Comparatively, methane reforming processes typically require ~ 5 kgH₂O/kgH₂ and electrolysis requires ~ 9 kgH₂O/kgH₂.

Perhaps the most compelling benefit of methane pyrolysis is its potential to significantly reduce the emissions intensity of both hydrogen and elemental carbon production compared to other processes. For example, the emissions intensity of producing synthetic graphite feedstock for battery manufacturing by incumbent processes [is estimated](#) to be 4.9 kgCO_{2e}/kg solid carbon. An ideal methane pyrolysis process producing 1 kg of hydrogen and 3 kg of synthetic graphite from 4 kg of natural gas could result in net emissions reduction of ~ 2.5 kgCO_{2e}/kg of total products. There could also be a significant economic opportunity for emissions reduction projects based on methane pyrolysis to generate and sell carbon credits when considering both hydrogen and elemental carbon production. A key knowledge gap addressed by this project was to analyze overall GHG emissions for combined methane pyrolysis and carbon processing commercial projects.

A [2020 Stantec study for COSIA](#) identified carbon black, nanofibers, and graphite as the primary forms of elemental carbon produced by methane pyrolysis. Prices for carbon products vary greatly by form (800-1,500 USD per tonne for carbon black, >100,000 USD per tonne for nanofibers, 7,000-20,000 USD per tonne for graphite). It is acknowledged that adding significant new supply of various carbon forms from methane pyrolysis would likely bring these prices down. In any case, existing application areas for carbon black include rubber products (95% of demand) and specialty pigments and electroconductive materials (5% of demand). Carbon nanofibers are currently used in advanced polymer composites, while graphite is used primarily in lithium-ion batteries according to the Stantec study. The study authors acknowledged the existence of many other pre-commercial, revenue-generating applications for solid carbon products, including use as additives in cement and asphalt, but did not assess these applications.

The key knowledge and technology gaps addressed by this project were to identify and assess the technoeconomic feasibility of the widest possible range of products and applications for methane pyrolysis carbon, which has not been done elsewhere. By assessing market potential and technoeconomic feasibility over a wide range of applications, this project contributed to improving methane pyrolysis project economics and supports adoption and deployment of methane pyrolysis for emissions reduction projects.

C. PROJECT DESCRIPTION

In this project, InnoTech Alberta aimed to generate knowledge about potential uses for methane pyrolysis carbon by identifying the widest possible range of products and applications, evaluating market potential,

characterizing the properties of actual methane pyrolysis carbon samples, and assessing technoeconomic feasibility and GHG emissions for a selected shortlist of promising products and applications. The original project objectives remained unchanged over the course of the project:

- Identify and characterize elemental carbon products of methane pyrolysis
- Develop preliminary business cases for selected applications through technoeconomic and GHG emissions analysis
- Improve the economic feasibility of methane pyrolysis

Table 1 lists the project-specific metrics that were used to measure the success of the project. At project completion, the target metrics included successful completion of all project deliverables, serving at least seven clients by executing the project, and identifying at least 10 viable products and applications for methane pyrolysis carbon. Target metrics for future commercialization of methane pyrolysis and associated carbon products and applications after project completion include further technology development of carbon products and applications identified by the project, serving at least 10 clients through further studies, applied research, testing, and technology development, and further developing up to five potential carbon products and applications following completion of the project.

Table 1: Project success metrics

Metric	Project Target	Commercialization / Mobilization Target	Comments (as needed)
Project deliverables	Completion of all project deliverables	Viable carbon applications are further developed in future projects	
Clients served	7	> 10	Completion of JIP leads to future projects with JIP members and additional companies.
Viable carbon application identification	10	5	JIP to evaluate technoeconomic feasibility of up to 10 carbon applications. It is expected that not all viable applications will be commercialized.

D. METHODOLOGY

1. SOLID CARBON MARKET STUDY & CONCEPTUAL FEASIBILITY ASSESSMENT

InnoTech conducted a review of public domain sources (e.g., market reports, academic publications, company websites, industry standards, product specifications) to identify product pathways and applications for methane pyrolysis (MP) carbon and incumbent competing products. Functional requirements and relevant physical properties of incumbent products were identified for a selected long list of products and applications of interest. Available market data (e.g., size, volume, compound annual growth rate – CAGR) for all identified products and applications were compiled and summarized. The market research analyzed six industries (manufacturing, construction, metallurgy, environmental, electronics, and advanced materials) including 52 specific applications served by 37 different carbon products.

InnoTech also reviewed and compiled information available in the public domain regarding the reported or claimed properties and forms of solid carbon produced by various methane pyrolysis technology developers.

An initial conceptual feasibility assessment was completed to match MP carbon products to relevant commercial products and applications. InnoTech also provided a qualitative appraisal of the difficulty and time required for MP carbon to be deployed commercially for a selected long list of potential products and applications.

2. METHANE PYROLYSIS CARBON SAMPLE CHARACTERIZATION

Five MP carbon samples were collected and characterized in lab analyses to establish typical ranges for key physical properties of interest, including:

- Identification and quantification of elemental carbon forms (e.g., amorphous carbon, graphitic carbon) and crystallinity by scanning electron microscopy with energy-dispersive x-ray spectroscopy (SEM-EDX), transmission electron microscopy (TEM), x-ray diffraction (XRD), and Raman spectroscopy,
- Particle size distribution by laser diffraction particle size analysis,
- Elemental composition by SEM-EDX, x-ray photoelectron spectroscopy (XPS), Fourier transform infrared (FTIR) spectroscopy, and thermogravimetric analysis (TGA),
- Surface area by the Brunauer-Emmett-Teller (BET) method, and
- Electrical conductivity by a modified version of the *ISO 10143:2019 – Calcined coke for electrodes* test method.

Full individual sample results were shared with their respective sample providers. Individual sample results were aggregated into property ranges in an anonymized summary reported to the project partners.

3. TECHNOECONOMIC ANALYSIS (TEA) AND EMISSIONS INTENSITY ANALYSIS

A comprehensive technoeconomic model was developed for the project in an Excel spreadsheet comprising the following main commercial project components:

- Methane pyrolysis,
- Carbon product upgrading & processing,
- Product delivery / shipping,
- Waste disposal, and
- Project GHG emissions.

Information was collected from the public domain to develop process steps, mass and energy balances, capital and operating expenses (CAPEX and OPEX), market volume forecasts, and product and waste

disposal pricing forecasts for the various methane pyrolysis and carbon product upgrading processes modelled in the TEA. Market volume constraints were imposed on the production scale of carbon products by assuming that production was limited to the capacity of the single largest facility globally for a given product or application. The production capacity of the single largest facility for a given product was assumed to grow according to that product's global compound annual growth rate (CAGR), allowing for larger production scales at later project start dates. Federal and provincial carbon tax implications were also included in the TEA. Cash flow analysis was done on earnings before tax (EBT) basis. Discount and inflation rates typical of this kind of analysis were assumed. The scope boundary of the life cycle analysis (LCA) for GHG emissions estimation included all activities associated with the methane pyrolysis and carbon upgrading processes, as well as feedstock, product, and waste transport. All identified Scope 1, 2, and 3 emissions were included in GHG emissions estimation. Identified Scope 3 emissions included transportation and disposal of catalysts, reagents, and waste. The model provided optionality to allocate GHG emissions on a mass, energy, or economic value basis.

The model was used to evaluate the technoeconomic feasibility of hypothetical commercial project scenarios comprised of methane pyrolysis plus carbon product upgrading. Each scenario was defined by combinations of conditions selected from the following options:

- Eight methane pyrolysis process types (microwave, catalytic, molten metal, three thermal subprocess types, and two plasma subprocess types),
- Three nominal hydrogen production scales (5 TPD H₂, 50 TPD H₂, 300 TPD H₂) corresponding to potential methane pyrolysis use cases envisioned by the project partners,
- Two commercial project jurisdictions (Alberta and British Columbia) with associated pricing forecasts for process inputs, waste disposal, and carbon tax, and
- 20 carbon product pathways, applications, or use scenarios, of which:
 - Four applications or uses did not employ a post-pyrolysis upgrading process, and
 - The remaining 16 product & application scenarios (including variations of similar products) employed post-pyrolysis upgrading processes.

The modelling considered scenarios in which some methane pyrolysis processes could directly produce specialized, high value elemental carbon forms such as graphene or carbon nanofibers or nanotubes. Production of these high value forms were modelled to represent claims by some methane pyrolysis technology developers. Purification processes were assumed to be required and were modelled for these specialized products. Production pathways in which a higher value form of carbon could conceivably be processed to a lower value carbon form or product were excluded from the analysis.

In total, 375 total commercial project scenarios were evaluated by technoeconomic analysis.

E. PROJECT RESULTS

1. SOLID CARBON MARKET STUDY & CONCEPTUAL FEASIBILITY ASSESSMENT

In a study on solid carbon product markets, InnoTech analyzed the market potential for methane pyrolysis (MP) carbon to be used in 52 specific applications served by 37 different carbon products across six industries (manufacturing, construction, metallurgy, environmental, electronics, and advanced materials). Table 2 lists the key findings from the market study for 11 selected products and applications in terms of global total addressable market (TAM) for MP carbon, the “value of carbon” in CAD / tonne of carbon [CAD/T], and CAGR. The “value of carbon” was intended to provide a qualitative indication of either the product’s nominal market sale price or the price at which it is assumed that solid carbon can be sold as an additive or substitute for other input materials. All results were aggregated and averaged over several sources of information available in the public domain. In general, products and applications with large TAM volumes for MP carbon (e.g., metcoke, cement production, carbides, hot mix asphalt) have relatively low values for solid carbon less than 1,000 CAD/T. Conversely, small TAM volume applications (e.g., graphite, graphene, carbon fibre, nanomaterials) correspond to relatively high values for solid carbon typically greater than 10,000 CAD/T. The single largest potential application for MP carbon was found to be for metcoke, with a global TAM volume for carbon of approximately 725 million tonnes per year (TPY).

