Canadian Carbonization Research Association

2021-2022 Annual Report
(April 1, 2021-March 31, 2022)

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The Canadian Carbonization Research Association (CCRA) was formed on September 2, 1965 – providing over 57 years of Research supporting the Canadian Coal and Carbonization Industries

CCRA
Canadian Carbonization Research Association

CHAIRMAN'S REMARKS

Since its inception in 1965, the Canadian Carbonization Research Association (CCRA) has provided an excellent framework for technical/technological cooperation between government and industry, which has been very successful for both parties. The CCRA is a unique organization in being Canada's only technical support for the Canadian metallurgical coal and coking industries. This organization continues to be of real value to its member companies and to the financial health of the associated industries. The value of its research is becoming more recognized and appreciated on a global basis.

The role of the CCRA is to strive to meet its members' needs. Its technical research program continues to evolve constantly as the demands of the coal, cokemaking and ironmaking industry change with the issues facing Canada. With new members arise more ideas leading to potential solutions for technical challenges facing the coal and steel industries. It is important to continue sharing our research findings with fellow researchers and industry. The CCRA has again published its work in several international journals and presented papers at both domestic and international conferences.

However, it must be recognized that the world is changing. GHG reduction in heavy industries such as steel, cement and limestone are becoming a major focal point. It has been announced that two of the three integrated steel companies in Canada are aiming for >60% GHG reduction with the transformation from traditional cokemaking, ironmaking and BOF steelmaking to EAF technology by 2030. These EAF's will be fed with either direct reduced iron or scrap. This still leaves GHG technical challenges for the remaining blast furnace that will be in operation for a few more years. However, in all cases, carbon capture and either sequestration or utilization will require further R&D initiatives.

Overall, CCRA must be visionaries during this transformational change period and prepare for the future. The Canadian Steel Producers Association (CSPA) see the CCRA as a technical leader in research and implementation of solutions for their members going forward. CCRA has a long history and successful collaboration with CanmetENERGY-Ottawa in technology development. This collaboration will continue and extend to other Canmet Laboratories at NRCan (CanmetENERGY-Ottawa, CanmetENERGY-Varennes and CanmetMATERIALS-Hamilton) to work on the broader scope of technology transformation and implementation for coal producers, steel producers, and other heavy industries. There are numerous scientific experts working at CanmetENERGY on decarbonization and these resources will be relied upon to further the CCRA R&D program.

The CCRA program continues to be updated to meet the current and future challenges. It must be noted that the CCRA will continue to support the very important coal and cokemaking sector in Canada. But CCRA has also recognized that the R&D program must also include GHG reduction for its members and other heavy industries. This aligns with Federal Government policy and direction.

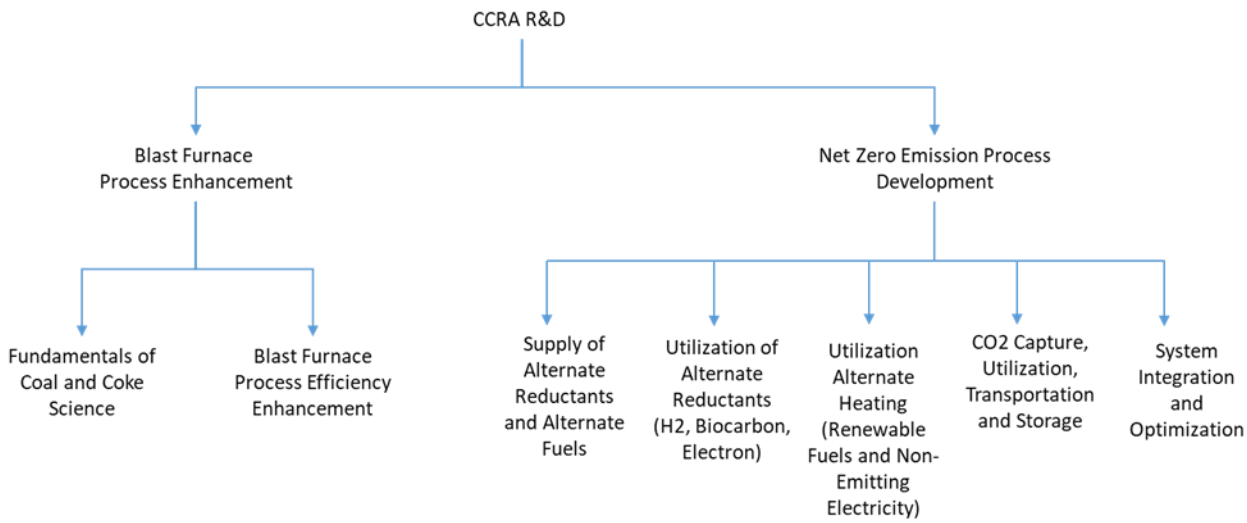
The Net Zero Emission Process Development program was added to the existing Blast Furnace process enhancement program. The new CCRA program will consist of the following:

Blast furnace process enhancement

- Fundamentals of coal science
- Blast furnace carbon efficient enhancement

Net Zero Emission Process Development

- Supply of Alternate Reductants and Alternative Fuels
- Utilization of Alternative Reductants (Biocarbon, H2, Electrons)
- Utilization of Alternate Heating (Renewable Fuels and Non-Emitting Electricity)
- CO2 Capture, Utilization , Transportation and Storage
- System Integration and Optimization



The CCRA will continue to advance technologies that will support our members GHG reduction initiatives now and in the future. We look forward to these new technical challenges and develop new partnerships as we transform our program. It is important to include other industries facing similar GHG reduction goals. Co-operation is key and CCRA will be active in including these partners.

Globally, the Canadian Carbonization Research Association is autonomous in its ability to continue to expand and meet its members' requirements. This remarkable co-operative relationship between the coal industry, steel industry and government is truly unique, and the CCRA R&D technical program will strive to address and reflect its members needs for years to come.