Table 2: Market potential for selected solid carbon products and applications (indicative values averaged over multiple sources)

Product / Application	Global Total Addressable Market (TAM) for Solid Carbon from Methane Pyrolysis [million TPY]	Value of Carbon [CAD/T]	CAGR (%)
Metallurgical Coke	725	330	5
Cement / Concrete	100	260	5
Carbides (Various Types and Uses)	19	800	6
Hot Mix Asphalt	19	200	5
Carbon Black (Various Grades and Uses)	15	1,500	5
Activated Carbon (Various Types and Uses)	4	3,600	7
Coated Spherical Purified Graphite (CSPG)	0.5	9,000	9
Engineered Biochar	0.2	4,400	13
Carbon Fibre	0.2	45,000	11
Carbon Nanomaterials (e.g., Nanotubes)	0.008	150,000	15
Graphene	0.003	95,000	25

Since the use or sale of MP carbon has not been broadly commercialized as of this report, the use of MP carbon in the products and applications identified in the market study remains mostly speculative. As such, the conceptual role(s) or function(s) that MP carbon could fulfill in each identified product and application were assessed as shown in Table 3. This table also lists the “commercial deployment horizon,” a qualitative indication of the assessed technology and commercial readiness and degree of post-pyrolysis

processing (hence capital investment) required for MP carbon to meet specifications or requirements in each product or application. Table 4 lists descriptions of the three-point qualitative ranking scale used to assess the commercial deployment horizon.

Table 3: Conceptual role(s), function(s) and commercial deployment horizon for methane pyrolysis carbon in selected products and applications

Product / Application	Conceptual Role(s) / Function(s) of Methane Pyrolysis Carbon	Commercial Deployment Horizon
Metallurgical Coke	• Partial replacement of typical input materials • Reduced cost and carbon intensity of input materials	2
Cement / Concrete	• Partial replacement of input materials • Potential for improved performance	2
Carbides (Various)	• Partial or direct replacement of input materials • Reduced cost and carbon intensity of input materials	2
Hot Mix Asphalt	• Partial replacement of bitumen-based asphalt binder or more general asphalt additive • Reduced carbon intensity of input materials • Potential for improved performance	1
Carbon Black (Various Grades)	• Partial or direct replacement of carbon black produced by other processes	2
Activated Carbon (Various)	• Direct replacement of input materials	3
Engineered Biochar	• Partial replacement of input materials	3
Coated Spherical Purified Graphite (CSPG)	• Direct replacement of input materials • Reduced carbon intensity of input materials	3
Graphene	• Direct replacement of input materials	3

Product / Application	Conceptual Role(s) / Function(s) of Methane Pyrolysis Carbon	Commercial Deployment Horizon
Carbon Fibre	• Partial replacement of input materials • Reduced cost and carbon intensity of input materials • Potential for improved performance	3
Carbon Nanomaterials (e.g., Nanotubes)	• Direct replacement of input materials	3

Table 4: Description of commercial deployment horizon rating scale used in Table 3

Commercial Deployment Horizon (Qualitative Rating)	Description
1	High commercial deployment readiness potential (mid to high TRL and minimal post-pyrolysis carbon processing likely required)
2	Moderate commercial deployment readiness potential (mid TRL and / or some post-pyrolysis carbon processing likely required)
3	Low commercial deployment readiness potential (low to mid TRL and/or significant post-pyrolysis carbon processing likely required)

Although metcoke and cement production have the largest market volumes, they are assessed to have longer commercial deployment horizons than hot mix asphalt. In the case of metcoke, MP carbon samples characterized for this project revealed that sample properties only partially met specifications for anode-grade petroleum coke (as discussed in **2. Methane Pyrolysis Carbon Sample Characterization**), suggesting that post-pyrolysis processing of solid carbon would likely be required to meet specifications. As for cement, several studies ([Li et al., 2021](#); [Pacific Northwest National Laboratory, 2024](#); [Nikolis et al., 2025](#)) provide evidence that MP carbon could potentially improve some concrete properties (e.g., compressive strength) when used as a small fractional replacement of either fly ash (a cementing agent) or aggregate materials. However, any potential improvement may come as a tradeoff for reductions in other important properties. Further testing and technology development are required to demonstrate and optimize the use of methane pyrolysis in concrete beyond lab scale testing.

Use of MP carbon in hot mix asphalt was assessed to have the shortest commercial deployment horizon of all products and applications reviewed in the market study. One US-based methane pyrolysis technology developer has demonstrated this use case in [recent pilot scale asphalt paving test strip trials](#). It is also believed that using MP carbon in this application would require minimal post-pyrolysis processing.

2. METHANE PYROLYSIS CARBON SAMPLE CHARACTERIZATION

Five technology developers supplied MP carbon samples to the project for characterization analysis. Table 5 compares the aggregated, anonymized properties of the MP carbon samples to specifications for ASTM D1765 N990 Grade carbon black, anode-grade petroleum coke (petcoke), and CSPG. The results indicated that the specific MP carbon samples supplied to the project only partially met product specifications. This suggests that further post-pyrolysis solid carbon processing would likely be required to meet product specifications for these specific applications. However, it should be noted that the specific samples provided to the project represent only a snapshot in time in the development of each sample provider's methane pyrolysis technology. InnoTech Alberta believes that most or all sample providers have been continuously refining their respective processes to improve their solid carbon properties, and that there is generally a significant opportunity to adjust methane pyrolysis processes to optimize carbon product properties.

Table 5: Comparison of properties of methane pyrolysis carbon samples, carbon black, petcoke, and graphite (CSPG)

Property	JIP Carbon Samples	Carbon Black (ASTM D1765 N990)	Petcoke for Anodes	Graphite (CSPG)
Fixed Carbon Content	Avg.: > 85 wt.%	> 99 wt.%	> 95 wt.%	≥ 99.90–99.95 wt.%
Graphitic Carbon Content	Avg.: > 10 wt.%	--	--	≥ 99.90–99.95 wt.%
Impurities	Average values: Al: > 50 wppm Fe: > 50 wppm Na: > 100 wppm S: > 500 wppm	S: < 1 – 2 wt.% Ash: < 0.5 - 0.75 wt.%	Volatiles: < 8 – 15 wt.% Ash: < 1 wt.% Fe: < 300 wppm Na: < 100 wppm	S: < 100 – 500 wppm Ash: < 100 – 300 wppm Fe, Al, Si: < 50 wppm
Particle Size Distribution	Average value: 10 µm < d_{50} < 25 µm	0.1 wt.% < 45 µm 7 wt.% < 125 µm 10 wppm > 500 µm	15 wt.% < 250 µm	d_{50} : 10 – 25 µm
Surface Area	Avg.: > 10 m ² /g	0 – 10 m ² /g	--	1.5 – 4.0 m ² /g

Property	JIP Carbon Samples	Carbon Black (ASTM D1765 N990)	Petcoke for Anodes	Graphite (CSPG)
Electrical Conductivity	Avg.: < 20 S/m	--	--	> 1,700 – 2,500 S/m

3. TECHNOECONOMIC ANALYSIS (TEA) AND EMISSIONS INTENSITY ANALYSIS

Baseline Reference Scenarios – Methane Pyrolysis Only with No Solid Carbon Processing

Three uses for MP carbon were modelled as baseline reference cases in which solid carbon was assumed to be sold directly without post-pyrolysis upgrading / processing:

- The carbon stream was treated as a waste product and disposed to landfill (assumed nominal operating expense of 50 CAD / T of carbon),
- Solid carbon was sold as an input material to asphalt or cement production (assumed nominal sale price of approximately 200 CAD / T of carbon), and
- Solid carbon was sold as metcoke (assumed nominal sale price of approximately 800 CAD / T of carbon).

The purpose of modelling these reference cases was to understand the respective baseline contributions to overall commercial project economics from hydrogen and solid carbon production and sales before considering solid carbon processing and upgrading. Commercial projects based on selling MP carbon for asphalt or cement production were modelled in Alberta and British Columbia (BC), respectively, corresponding to the primary operating jurisdictions of the project partners.

Figure 1 shows the normalized internal rate of return (IRR) for methane pyrolysis commercial projects based on a microwave-powered process in which solid carbon was not further upgraded after pyrolysis (i.e., MP carbon was assumed to meet product specifications as produced from the MP process). Absolute IRR values were normalized relative to the group average. Projects for which normalized IRR values were below approximately 35% were deemed non-viable. The results indicated that methane pyrolysis commercial projects improved significantly as the nominal production scale increased from 5 TPD H₂ to 300 TPD H₂ due to economy of scale effects. The normalized IRRs for methane pyrolysis commercial projects at 5 TPD H₂ across all uses for solid carbon were found to be economically unfeasible. All methane pyrolysis commercial projects at 50 TPD H₂ and greater were deemed economically viable in both Alberta and BC, even in the case of treating the carbon stream as a waste product by disposal to landfill. Project IRRs were slightly better in BC compared to Alberta due to lower industrial electricity rates and a lower electric grid emission factor in BC. However, this assessment could change if the cash flow analysis were done on earnings after tax (EAT) basis. Selling MP carbon for use in asphalt or as metcoke only marginally improved project IRRs as the economics were dominated by sales of hydrogen and its forecasted sale price over the commercial project lifespan.