Ted Todoschuk

Ted Todoschuk,
Chairman, Board of Directors

TECHNICAL COMMITTEE REPORT

TECHNICAL COMMITTEE MEETINGS

The CCRA Technical Committee held four meetings during Fiscal Year 2020-2021:

Meeting No.	Location	Date
255	Virtual	June 15-16, 2021
256	Virtual	September 28-29, 2021
257	Virtual	January 25-26, 2022
258	Virtual	March 29-30, 2022

The 2021-22 Research Program consisted of four main research areas:

1. Fundamentals of Coal Science
2. Blast Furnace Ironmaking Process Carbon Efficiency Enhancement
3. Substitution of Fossil Carbon by Renewable Biocarbon in Pyrometallurgical Processes
4. Carbon Neutral Ironmaking Technology Development

In total, 10 projects were part of the active Research Program.

Major Accomplishments/Highlights:

Publications:

During FY 2021-22, CCRA published 1 paper in peer reviewed. Because of the uncertainty on travel, no papers were presented in international conferences.

- Interaction Behavior of Biogenic Material with Electric Arc Furnace Slag, Fuels 2021, 2(4), 420-436; https://doi.org/10.3390/fuels2040024

1. Research Program: Fundamentals of Coal Science

CCRA 54: ISO and ASTM Coal and Coke Standards

The study on effect of particle size on rheology measurement for both Appalachian and Western Canadian coal samples was completed (*CCRA Report: Coal Rheology – Effect of Coal Origin, Rank and Particle Size*). It was observed that:

- Similar to the Appalachian coals, the %-140 sieve material did show lower fluidity values for WCC's, but the fluidity temperature range was less influenced by grain size. Fluidity temperature range is an improved indicator of WCC caking properties than actual ddpm's.
- Similar to the Appalachian coals, particle size <140 sieve starts to have lower dilatation, but the temperature range was not so impacted for these finer particles. Dilatation temperature range (T3-T1) is an improved indicator of WCC caking properties than %dilatation. This is most important for coals that only contract.

This information will be shared with ASTM D05 so that:

- Temperature range should be identified as a key indicator in reporting results for both the gieseler and dilatometer.
- The recommended particle size for the gieseler is -40+140 sieve.
- The recommended particle size for the dilatometer is -60+140 sieve.

A draft paper was completed for publication in 2022

CCRA 90: Exploration Sample Assessment for Current and New Coal Mines in Canada

The project was reorganized, and activities were categorized in three parts.

- Effect of clean coal composition preparation by float/sink with organic liquid:

  Float/sink with organic liquid is a standard technology used by the coal industry in preparation of clean coal composite samples for coal property evaluation. It was observed that the organic liquid affects the thermal rheology properties of the clean coal composite. It may lead to an underestimation of the coking potential of the sample (*Fuel Processing Technology 2017: Effects of organic liquids on coking properties of a higher-inert Western Canadian Coal*).

  It is also proposed that the organic liquid may also affects the grindability of the samples prepared by float/sink with organic liquid. Detail experimental plan is under development.

- Development of clean coal composition preparation by water base Robin Jig technology:

  Because of the known influence of organic liquid on clean coal composition properties, it was proposed to prepare coal samples for evaluation by using a new water-based Robin Jig technology. A Robin Jig was successfully implemented for evaluation of performance in clean coal composite preparation. The properties of samples prepared by the Robin Jig were compared with the one prepared by conventional organic liquid flow/sink. Small scale and pilot scale carbonization of the prepared samples were conducted to compare the coking performance and the coke quality evaluated.

  It was concluded that the Robin Jig technology is capable to replace the organic liquid float/sink

technology for clean coal composite sample preparation. Further development of the Robin Jig technology is still undergoing. It is to ensure the technology is applicable to different type of raw coal samples.

- Alternate liquid for float/sink washability study:

  Besides preparing clean coal composite samples for property evaluation, the organic liquid float/sink also provides information in wash plant design. This functionality cannot be replaced by the Robin Jig. Therefore, organic float/sink is still needed. However, the organic liquid is potentially hazardous and imposes risk to the health and safety of the operator. In order to better protect the operator, it is necessary to identify alternate liquid for float/sink analysis.

  After extensive review, the 3M FC-770 and Novec 7700 were identified as potential candidates. A series of studies were conducted to compare the performance of the Novec 7700 in float/sink analysis. Clean coal composite samples prepared by conventional organic liquid float/sink, by Novec 7700 float/sink and by the Robin Jig were compared. The samples were also carbonized using the Canmet SHO for comparison of resultant coke properties. It was observed that there were no difference in both coal and resultant coke properties. It was concluded that the Novec 7700 was potentially suitable for replacing the hazardous organic liquid for float/sink analysis. Further study on the performance of Novec 7700 is currently undergoing.

CCRA 81: Mineral Matters in Western Canadian Coal

An analytical technique for the characterization of minerals in both coal and coke was developed. The technique involves XRD analysis of the sample followed by MLA analysis. The technique was applied to three selected coal samples as well as the three corresponding coke samples. These three particular samples were chosen because of the CSR prediction based on coal properties did not align with the actual measured CSR. It was originally believed that the discrepancy could be explained by unexpected mineralogy.

Analysis results revealed that the transformation of mineral during coking was a complex process. Moreover, it was observed that a significant amount of minerals converted from crystalline state to amorphous state during the coking process. It was hypothesized that the amorphous minerals in coke was formed by the fusion of minerals during coking similar to slagging. It is generally believed that minerals in the amorphous phase are less detrimental to coke reactivity in comparison to minerals in the crystalline phase. Therefore, the distribution of elements between the crystalline and amorphous phase is expected determining the reactivity of the resultant coke.

Because of the data available is still very limited, it is not sufficient to validate the above-mentioned hypothesis. In order to further understand the effect of mineralogy on resultant coke properties, more coal and corresponding coke samples will be collected and analyzed in next fiscal year.

CCRA 80: Characterization of Coal Washing Plant Streams and Product Quality Upgrade

No activity was conducted in FY 2021-22.

CCRA 86: Performance of Canadian Coals in High Inert Blends

No activity was conducted in FY 2021-22.

CCRA 87: Technical Merits of Western Canadian Coals

The automatic Sapozhnikov plastometer in Canmet was successfully commissioned in last fiscal year. The parameters measured by the Sapozhnikov plastometer, especially the maximum plastic layer thickness (Y-value), is generally believed to indicate the coking potential of a given coal sample. It was demonstrated in the previous work that the Y-value is actually related to the melting range of coal measured in Gieseler plastometer. Since the melting range of Western Canadian Coals are generally lower than Appalachian coals, the Y-value of WCC is also generally lower than Appalachian coal. Therefore, the Sapozhnikov plastometer is very often underestimates the coking potential of WCC. The situation is very similar to the discrimination of WCC due to its relative low fluidity. In order to demonstrate the technical merit of WCC, collection of Sapozhnikov parameters data and coke quality data is currently underway.

CCRA 93: Performance of Western Canadian Coal in Stamp Charge

No activity was conducted in FY 2021-22.

2. Research Program: Blast Furnace Ironmaking Process Carbon Efficiency Enhancement

CCRA 91: Blast Furnace Energy Reduction Initiatives using Auxiliary Fuel Injection

No activity was conducted in FY 2021-22

CCRA 82: Factors Affecting Coke Bed Permeability

The analysis of coke size and shape change was completed (CCRA 82:001/2021 Effect of Coal Blend Composition on Resultant Coke Size and Shape Characteristics and Degradation Behavior). It was observed that the incorporation of WCC into the coal blend appears to reduce the mean coke size as determined by sieve analysis. The equivalent diameter, which determines the permeability of a coke bed, is almost identical with and without WCC in the coal blend. The issue is that sieve analysis ignores the length of the coke particle. The coke particle produced from the blend containing WCC is slightly elongated, and sieve analysis underestimates the actual size. Furthermore, with sufficient stabilization, both the shape and size of coke particle between the two-coal blend examined are almost identical.

In order to further validate the observed phenomenon, another set of coke samples originating from coal blends with and without WCC was prepared. Similar analysis will be conducted in the current fiscal year.

CCRA 77: Energy Recovery Cokemaking Technology

It was decided by the CanmetENERGY-Ottawa management to end the ERCO construction project. CCRA members were informed of the decision in November. The decision was based on the considerations including the need for this technology development research in the Canadian context and the risk of further technical challenges in construction and operating the oven. It was estimated the total expenditure of the project was $4,020K including $620K CCRA contribution.

CCRA 84: Coke Degradation Mechanisms

No activity was conducted in FY 2021-22

CCRA 94: High Temperature Properties of Coke

No activity was conducted in FY 2021-22

3. Research Program: Substitution of Fossil Carbon by Renewable Biocarbon in Pyrometallurgy Processes

CCRA 70A: Raw materials, Pyrolysis Technology and Transportation

Canada proposed to ISO/TC238 (Solid Biochar) to include metallurgical processes and the proposal was accepted. A task group was formed, and the mandate of this task group was to map global market needs for new or expanded standards on solid biofuels and bioreductants for the iron and steel sector and assess whether ISO/TC238 is the most suitable technical committee to undertake this work. A report will be presented to TC238 for further discussions and decisions on how to proceed.

The Bioenergy group of CanmetENERGY has successfully commissioning the continuous screw reactor for studying slow pyrolysis. Besides producing solid biocarbon by slow pyrolysis, the reactor is also equipped to examine the properties of the gas and liquid phase materials co-produced during pyrolysis. The information collected is essential to study the potential of using the pyrolysis co-products for supporting the heat demand of the steel production processes.

CCRA 70B: Substitution of Blast Furnace Pulverized Coal Injection and EAF Slag Foaming Injection by Biocarbon

Industrial scale biocarbon injection trials were conducted successfully at AM Dofasco. During the plant trial, the biocarbon and coal was pre-mixed then pulverized. The pulverized biocarbon/coal mixture was injected into the blast furnace. A total of 3 trials were conducted at 5%, 10% and 15% substitution of coal by the selected biocarbon. Each trial lasted for about 6 hours and a total of about 200 tonnes of biocarbon was consumed.

CanmetMATERIALS has received a furnace previously used by McMaster University for carbon injection studies. The furnace will be set up in CanmetMATERIALS for studying biocarbon injection for slag foaming in the next fiscal year.

CCRA 70C: Incorporation of Biocarbon in Cokemaking by Densification and Utilization of Biocoke in Blast Furnace Ironmaking

Two pilot scale carbonization tests were conducted in FY 2021/22 to evaluate the performance of coal/biocarbon briquettes in Cokemaking. In both tests, the same amount of solid biocarbon was incorporated into the coal blend for testing.

In one test, the loose solid biocarbon was incorporated into the coal blend directly without any processing. In the second test, the solid biocarbon was briquetted with coal and the bio-briquette was incorporated into the coal blend. By comparing the test results, the performance of the bio-briquette could be evaluated along with the need for briquetting.

The physical and chemical properties of the resultant bio-coke from the pilot scale carbonization test was measured. It was observed that the resultant bio-coke quality of the bio-briquette test was improved in comparison to the loose biocarbon test. However, the physical strength of the biocoke from bio-briquette test was still lower than expected and did not meet the requirement for industrial blast furnace application.