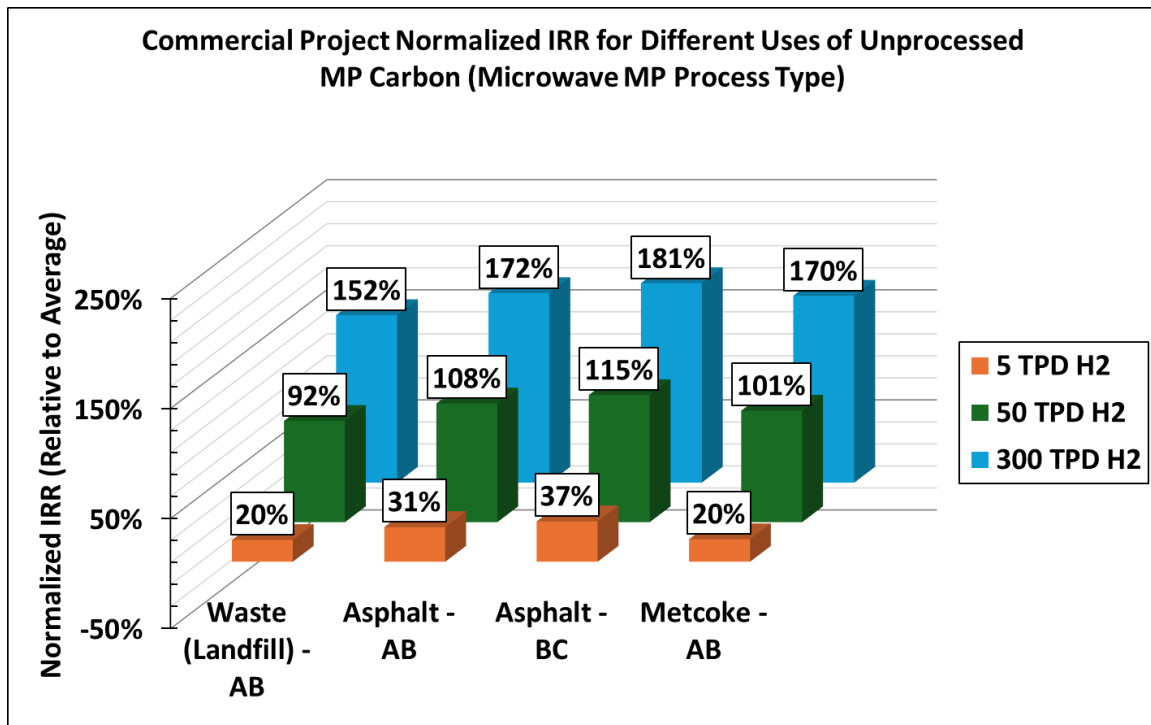


Figure 1: Methane pyrolysis commercial project economic viability for reference cases in which solid carbon was not processed post-pyrolysis

Although the sale of MP carbon was found to improve commercial project economics only marginally, InnoTech considers the use and sale of MP carbon sales to be critical to minimize the carbon intensity (CI) of methane pyrolysis commercial projects. Table 6 shows how the CI of commercial projects can vary substantially depending on whether MP carbon is valorized and included in CI calculations for commercial projects when GHG emissions are allocated on a mass basis. When MP carbon is treated as waste and sent to landfill, all GHG emissions associated with a commercial project are allocated to the hydrogen product. When MP carbon is valorized for non-combustion uses and included in CI calculations, InnoTech considers GHG emissions allocation on a mass basis to be the most appropriate allocation basis. The average CI was estimated to be 6.7 kg CO_{2e} / kg H₂ over all MP process types modelled. In this case, no MP commercial project met the Canadian Federal clean hydrogen investment tax credit (ITC) maximum CI threshold of 4.0 kg CO_{2e} / kg H₂. This means that commercial projects not selling MP carbon as product(s) are unlikely to be eligible for Federal clean hydrogen ITCs. However, when MP carbon is sold as a product, GHG emissions for a commercial project can conceptually be allocated to all products (H₂ and carbon). When MP carbon was included in the CI calculation on a mass basis, the average CI over all MP process types decreased to 1.5 kg CO_{2e} / kg H₂, well below the Federal clean hydrogen ITC maximum threshold.

Table 6: Average carbon intensity for all MP process types and two solid carbon uses (waste and asphalt) at nominal 50 TPD H₂ scale

Carbon Intensity (CI) Calculation Basis	CI [kg CO _{2e} / kg products]
MP Carbon Treated as Waste – GHGs Allocated to Hydrogen Product – Average CI for All MP Process Types at 50 TPD H ₂	6.7
Canada Federal Clean Hydrogen Investment Tax Credit (ITC) – Maximum Allowable CI	4.0
MP Carbon Sold for Asphalt or Cement Production – GHGs Allocated to Hydrogen and Carbon Products on a Mass Basis – Average CI for All MP Process Types at 50 TPD H ₂	1.5

An important caveat and risk to MP commercial projects is that InnoTech believes there are currently no registered emission quantification protocols allowing project GHG emissions to be attributed to MP carbon products in any Canadian jurisdiction. **A crucial next step will be for Federal, Provincial, and Territorial regulators to approve emission quantification protocols allowing MP commercial project GHG emissions to be allocated to MP carbon products if those products are valorized and not sent to landfill.** This will enable methane pyrolysis commercial projects to advance carbon credit claims, emission offsets, and be eligible for Federal ITCs.

Solid Carbon Upgrading Scenarios

The MP carbon characterization results discussed in 2. Methane Pyrolysis Carbon Sample Characterization suggested that MP carbon will likely require upgrading / processing post-pyrolysis for many applications of interest. This conclusion was also supported by information in the public domain regarding MP carbon properties. Capital expenses (CAPEX) in [CAD] and CAPEX intensity in [CAD / kg of carbon products] were modelled for 11 selected products and applications based on published or measured MP carbon properties and required process steps to produce various products.

Figure 2 shows the normalized CAPEX intensity for upgraded MP carbon products at a nominal 50 TPD H₂ scale. Absolute CAPEX intensity values were normalized relative to the group average. Significant variation in CAPEX intensities were observed from 2% relative to the group average for activated carbon to 323% relative to the group average for graphene. CAPEX intensity also tended to be lower for relatively high volume, mid to low value products (e.g., activated carbon, carbon black), and higher for relatively low volume, high value products (e.g., carbon nanotubes, graphene). In general, the CAPEX intensity results indicated that processing MP carbon to increasingly specialized, specified products requires greater capital investment.

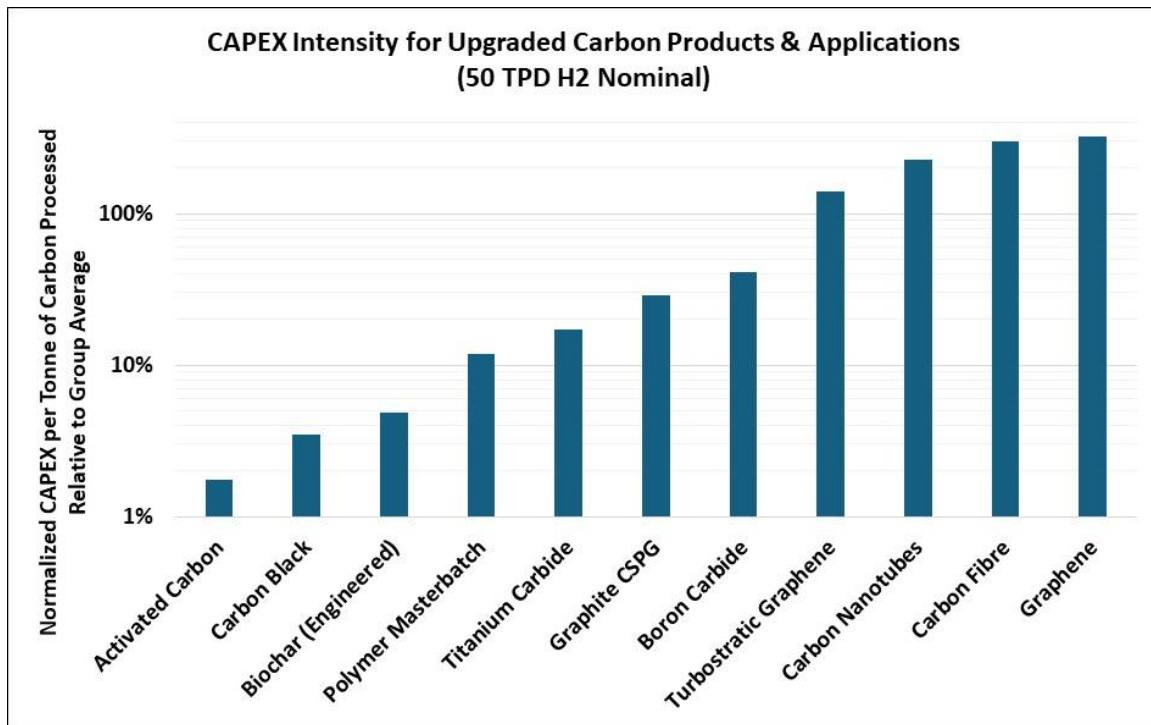


Figure 2: Normalized CAPEX intensity for upgraded MP carbon products at a nominal 50 TPD H₂ scale

Carbon upgrading commercial projects were first modelled on a standalone basis separate from methane pyrolysis in the technoeconomic analysis. This was done to understand:

- The economic viability of MP carbon upgrading in isolation because a carbon upgrading process is incremental to methane pyrolysis and can conceivably be paired with any methane pyrolysis process type that can supply the required form of solid carbon, and
- Respective contributions to overall commercial project economics from methane pyrolysis and carbon upgrading in later analysis.

The modelled economic viability of MP carbon upgrading commercial projects is summarized in Figure 3 to Figure 6. These figures show the results for the most viable products using amorphous carbon, carbon black, graphite, and various “specialty” carbon forms as feedstock. Each plot shows the normalized IRR values for carbon upgrading commercial projects on the vertical axis and the carbon feed rate to the upgrading process in tonnes per day [TPD] on the horizontal axis. Absolute project IRR values were normalized relative to the group average IRR value for all products shown in each plot. The balloon size for each data point represented the estimated CAPEX for each upgrading project relative to all other CAPEX values in the same plot.

A general trend observed for all results shown in Figure 3 to Figure 6 is that project IRR values decreased as the carbon feed rate increased. Products at lower carbon feed rates generally corresponded with smaller market volumes and higher sale prices. Conversely, products at higher carbon feed rates generally corresponded with larger market volumes and lower sale prices.

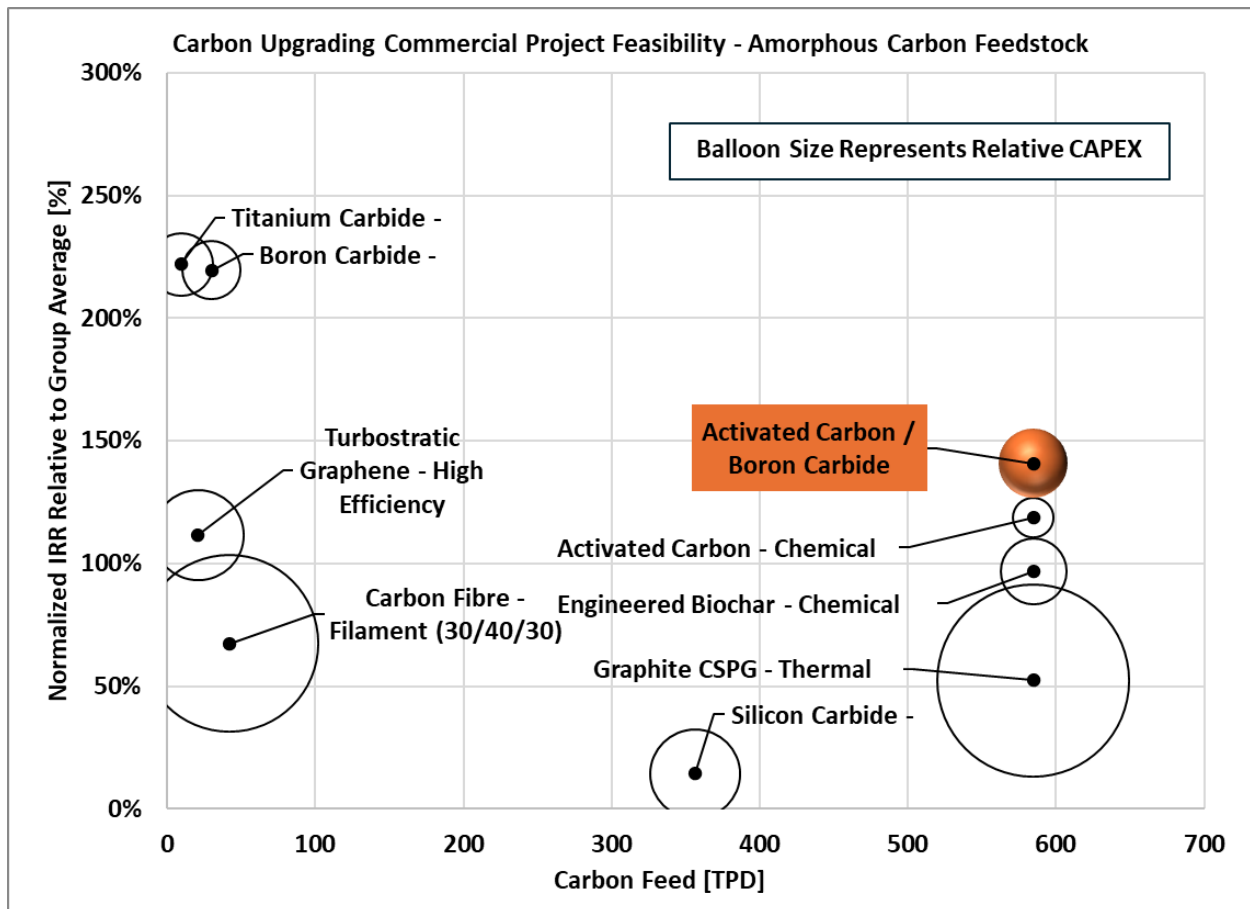


Figure 3: MP carbon upgrading commercial project viability starting from amorphous carbon feedstock

The results shown in Figure 3 indicated that titanium carbide, boron carbide, turbostratic graphene, and activated carbon were the most viable products starting from amorphous carbon feedstock. Amorphous carbon feedstock was assumed to be an unstructured carbon black-like material that does not meet specifications for any standard carbon black product grades. The most viable products also corresponded to smaller CAPEX values relative to less viable products. Considering that methane pyrolysis commercial project viability was found to increase significantly with production scale, and that hydrogen sales dominate project viability, identifying viable products with large market volumes (activated carbon, engineered biochar, CSPG) is important to enable large scale methane pyrolysis projects. A key finding based on the results shown in Figure 3 is that the IRR for a carbon upgrading project can be maximized by producing multiple carbon products at different production scales. The data point in Figure 3 labeled 'Activated Carbon / Boron Carbide' represents an optimal scenario maximizing the IRR at the largest production scale by producing both activated carbon at 555 TPD and boron carbide at 30 TPD from amorphous carbon. These products are deemed to have relatively low technical risk since amorphous carbon is often the most common form of carbon produced by methane pyrolysis.

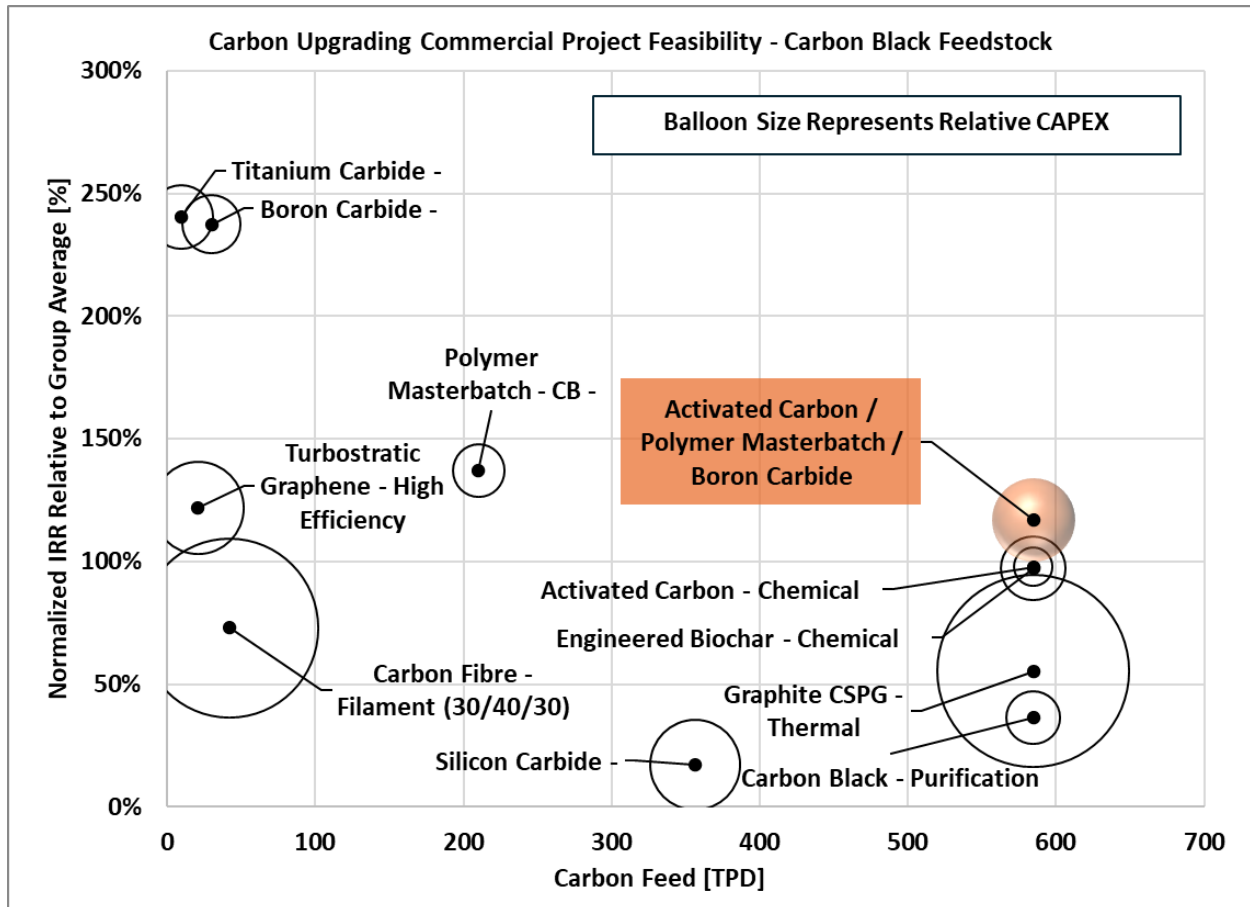


Figure 4: MP carbon upgrading commercial project viability starting from carbon black feedstock