Detailed microscopic analysis was conducted to better understand the test results. It was concluded that the reduction in coke strength was due to the fact that the biocarbon embedded in the coke matrix formed a weak point within the coke particles. When the coke was under impact, breakage of coke occurred at the location of the biocarbon. It was further identified that the creation of weak points was due to the particle size of the biocarbon used in the test. If the particle size was too big, it resulted in a coke matrix that could not fully embed the biocarbon particle, leading to creation of a weak point within a piece of coke.

With the information collected in the pilot scale carbonization test, it was concluded that the root cause of low coke physical strength was the particle size of the biocarbon used. Another series of carbonization tests are being prepared. In this series of tests, the biocarbon particle size will be reduced to less than 0.5mm for preparation of coal/biocarbon for incorporation into the coal blend. These carbonization tests will be conducted in next fiscal year.

CCRA 70D: Biocarbon for Non-Ferrous Metal Production

No activity was conducted in FY 2021-22

4. Carbon Neutral Ironmaking Technology Development

With the announcements from two of the three-member steel companies that have publicly committed to achieve decarbonization by altering their steel production routes from the traditional cokemaking/ironmaking route to scrap/DRI and EAF, the CCRA road map for guide R&D activities needs to change.

The CCRA program is being updated to meet the current and future challenges. The Net Zero Emission Process Development program was added to the existing Blast Furnace Process Enhancement program. The proposed changes in the CCRA Research Program will encompass the current work for coal/coke/cokemaking/BF. The carbonization work is still important for both existing coal members, but also to support new coal mining ventures. However, the scope of CCRA R&D program will be significantly expanded in the future. It will be a very big challenge but also an excellent opportunity to further develop CCRA.

5. CanmetENERGY Met Fuels Lab Facilities

Annual MWO Benchmarking

Annual benchmarking of the Canmet MWOs is conducted to ensure the reliability of the equipment. No issues were seen in the results.

In FY 2021/22, the scope of benchmarking study was extended to include the newly installed 80kg small sale carbonization oven in TECK.

High Temperature Furnace Re-Commissioning

The re-commissioning of the high temperature furnace was completed, and demonstration runs were conducted successfully. Results from previous studies were similar. There has been a technical knowledge exchange with AM Dofasco who have ran this oven historically at their R&D center.

CanmetENERGY-Ottawa Met Fuels Facilities Utilization:

Table 1 - Utilization of CanmetENERGY Facilities
2020-21 vs 2021-2022

Oven	Utilization of CanmetENERGY Facilities							
	Coal Companies		Steel Companies		CCRA Research		Totals	
	Sole – Heated Oven							
	20	**21**	**20**	**21**	**20**	**21**	**20**	**21**
SHO1	41	52	26	10	3	2	70	64
SHO2	54	81	34	31	7	6	95	118
SHO3	0	0	1	0	0	0	1	0
Total SHO	**95**	**133**	**61**	**41**	**10**	**8**	**166**	**182**
	CSR/CRI							
CSR	91	144	13	2	8	10	112	156
SHO/CSR	9	11	23	14	11	7	43	32
Total CSR	**100**	**155**	**36**	**16**	**19**	**17**	**155**	**188**
	Movable Wall Oven							
18 Inch	1	0	25	15	2	3	28	18
Carbolite	83	133	0	0	1	4	84	137
Total MWO	**84**	**133**	**25**	**15**	**3**	**7**	**112**	**155**
	PCI Injection Test Rig							
PCI	**0**	**0**	**0**	**4**	**2**	**0**	**2**	**4**

OTHER BUSINESS

1. **CCRA Technical Roadmap**
   a. The roadmap was reviewed and aligned with the Technical Committee planning table. The research activities/streams have been reorganized and updated to better reflect current project work.
   b. The CCRA BOD is responsible for updating and planning the roadmap for the Technical Committee.
   c. The roadmap will continue to be updated in 2022-23 to address the R&D needs for achieving the steel industry goal of net zero emission in 2050 while continue to provide support on coal and coke research.

2. **CCRA Research Program**
   a. Progress in all CCRA projects now being tracked with A3 plans and planning table.

3. **CanmetENERGY Met Fuels Activities**
   a. Revenues for 2021-22, $1.2M
   b. New staffing & training actions has progressed

4. CanmetENERGY Met Fuels Facilities Upgrade:

a. Facilities upgrades including coke oven gas analysis, automatic coke stabilization and screening are on hold.

5. CCRA Documents Management

All CCRA documents are stored in Google drive to allow easy access by all members. A link was provided in the CCRA website members only area to access all documents

https://drive.google.com/drive/folders/1bdiZbm-q2ziKVzVNUtg44exPEtK8JVux?usp=sharing

Documents include:

i. Technical committee meeting minutes
ii. Board of Director meeting minutes
iii. Annual reports
iv. A3 plans
v. Publications
vi. Technical projects progress reports

6. CCRA website

The CCRA website (www.cancarb.ca) was completely redesigned and fully implemented. The website is managed and maintained by Fullview Design, a website development company in Ottawa.