The results shown in Figure 4 indicated that titanium carbide, boron carbide, turbostratic graphene, polymer masterbatch with carbon black (CB) additive, and activated carbon were the most viable products starting from carbon black feedstock. Carbon black feedstock was assumed to be a solid carbon material close to meeting a standard carbon black product grade (e.g., ASTM D1765 N990 grade). The maximum project IRR at the largest modelled production scale occurred for production of activated carbon at 374 TPD, polymer masterbatch with CB additive at 180 TPD, and boron carbide at 30 TPD. It is interesting to note that most products shown in Figure 4 resulted in more favourable project economics than simply purifying carbon black feedstock into a graded carbon black product.

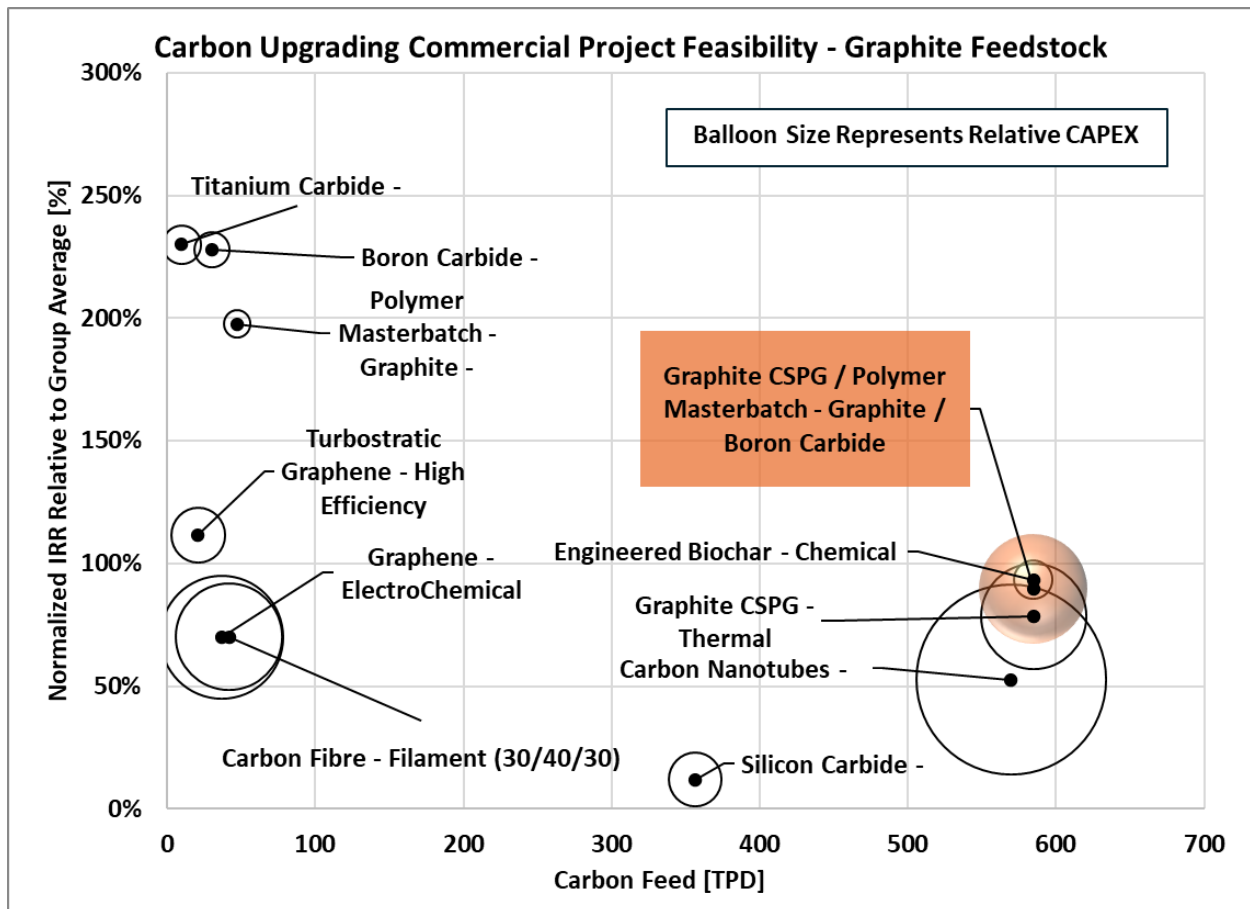


Figure 5: MP carbon upgrading commercial project viability starting from graphite feedstock

The results shown in Figure 5 indicated that titanium carbide, boron carbide, polymer masterbatch with graphite additive, turbostratic graphene, engineered biochar, and CSPG were the most viable products starting from graphite feedstock. The maximum project IRR at the largest modelled production scale occurred for production of CSPG at 537 TPD, boron carbide at 30 TPD, and polymer masterbatch with graphite additive at 17 TPD. Engineered biochar resulted in a higher IRR value than CSPG at the same production scale but was excluded from the “optimal” project scenario as it was deemed to pose a high technical feasibility risk. InnoTech Alberta believes that non-biological carbon sources have not been demonstrated as viable biochar substitutes. Another important technical feasibility risk for all methane pyrolysis and carbon upgrading commercial projects aiming to use graphite is believed to be the physical separation, recovery, and purification of graphite from any other carbon forms produced by methane pyrolysis.

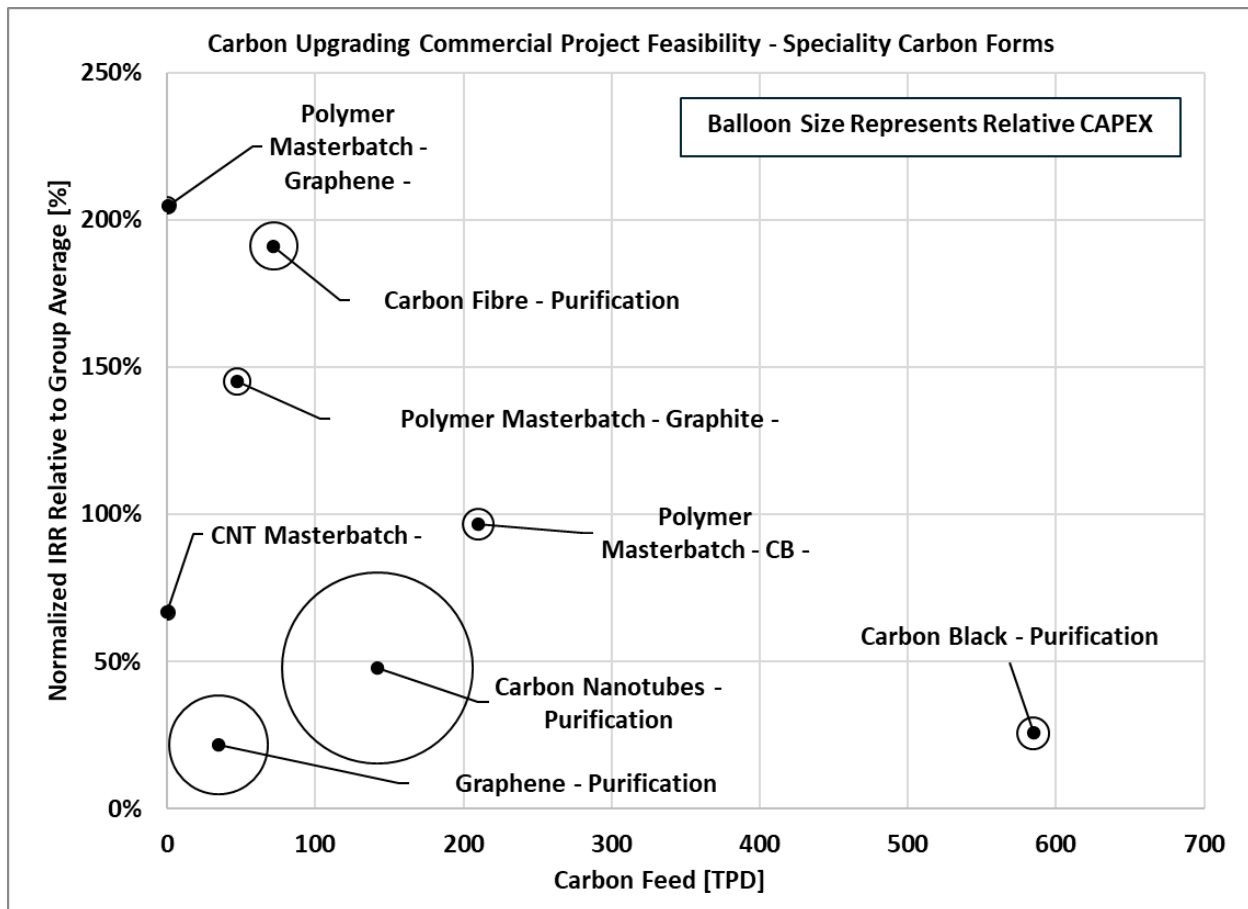


Figure 6: MP carbon upgrading commercial project viability starting from “specialty” carbon forms

The results shown in Figure 6 represented the most economically favourable carbon upgrading projects when purifying “specialty” carbon forms claimed to be made directly by some pre-commercial methane pyrolysis processes. The highest project IRR was modelled for polymer masterbatch with a graphene additive, but this product was severely limited to a production scale of 0.5 TPD. At the largest modelled production scale, purification of carbon black was identified as the only viable product.

Table 7 lists the three most viable upgraded carbon product pathways at each modelled production scale. The table lists normalized IRR and return on investment (ROI) values for the most viable individual products. Absolute IRR and ROI values were normalized relative to the group average value at each production scale. The model results indicated the following products to be the most economically promising and technically feasible products using methane pyrolysis carbon as a feedstock in post-pyrolysis upgrading:

- **Polymer Masterbatch**
- **Boron and Titanium Carbides**
- **Activated Carbon**
- **Graphite (CSPG)**

- **Turbostratic Graphene**

All these products can conceivably be produced starting from an amorphous carbon or carbon black feedstock, which are the most common forms produced by methane pyrolysis.

Table 7: Most viable upgraded carbon products at various MP production scales

Product / Application	H ₂ Prod. Scale [TPD]	Normalized Metrics	
		IRR (%)	ROI (%)
Polymer Masterbatch (Carbon Black)	300	128	109
Activated Carbon	300	120	95
Graphite CSPG	300	76	40
Boron or Titanium Carbides	50	179	218
Polymer Masterbatch (Graphite)	50	155	173
Graphite CSPG	50	104	92
Boron or Titanium Carbides	5	127	131
Polymer Masterbatch (Graphite)	5	69	63
Turbostratic Graphene	5	62	56

4. PROJECT SPECIFIC METRICS

Table 8 lists the project specific success metrics with actual outcomes at project completion. All project deliverables were completed as intended. The project exceeded its target to serve seven clients by serving a total of 12 clients through project delivery and by providing methane pyrolysis carbon sample characterization results to the sample providers. The project identified 11 viable carbon product types using methane pyrolysis carbon as a feedstock, which exceeded the project target of 10.

Table 8: Project success metrics with outcomes

Metric	Project Target	Commercialization / Mobilization Target	Comments (as needed)	Actual to Date
Project deliverables	Completion of all project deliverables	Viable carbon applications are further developed in future projects	All project deliverables completed	Complete
Clients served	7	> 10	Completion of JIP leads to future projects with JIP members and additional companies. Actual clients served to date include the JIP project partners and methane pyrolysis carbon sample providers.	12
Viable carbon application identification	10	5	JIP to evaluate technoeconomic feasibility of up to 10 carbon applications. It is expected that not all viable applications will be commercialized.	11

F. KEY LEARNINGS

Key learnings from the project include:

- Methane pyrolysis commercial projects are economically viable in Alberta and British Columbia at production scales of 50 TPD H₂ and greater. At lower production scales, carbon product sales are likely needed to make commercial projects viable
- Methane pyrolysis commercial projects are slightly more favourable in British Columbia (BC) compared to Alberta on earnings before tax (EBT) basis due to lower electricity rates and a lower grid emission factor in BC
- Methane pyrolysis commercial project economics are dominated by hydrogen pricing and sales
- Sale of unprocessed methane pyrolysis carbon marginally improves project economics
- In concept, the sale of methane pyrolysis carbon can significantly reduce the carbon intensity of methane pyrolysis projects by providing a justification for allocating project GHG emissions to the carbon products. However, there is currently no regulatory mechanism to allocate GHG emissions from methane pyrolysis projects to the solid carbon co-products

- Methane pyrolysis carbon products and applications that likely require minimal processing after pyrolysis include asphalt, cement, metallurgical coke, and potentially low-grade carbon black
- Using methane pyrolysis carbon products in high volume applications helps de-risk the viability of large-scale commercial projects
- There are at least 11 products and applications assessed to be economically viable for use of methane pyrolysis carbon
- Methane pyrolysis carbon properties need to be modified by refining the pyrolysis process itself and/or processing the carbon stream after pyrolysis to meet product specifications for most of the viable products and applications identified in the project
- The most economically promising and technically feasible products using methane pyrolysis carbon include polymer masterbatch, boron and titanium carbides, activated carbon, coated spherical purified graphite (CSPG), and turbostratic graphene
- Key risks, unknowns, and future challenges and opportunities include:
 - Technical – Separation, recovery, and purification of high value carbon forms produced by methane pyrolysis (e.g., graphite, nanomaterials)
 - Economic – Market constraints for small volume, high value carbon products
 - Economic – Market acceptance and incentives to use methane pyrolysis carbon in high volume, low value applications
 - Regulatory – Development and acceptance of emission quantification protocols allowing for GHG emissions allocation to carbon co-products

G. OUTCOMES AND IMPACTS

1. PROJECT OUTCOMES AND IMPACTS

The project outcomes have identified several viable products and applications for methane pyrolysis carbon. The findings provide guidance and a path forward to prioritize future carbon product technology development. Some of the project participants and funders have indicated interest in participating in future carbon product demonstration projects.

The project partners might use the technoeconomic model developed for the project to evaluate the feasibility of methane pyrolysis and carbon upgrading commercial projects for specific scenarios not evaluated in this project.

By highlighting key risks, unknowns, challenges, and opportunities arising from the project findings, economic and regulatory gaps can be closed through future technology demonstration projects, advocacy, life cycle analysis, emission quantification protocol development, and regulatory action.

2. CLEAN ENERGY METRICS

Table 9 lists the Clean Resources project target, commercialization target metrics for the project, and actual performance at project completion. All project target metrics were met or exceeded except for Practices informed / influenced.

Table 9: Clean Resources metrics

Metric	Project Target	Commercialization / Mobilization Target	Comments	Actual at Project Completion
Investment in 4 Core Strategic Technology Areas	Clean Technology	Clean Technology		Clean Technology
Future Capital Investment	0	\$100 MM	Commercialization Target: Project partners use the project results to inform capital investment decisions for methane pyrolysis projects and/or carbon product upgrading facilities.	0
Clients selling goods or services internationally	Yes	Yes	Two US-based companies were served on the project.	Yes
Clients selling goods or services domestically	Yes	Yes	--	Yes
Students Trained (M.Sc., Ph.D., Postdoc)	1	1	Project Target: InnoTech employed one MITACS-funded Postdoc who supported on project delivery. Two NAIT students contributed to the market research phase of the project.	3
Jobs: Projected new jobs created from future deployment	0	100	Project Target: The project contributed to justify the creation of one new FTE role.	1

Metric	Project Target	Commercialization / Mobilization Target	Comments	Actual at Project Completion
New products/services created	10	5	Project Target: The project results demonstrated technoeconomic feasibility for 11 carbon applications. One carbon characterization method was developed at InnoTech specifically for this project. Commercialization Target: It is likely that not all applications evaluated in the JIP will be commercialized.	12
Practices informed/influenced	20	5	Project Target: 10 carbon characterization analyses were used and evaluated. 3 carbon product specifications and quality testing protocols were identified. Commercialization Target: Only applications that are eventually commercialized are relevant for practices informed / influenced.	13
TRL advancement	1	3	The JIP was mostly limited to paper studies, but lab characterization of actual samples helped demonstrate properties and suitability of elemental carbon for various applications.	1
Publications	1	10	This Final Public Report constitutes a publication. Viable applications identified in the project will likely result in future studies and potential for additional publications.	1
Patents & Records of Invention filed	1	3	InnoTech Alberta may make patentable discoveries in the course of evaluating various carbon applications.	0

Metric	Project Target	Commercialization / Mobilization Target	Comments	Actual at Project Completion
GHG emissions: Projected reductions from future deployment (to 2030)	0	1.3 million tonnes	Commercialization Target: Assuming linearly increasing deployment of methane pyrolysis from 2024 to 2030, eventually reaching 1% of all hydrogen production in Alberta in 2030. Assuming 2.5 kgCO ₂ e emissions reduction per 1 kg of products relative to incumbent processes.	0

3. PROGRAM SPECIFIC METRICS

Table 10 lists one program specific metric for the project. Methane pyrolysis carbon upgrading commercial projects were estimated to offset or reduce the cost of hydrogen production by approximately \$2 / kg H₂ on average, which was below the project target of \$3 / kg H₂.