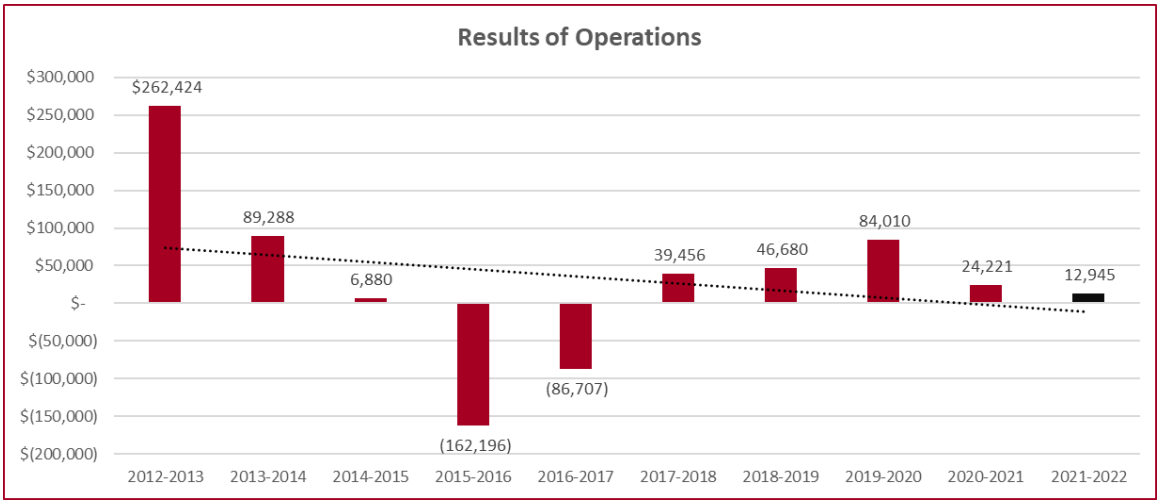
Roben Jig tube filled with coal and water and ready to be jigged.

Technicians getting ready to invert the jig tube holding jigged coal.

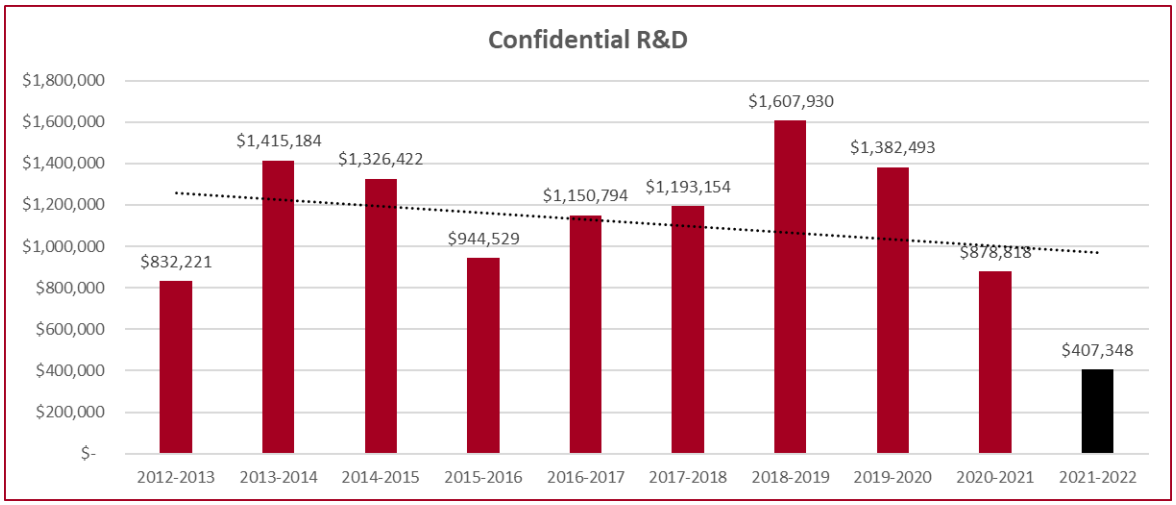
The first slice of coal is ready to be removed from the cylinder. It has been pushed up from the bottom and will be scraped off into a weighing container for Apparent Relative Density test.

FINANCIAL YEAR IN REVIEW

CCRA ended the 2021-2022 fiscal year with an operating surplus of $12,945 a decrease to the $24,221 operating surplus reported in the prior year. This reduction is due to the reduction in membership contributions and interest income. The trendline reflects the intent of CCRA's financial plan where minimal annual operating surpluses are targeted to enable maximum contributions to its varied research initiatives including its research support contributions to CanmetENERGY.

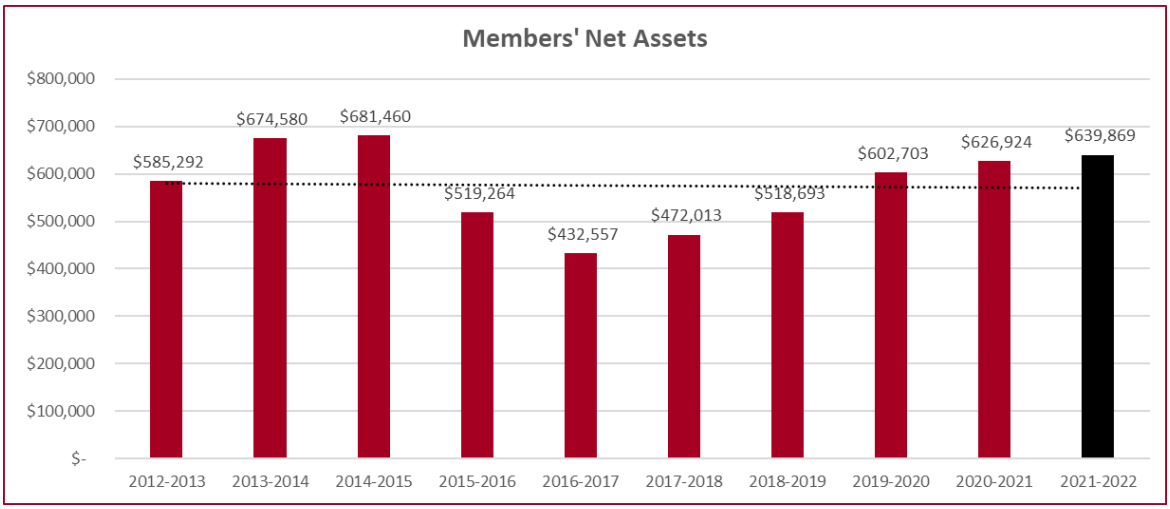


As was the case for many organizations, the continuation of the COVID-19 Pandemic for a second year continued to impact CCRA with further reductions in its Confidential Oven Testing Program as member organizations and CanmetENERGY focused on the health and safety of their employees and focused their activities on essential and permitted activities. As a result, CCRA's activity during 2021-2022 was the lowest reported during the last ten years and represented 29.5% of the levels achieved immediately before the COVID-19 Pandemic.