Table 10: Program specific metrics

Metric	Project Target	Commercialization / Mobilization Target	Comments (as needed)	Actual at Project Completion
\$ intensity cost reduction on production of H ₂	\$3 / kg H ₂	\$3 / kg H ₂	Assuming sale of 3 kg carbon / 1 kg H ₂ produced and \$1,000/T value of carbon (approximate value of low grade carbon black).	\$2 / kg H ₂

4. PROJECT OUTPUTS

The project was announced publicly in a [social media post](#) on InnoTech Alberta's LinkedIn account and in a [news story](#) on InnoTech Alberta's website.

H. BENEFITS

1. ECONOMIC

Project execution and delivery contributed to the creation of one full-time equivalent (FTE) position at InnoTech Alberta. The project results indicated technoeconomic feasibility and potential commercial

opportunities for up to 11 products and applications for methane pyrolysis carbon. At the largest modelled nominal production scale (300 TPD H₂ or 90,000 TPY H₂), a typical methane pyrolysis and carbon upgrading commercial project was estimated to create approximately 75 jobs. The project results demonstrated that using methane pyrolysis carbon in specific applications in the construction, manufacturing, petrochemical, environmental, and advanced materials sectors is economically viable and technically feasible.

2. ENVIRONMENTAL

The project did not result in direct or indirect GHG emissions reductions. However, the project results indicated the potential to reduce the carbon intensity of methane pyrolysis commercial projects by approximately 80% on average on a mass basis if methane pyrolysis carbon is sold as a commercial product rather than treated as a waste product and allocating GHG emissions to both the hydrogen and carbon products. At the largest modelled production scale (300 TPD H₂ or 90,000 TPY H₂), a hypothetical methane pyrolysis commercial project selling unprocessed solid carbon as a partial substitute for asphalt binder is estimated to result in direct GHG emissions reductions of approximately 256,000 TPY CO_{2e} relative to a selected baseline reference. The baseline reference is assumed to be hydrogen production from autothermal reforming with carbon capture and storage (ATR-CCS) and use of Alberta oil sands-derived bitumen as asphalt binder.

3. SOCIAL

The project results provide guidance to safeguard potential investments in methane pyrolysis commercial projects in Alberta by demonstrating economically viable product pathways for use of methane pyrolysis carbon. The results support large scale deployment of, and investment in, methane pyrolysis technology in Alberta.

4. BUILDING INNOVATION CAPACITY

The project employed one Postdoctoral fellow who supported in project execution, and two NAIT polytechnic students who supported in conducting market research for the project.

The project made use of several instruments owned by InnoTech Alberta for carbon sample characterization procured through capital grant funding from the Hydrogen Centre of Excellence. One new carbon sample characterization test (electrical conductivity for compressed powder materials) was developed at InnoTech Alberta for the project. Some carbon sample characterization tests were conducted using research infrastructure at the University of Calgary.

I. RECOMMENDATIONS AND NEXT STEPS

We make the following recommendations for support and development of methane pyrolysis commercial projects based on the project findings:

- Methane pyrolysis commercial project developers should maximize the scale of commercial projects to maximize economic benefits and return on investment,
- Methane pyrolysis commercial project developers should target asphalt, metallurgical / petroleum coke, and low-grade carbon black as initial markets for solid carbon because:
 - Valorizing solid carbon can reduce the carbon intensity of methane pyrolysis by a factor of $\sim 4x$ and may enable methane pyrolysis projects to qualify for clean hydrogen investment tax credits,
 - Solid carbon sold into these markets will likely require the least amount of post-pyrolysis processing (and associated investment), and
 - These applications have large addressable markets, which reduces risk for large scale methane pyrolysis projects by finding large potential offtakes for solid carbon.

Based on the project learnings, the following actions are recommended for further development of products and applications using methane pyrolysis carbon as a feedstock over the next two years:

- Lab and pilot scale demonstration projects using methane pyrolysis carbon as additives or substitutes in asphalt, cement, and metallurgical / petroleum coke,
- Testing methane pyrolysis carbon samples for their ability to meet ASTM D1765 and other product specifications for carbon black,
- Lab scale proof of concept and prototyping projects using methane pyrolysis carbon in the most economically promising products evaluated in the project: polymer masterbatch, carbides, activated carbon, coated spherical purified graphite (CSPG), and turbostratic graphene,
- Develop new emission quantification protocols for methane pyrolysis commercial projects in which emissions can be allocated to carbon products, or advocate for regulators to include such protocols in their registers if they have already been developed.
- Lab scale testing of various methods to physically separate, recover, and purify different forms of elemental carbon produced by methane pyrolysis.

InnoTech Alberta has developed several project concepts it intends to lead and has communicated the project concepts to Alberta Innovates, Natural Resources Canada (NRCan), the project partners, and other identified partners based on the findings and recommended actions.

J. KNOWLEDGE DISSEMINATION

The full, confidential results of the project were communicated to the project partners. Non-confidential knowledge gained from the project has been communicated in this Final Public Report and published by Alberta Innovates. The knowledge gained from the project is expected to guide development and investment in methane pyrolysis and solid carbon upgrading commercial projects.

K. CONCLUSIONS

The Elemental Carbon Market Assessment – Joint Industry Project (JIP) evaluated the feasibility of potential products and applications for elemental carbon produced by methane pyrolysis, an emerging hydrogen production technology. The objective of this JIP was to identify applications, evaluate market potential, and assess technoeconomic feasibility for elemental carbon products produced by or derived from methane pyrolysis technologies to support further development, adoption, and deployment of methane pyrolysis.

Key components of the project were:

- Market research on solid carbon products and applications,
- Lab characterization of methane pyrolysis samples to determine their properties and ability to meet various product specifications, and
- Technoeconomic and GHG emissions analysis for hypothetical methane pyrolysis and carbon upgrading commercial projects in Alberta and British Columbia.

Important findings and learnings from the project include:

- Methane pyrolysis commercial project economics improved as production scale increased and were most sensitive to hydrogen pricing and sales,
- 11 growing product and application areas for methane pyrolysis carbon were identified, of which:
 - Three to four potential applications and product pathways (asphalt, cement, metallurgical / petroleum coke, and low-grade carbon black) represent large offtake markets that may require minimal post-pyrolysis processing,
 - Seven to eight potential product pathways (carbides, activated carbon, engineered biochar, coated spherical purified graphite, graphene, carbon fibre, and carbon nanomaterials) represent small to medium-sized offtake markets with higher product values, but these will very likely require more significant post-pyrolysis processing,

- The properties of actual methane pyrolysis carbon samples analyzed in the JIP only partially met product specifications for metcoke and low-grade carbon black, suggesting that further optimization to methane pyrolysis processes or post-pyrolysis carbon processing are required to meet product specifications,
- The most economically viable and technically feasible product pathways for upgrading methane pyrolysis carbon included polymer masterbatch, boron and titanium carbides, activated carbon, graphite (CSPG), and turbostratic graphene.
- Key risks, unknowns, and future challenges and opportunities include:
 - Technical – Separation, recovery, and purification of high value carbon forms produced by methane pyrolysis (e.g., graphite, nanomaterials),
 - Economic – Market constraints for small volume, high value carbon products,
 - Economic – Market acceptance and incentives to use methane pyrolysis carbon in high volume, low value applications, and
 - Regulatory – Development and acceptance of emission quantification protocols allowing for GHG emissions attribution to carbon products.

The project resulted in the following outcomes and impacts:

- Several viable products and applications for methane pyrolysis carbon were identified,
- Several next steps and new project concepts have been identified and formulated based on the project findings,
- Some project funders and partners have indicated interest in participating in future carbon product demonstration projects.

The project generated knowledge that could lead to various economic, environmental, and social benefits if new methane pyrolysis and carbon upgrading commercial projects are developed in Alberta. Project delivery was supported by one Postdoctoral fellow and two NAIT polytechnic students.

Next steps and future projects include:

- Various lab and pilot scale demonstration projects using methane pyrolysis carbon in asphalt, cement, metallurgical / petroleum coke, carbon black, polymer masterbatch, carbides, activated carbon, and carbon fibre, and
- Development and acceptance of new emission quantification protocols for methane pyrolysis commercial projects in which emissions can be attributed to solid carbon products, thereby reducing overall commercial project emissions intensity on a total products basis.

L. APPENDIX A – MARKET RESEARCH SOURCES

This Appendix lists sources used to generate indicative market values provided in Table 2 in the report.

Activated Carbon (Various)

<https://www.globenewswire.com/news-release/2025/02/27/3033615/28124/en/Activated-Carbon-Global-Industry-Overview-2024-2030-Growing-Demand-in-Water-Treatment-and-Air-Purification-EPA-Regulations-Drive-Adoption.html>
<https://www.mordorintelligence.com/industry-reports/activated-carbon-market>
<https://www.fortunebusinessinsights.com/activated-carbon-market-102175>
<https://www.researchandmarkets.com/reports/4829813/activated-carbon-market-global-forecast-2025>
<https://www.precedenceresearch.com/activated-carbon-market>
<https://www.researchnester.com/reports/activated-carbon-market/4492>
<https://www.cognitivemarketresearch.com/activated-carbon-market-report>

Cement / Concrete

[Canada Cement Industry Report 2024: Output to Grow by 3.5% this Year - Portland Cement, Blended Cement, Specialty Cement, and Green Cement Forecasts to 2028 - ResearchAndMarkets.com | Business Wire cement-eng.pdf](#)
[Ready-Mix Concrete Manufacturing in Canada - Market Research Report \(2014-2029\)](#)
[Canada Precast Concrete Market Size & Outlook, 2030](#)
[Cement Market Size & Share, Growth Trends 2037](#)
[Cement Market Size, Growth, Industry Share, Trends, 2032](#)
[Global Cement Market Size To Worth USD 612.12 Billion By 2033 | CAGR Of 4.27%](#)
[Canada Production: Cement | Economic Indicators | CEIC](#)
[Portland Cement - Type 10 - 40 kg 100051652 | RONA](#)
[2025DufferinConcrete PriceList.indd](#)
[Western Price List - Canada Building Materials](#)
[Ready Mix Concrete Market Size & Industry Statistics | 2034](#)
[Ready-mix Concrete Market Size And Share Report, 2032](#)
[Ready-Mix Concrete Market Size, Share | Industry Outlook, 2032](#)
[Ready-Mix Concrete Market Size, Share, Analysis and Forecast by 2033](#)
[North America Ready-Mix Concrete Market Aims \\$65.44B Growth](#)
[North America Ready-Mix Concrete Market Poised for Robust](#)
[Precast Concrete Market Size, Share & Growth Report, 2030](#)
[Precast Concrete Market Size, Share | Global Report \[2032\]](#)
[Precast Concrete Market Size USD 266.76 Bn By 2033](#)
[Precast Concrete Market Size, Growth and Forecast by 2033](#)
[North America Precast Concrete Market to 2030 - By Size, Share, Growth by End User and Forecast | Business Market Insights](#)
[North America Precast Concrete Market Size & Outlook, 2030](#)
<https://www.mordorintelligence.com/industry-reports/cement-market>
[Experimental evaluation of using pyrolyzed carbon black derived from waste tires as additive towards sustainable concrete - ScienceDirect](#)
[Effect of carbon black on electrical curing of fresh concrete for cold regions - ScienceDirect](#)

<https://www.sid.ir/filesserver/je/103820170102.pdf>

[Experimental study of the simultaneous effect of nano-silica and nano-carbon black on permeability and mechanical properties of the concrete - ScienceDirect](#)

<https://finance.yahoo.com/news/portland-cement-market-report-2026-153000124.html>

<https://www.fortunebusinessinsights.com/portland-cement-market-112870>

<https://www.gminsights.com/industry-analysis/portland-cement-market>

<https://www.theinsightpartners.com/reports/portland-cement-market>

Carbides (Various)

<https://www.globenewswire.com/news-release/2022/05/03/2434786/0/en/Global-Tungsten-Market-to-Reach-115-Thousand-Metric-Tons-by-2026.html>

<https://www.mordorintelligence.com/industry-reports/calcium-carbide-market/market-size>

<https://www.astuteanalytics.com/industry-report/boron-carbide-market>

<https://www.sphericalinsights.com/reports/boron-carbide-market>

<https://www.precedenceresearch.com/titanium-powder-market>

<https://www.grandviewresearch.com/industry-analysis/silicon-carbide-fine-powder-market-report>

<https://www.giiresearch.com/report/smrc1617214-silicon-carbide-fine-powder-market-forecasts.html>

<https://www.factmr.com/report/chromium-carbide-market>

<https://xresearch.biz/shop/chromium-carbide-market>

<https://www.businessresearchinsights.com/market-reports/chromium-carbide-market-109115>

<https://www.giiresearch.com/report/ires1606338-chromium-carbide-market-by-form-amorphous.html>

<https://www.linkedin.com/pulse/tantalum-carbide-market-growth-analysis-o1i2e/>

<https://www.factmr.com/report/tantalum-carbide-coatings-for-graphite-market>

<https://www.persistencemarketresearch.com/market-research/tantalum-carbide-coating-for-graphite-market.asp>

<https://www.databridgemarketresearch.com/reports/global-tantalum-carbide-coating-for-graphite-market>

<https://www.factmr.com/report/niobium-carbide-market>

<https://www.businessresearchinsights.com/market-reports/niobium-carbide-market-101325>

<https://www.linkedin.com/pulse/global-vanadium-carbide-powders-market-e-commerce-ivbnf/>

<https://www.coherentmarketinsights.com/industry-reports/tungsten-carbide-market>

<https://www.fortunebusinessinsights.com/industry-reports/calcium-carbide-market-101580>

[https://www.marketresearchfuture.com/reports/silicon-carbide-powder-market-26025#:~:text=Silicon%20Carbide%20Powder%20Market%20Overview,\(USD%20Billion\)%20by%202032.Silicon Carbide Fine Powder Market Size, Share Report 2030](https://www.marketresearchfuture.com/reports/silicon-carbide-powder-market-26025#:~:text=Silicon%20Carbide%20Powder%20Market%20Overview,(USD%20Billion)%20by%202032.Silicon Carbide Fine Powder Market Size, Share Report 2030)

<https://www.strategymrc.com/report/silicon-carbide-fine-powder-market>

Carbon Black (Various)

<https://www.globalsources.com/Carbon-black/carbon-black-1214793916p.htm?source=Related Prod from Verified Supp>

https://www.globalsources.com/product/carbon-black_1183126115f.htm
<https://www.asbury.com/shop-now/products/carbon-black/>
<https://www.persistencemarketresearch.com/market-research/carbon-black-market.asp>
<https://finance.yahoo.com/news/carbon-black-market-size-cross-130500196.html>
<https://www.chemanalyst.com/industry-report/carbon-black-market-440>
<https://www.cervicornconsulting.com/carbon-black-market>
<https://www.fortunebusinessinsights.com/industry-reports/carbon-black-market-101718>
<https://www.mordorintelligence.com/industry-reports/carbon-black-market>

Carbon Fibre

<https://www.mordorintelligence.com/industry-reports/carbon-fiber-market>
<https://www.precedenceresearch.com/carbon-fiber-market>
<https://www.globenewswire.com/news-release/2026/02/05/3232786/0/en/Global-Demand-for-Carbon-Fiber-Continues-to-Rise.html>
<https://www.grandviewresearch.com/industry-analysis/carbon-fiber-market-analysis>
<https://www.fortunebusinessinsights.com/industry-reports/carbon-fiber-market-101719>
<https://www.bccresearch.com/market-research/advanced-materials/carbon-fiber-market.html>
<https://www.rootsanalysis.com/carbon-fiber-market>

Carbon Nanomaterials (Various)

<https://www.fortunebusinessinsights.com/carbon-nanotubes-cnt-market-102700>
<https://www.mordorintelligence.com/industry-reports/carbon-nanotubes-market>
<https://www.precedenceresearch.com/carbon-nanotubes-market>
<https://www.grandviewresearch.com/industry-analysis/carbon-nanotubes-cnt-market>
<https://www.researchandmarkets.com/reports/5939207/carbon-nanotube-global-market-report>
<https://finance.yahoo.com/news/carbon-nanotube-cnt-market-reach-155700594.html>

Coated Spherical Purified Graphite (CSPG)

<https://www.globenewswire.com/news-release/2025/10/07/3162274/0/en/Global-Graphite-Market-2026-2036-Graphite-Demand-is-Projected-to-Rise-310-by-2036-with-Battery-Anodes-Growing-from-28-of-Consumption-in-2024-to-62-by-2036.html>
<https://www.futuremarketsinc.com/the-global-graphite-market-2026-2036/>
<https://www.marketgrowthreports.com/market-reports/spherical-graphite-market-103408>
<https://www.marketresearchfuture.com/reports/spherical-graphite-market-38257>

Graphene

<https://www.fortunebusinessinsights.com/graphene-market-102930>
<https://www.idtechex.com/de/research-article/the-graphene-market-to-reach-3-800-tonnes-per-year-in-2026/9213>
<https://www.precedenceresearch.com/graphene-market>

<https://www.mordorintelligence.com/industry-reports/graphene-market>

Engineered Biochar

<https://www.fortunebusinessinsights.com/industry-reports/biochar-market-100750>

<https://www.persistencemarketresearch.com/market-research/biochar-market.asp>

<https://finance.yahoo.com/news/latest-global-biochar-market-size-194800094.html>

<https://www.grandviewresearch.com/industry-analysis/biochar-market>

<https://www.precedenceresearch.com/biochar-market>

<https://www.transparencymarketresearch.com/biochar-market.html>

Hot Mix Asphalt

<https://www.freedoniagroup.com/industry-study/global-asphalt-bitumen>

<https://www.precisionbusinessinsights.com/market-reports/asphalt-market>

<https://straitsresearch.com/report/asphalt-market>

<https://homeguide.com/costs/asphalt-prices>

<https://www.asphaltcalculators.org/blog/comprehensive-asphalt-2026/>

Metallurgical Coke

<https://discoveryalert.com.au/global-metallurgical-coke-market-outlook-2025/>

<https://www.researchandmarkets.com/reports/5766572/metallurgical-coke-market-report>

<https://businessanalytiq.com/procurementanalytics/index/coke-of-coal-price-index/>

<https://www.metal.com/coke>

<https://www.globalbankingandfinance.com/metallurgical-coke-market-to-reach-325-78-billion-by-2034-driven-by-steel-and-industrial-growth>

<https://www.mordorintelligence.com/industry-reports/metallurgical-coke-market>

<https://www.fortunebusinessinsights.com/industry-reports/metallurgical-coke-market-101347>

<https://www.thebusinessresearchcompany.com/report/metallurgical-coke-global-market-report>