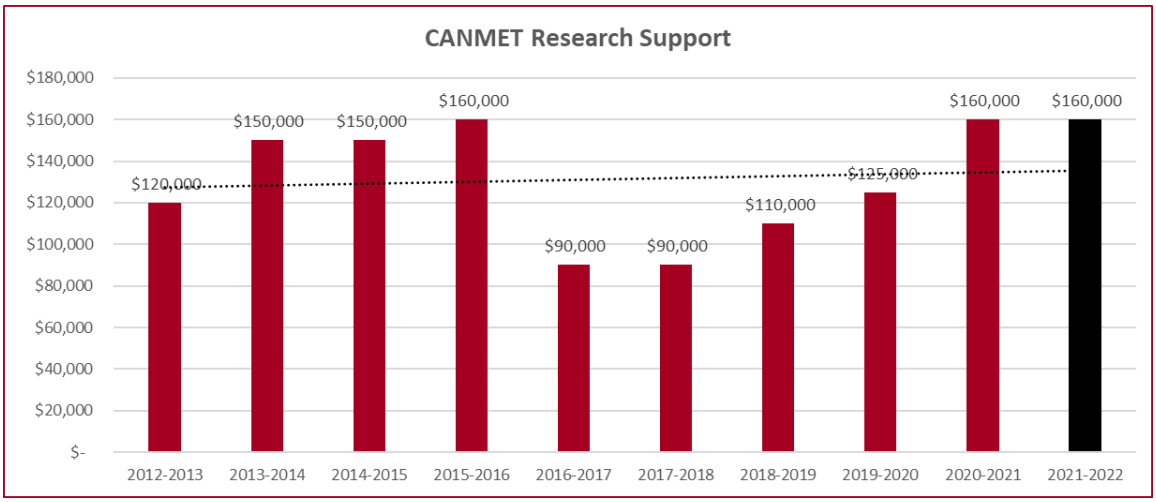
Financially, Members' Net Assets at year-end totaled $639,869 reflecting a 2.1% increase to the level reported at the end of previous fiscal year. Despite periods of volatility in Members' Net Asset levels during the past decade, the trend line clearly reflects the desired outcomes where the level of Members' Net Assets remains stable. The base level has sustained CCRA during past downturns in the economic

cycle where membership levels and resulting contributions can temporarily decline. With this financial plan, CCRA remains in a strong financial position to fulfill its mandate in the coming years.



Because of this prudent financial planning, CCRA can absorb short-term temporary declines in membership levels or absorb other unexpected unfavorable developments while continuing to be a dependable funding partner of CanmetENERGY through its annual research support payments and confidential oven testing program.

Despite the downturn in the level of Confidential Oven Testing and Memberships, CCRA has been able to maintain its research support payments to CANMET at the highest levels of the past decade during the last two fiscal years despite the impacts resulting from the Covid-19 Pandemic.



CCRA continues to minimize its administrative costs in order to maximize the amounts available to support research programs. During 2021-2022, administrative overhead of $25,592 only represented 4.1% of total current year expenditures despite a significant reduction in total expenditures during the year. This demonstrates CCRA's continued commitment to minimize overhead costs in order to maximize its contributions to research and development initiatives.

In summary, CCRA continues to remain in a strong financial position necessary to support its continued investment in research initiatives supporting the coal and carbonization industries in Canada.

Brian D'Amboise, CPA, CA
Treasurer

AUDITED FINANCIAL STATEMENTS

CRAWFORD SMITH & SWALLOW

CANADIAN CARBONIZATION RESEARCH ASSOCIATION

Financial Statements

March 31, 2022

CRAWFORD SMITH & SWALLOW

CANADIAN CARBONIZATION RESEARCH ASSOCIATION

Financial Statements

March 31, 2022

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INDEPENDENT AUDITORS' REPORT

To the Members of the
Canadian Carbonization Research Association

Opinion
We have audited the accompanying financial statements of the Canadian Carbonization Research Association, which comprise the statement of financial position as at March 31, 2022, and the statements of operations and changes in members' net assets and cash flows for the year then ended, and notes to the financial statements, including a summary of significant accounting policies.

In our opinion, the accompanying financial statements present fairly, in all material respects, the financial position of Canadian Carbonization Research Association as at March 31, 2022, and the results of its operations and its cash flows for the year then ended in accordance with Canadian accounting standards for not-for-profit organizations.

Basis for Opinion
We conducted our audit in accordance with Canadian generally accepted auditing standards. Our responsibilities under those standards are further described in the *Auditors' Responsibilities for the Audit of the Financial Statements* section of our report. We are independent of the Association in accordance with the ethical requirements that are relevant to our audit of the financial statements in Canada, and we have fulfilled our other ethical responsibilities in accordance with these requirements. We believe that the audit evidence we have obtained is sufficient and appropriate to provide a basis for our opinion.

Responsibilities of Management and Those Charged with Governance for the Financial Statements
Management is responsible for the preparation and fair presentation of these financial statements in accordance with Canadian accounting standards for not-for-profit organizations, and for such internal control as management determines is necessary to enable the preparation of financial statements that are free from material misstatement, whether due to fraud or error.

In preparing the financial statements, management is responsible for assessing the Association's ability to continue as a going concern, disclosing, as applicable, matters related to going concern and using the going concern basis of accounting unless management either intends to liquidate the Association or to cease operations, or has no realistic alternative but to do so.

Those charged with governance are responsible for overseeing the Association's financial reporting process.

Auditors' Responsibilities for the Audit of the Financial Statements
Our objectives are to obtain reasonable assurance about whether the financial statements as a whole are free from material misstatement, whether due to fraud or error, and to issue an auditors' report that includes our opinion. Reasonable assurance is a high level of assurance, but is not a guarantee that an audit conducted in accordance with Canadian generally accepted auditing standards will always detect a material misstatement when it exists. Misstatements can arise from fraud or error and are considered material if, individually or in the aggregate, they could reasonably be expected to influence the economic decisions of users taken on the basis of these financial statements.

As part of an audit in accordance with Canadian generally accepted auditing standards, we exercise professional judgment and maintain professional skepticism throughout the audit. We also:

a) Identify and assess the risks of material misstatement of the financial statements, whether due to fraud or error, design and perform audit procedures responsive to those risks, and obtain audit evidence that is sufficient and appropriate to provide a basis for our opinion. The risk of not detecting a material misstatement resulting from fraud is higher than for one resulting from error, as fraud may involve collusion, forgery, intentional omissions, misrepresentations, or the override of internal control.

b) Obtain an understanding of internal control relevant to the audit in order to design audit procedures that are appropriate in the circumstances, but not for the purpose of expressing an opinion on the effectiveness of the Association's internal control.

c) Evaluate the appropriateness of accounting policies used and the reasonableness of accounting estimates and related disclosures made by management.

d) Conclude on the appropriateness of management's use of the going concern basis of accounting and, based on the audit evidence obtained, whether a material uncertainty exists related to events or conditions that may cast significant doubt on the Association's ability to continue as a going concern. If we conclude that a material uncertainty exists, we are required to draw attention in our auditors' report to the related disclosures in the financial statements or, if such disclosures are inadequate, to modify our opinion. Our conclusions are based on the audit evidence obtained up to the date of our auditors' report. However, future events or conditions may cause the Association to cease to continue as a going concern.

e) Evaluate the overall presentation, structure and content of the financial statements, including the disclosures, and whether the financial statements represent the underlying transactions and events in a manner that achieves fair presentation.

We communicate with those charged with governance regarding, among other matters, the planned scope and timing of the audit and significant audit findings, including any significant deficiencies in internal control that we identify during our audit.

We also provide those charged with governance with a statement that we have complied with relevant ethical requirements regarding independence, and to communicate with them all relationships and other matters that may reasonably be thought to bear on our independence, and where applicable, related safeguards.

Niagara Falls, Ontario
June 20, 2022

CRAWFORD SMITH & SWALLOW
CHARTERED PROFESSIONAL ACCOUNTANTS LLP

LICENSED PUBLIC ACCOUNTANTS

3

CANADIAN CARBONIZATION RESEARCH ASSOCIATION

STATEMENT OF FINANCIAL POSITION

March 31, 2022

Assets	2022 $	2021 $
Current Assets		
Cash	36,898	19,285
Temporary investments - note 2	800,850	1,652,111
Prepaid expenses	3,087	2,689
	840,835	**1,674,085**
Liabilities and Members' Net Assets		
Current Liabilities		
Accounts payable and accrued liabilities	8,509	21,908
Government remittances payable	12,057	14,957
Due to CANMET	80,000	834,796
Deferred revenue	100,400	175,500
	200,966	1,047,161
Members' Net Assets	639,869	626,924
	840,835	**1,674,085**

Signed on behalf of the Board:

Director

Director

See accompanying notes

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CANADIAN CARBONIZATION RESEARCH ASSOCIATION

STATEMENT OF OPERATIONS AND CHANGES IN MEMBERS' NET ASSETS

for the year ended March 31, 2022

	2022 $	2021 $
Revenue		
Confidential research and development	407,348	878,818
Research levies	215,000	225,000
Outside research grants		4,958
Membership fees	600	800
Interest income	3,103	6,456
	626,051	1,116,032
Operating Expenses		
Confidential research and development	407,348	878,818
CANMET research support	160,000	160,000
Consulting	4,000	3,000
Outside research	16,166	17,074
Office	15,392	23,339
Professional fees	7,140	6,797
Insurance	3,060	2,783
	613,106	1,091,811
Excess of Revenue over Expenses for the Year	12,945	24,221
Members' Net Assets, Beginning of Year	626,924	602,703
Members' Net Assets, End of Year	**639,869**	**626,924**

See accompanying notes

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CANADIAN CARBONIZATION RESEARCH ASSOCIATION

STATEMENT OF CASH FLOWS

for the year ended March 31, 2022

	2022 $	2021 $
Operating Activities		
Excess of revenue over expenses for the year	12,945	24,221
Changes in working capital components - note 3	(846,593)	840,246
Funds provided (used) by operating activities	(833,648)	864,467
Investing Activities		
Decrease (increase) in temporary investments	851,261	(894,504)
Increase (Decrease) in Cash	17,613	(30,037)
Cash, Beginning of Year	19,285	49,322
Cash, End of Year	**36,898**	**19,285**

See accompanying notes

CANADIAN CARBONIZATION RESEARCH ASSOCIATION

NOTES TO FINANCIAL STATEMENTS

for the year ended March 31, 2022

Organization

Canadian Carbonization Research Association (the "Association") is a national organization which initiates, coordinates and provides funding towards research and development having particular importance to the coal and carbonization industries of Canada. The organization was incorporated under the Canada Corporations Act as a not-for-profit association in July 1981. In January 2014, the Association was issued a Certificate of Continuance under the Canada Not-for-profit Corporations Act.

1. Significant Accounting Policies

The financial statements of the Association are the representations of management prepared in accordance with Canadian accounting standards for not-for-profit organizations, consistently applied. Because a precise determination of many assets and liabilities is dependent upon future events, the preparation of periodic financial statements necessarily involves the use of estimates and approximations. These have been made using careful judgement in the light of available information. The financial statements have, in management's opinion, been properly prepared within reasonable limits of materiality and within the framework of the accounting policies summarized below:

Financial reporting framework

The Association, being a not-for-profit organization, chose to establish their financial statements in accordance with Canadian accounting standards for not-for-profit organizations, issued by the Chartered Professional Accountants of Canada.

Revenue recognition

Revenue from memberships is recognized over the membership term. Revenue related to memberships received in advance of the fee being earned or the service is performed is deferred and recognized when the fee is earned or service performed. Research levies, consulting funding and other income are recognized in the fiscal year for which they have been assessed. Confidential research and development revenues are recognized when the related services are provided. Interest is recognized when earned and dividends when declared.

Temporary investments

Temporary investments are valued at cost which approximates market value.

Financial instruments

The Association's financial instruments consisting of cash, temporary investments, accounts payable and accrued liabilities and due to CANMET are initially measured at fair value on acquisition and are subsequently measured at amortized cost. Transaction costs and financial fees associated with financial instruments carried at amortized cost are recorded as adjustments to the initial fair value recognized, and amortized over the life of the financial instrument.

CANADIAN CARBONIZATION RESEARCH ASSOCIATION

NOTES TO FINANCIAL STATEMENTS

for the year ended March 31, 2022

1. Significant Accounting Policies - continued

Foreign currency translation

These financial statements are presented in Canadian dollars. Assets and liabilities denominated in foreign currencies are translated at the exchange rates in effect at the statement of financial position date. Revenue and expenses are translated at rates of exchange prevailing on the transaction date. Gains and losses on translation are reflected in excess of revenue over expenses of the period.

2. Temporary Investments

Temporary investments are guaranteed investment certificates with interest rates between 0.80% and 1.20% and mature between February, 2023 and March, 2023. They are subject to insignificant risk of change in value.

3. Statement of Cash Flows

Changes in working capital components include:

	2022 $	2021 $
Accounts receivable		91,097
Prepaid expenses	(398)	(193)
Accounts payable and accrued liabilities	(13,399)	(10,463)
Government remittances payable	(2,900)	3,446
Due to CANMET	(754,796)	766,559
Deferred revenue	(75,100)	(10,200)
	(846,593)	**840,246**

4. Financial Risks

Transactions in financial instruments expose the Association to certain financial risks and uncertainties. These risks include:

Interest rate risk

Interest rate risk is the risk that future cash flows of a financial instrument will fluctuate due to changes in market interest rates. The Association holds investments that earn income at varying rates of return which are dependent upon market conditions. Accordingly, the Association is exposed to the effects of fluctuations in market rates. Interest received in the year amounted to $ 3,103 (2021 - $ 6,456). As a result of a decrease in temporary investments during the year, the Association's exposure to interest rate risk has decreased over the prior year.

CANADIAN CARBONIZATION RESEARCH ASSOCIATION

Schedule 1

UNAUDITED FIVE YEAR FINANCIAL REVIEW

UNAUDITED STATEMENT OF OPERATIONS AND MEMBERS' NET ASSETS

for the year ended March 31, 2022

	2022 $	2021 $	2020 $	2019 $	2018 $
Revenue					
Confidential research and development	407,348	878,818	1,382,493	1,607,390	1,193,154
Research levies	215,000	225,000	225,000	195,000	160,000
Outside research grants		4,958	72,561	79,852	191,846
Membership fees	600	800	800	700	400
Interest income	3,103	6,456	10,824	12,795	8,094
Other income			3,642		1,121
	626,051	1,116,032	1,695,320	1,895,737	1,554,615
Operating Expenses					
Confidential research and development	407,348	878,818	1,382,493	1,607,390	1,193,154
CANMET research support	160,000	160,000	125,000	110,000	90,000
Consulting	4,000	3,000	3,000	22,232	5,800
Outside research	16,166	17,074	72,561	79,852	200,146
Office	15,392	23,339	17,853	17,479	16,449
Professional fees	7,140	6,797	7,795	9,539	7,045
Insurance	3,060	2,783	2,608	2,565	2,565
	613,106	1,091,811	1,611,310	1,849,057	1,515,159
Excess of Revenue over Expenses for the Year	12,945	24,221	84,010	46,680	39,456
Members' Net Assets, Beginning of Year	626,924	602,703	518,693	472,013	432,557
Members' Net Assets, End of Year	**639,869**	**626,924**	**602,703**	**518,693**	**472,013**

See accompanying notes

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CANADIAN CARBONIZATION RESEARCH ASSOCIATION

Schedule 1 - continued

UNAUDITED FIVE YEAR FINANCIAL REVIEW

UNAUDITED STATEMENT OF FINANCIAL POSITION

as at March 31, 2022

	2022 $	2021 $	2020 $	2019 $	2018 $
Assets					
Current Assets					
Cash	36,898	19,285	49,322	95,857	44,958
Temporary investments	800,850	1,652,111	757,607	575,791	526,361
Accounts receivable			91,097	17,091	2,205
Prepaid expenses	3,087	2,689	2,496	2,225	1,725
	840,835	**1,674,085**	**900,522**	**690,964**	**575,249**
Liabilities and Members' Net Assets					
Current Liabilities					
Accounts payable and accrued liabilities	8,509	21,908	32,371	8,961	17,282
Government remittances payable	12,057	14,957	11,511	17,710	
Due to CANMET	80,000	834,796	68,237		22,500
Deferred grant					63,454
Deferred revenue	100,400	175,500	185,700	145,600	
	200,966	1,047,161	297,819	172,271	103,236
Members' Net Assets	639,869	626,924	602,703	518,693	472,013
	840,835	**1,674,085**	**900,522**	**690,964**	**575,249**

See accompanying notes

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CCRA HISTORY

The Canadian Carbonization Research Association (CCRA) was formed on September 2, 1965 with the adoption of a Constitution by the Canadian Steel and Coal industries, as a mechanism to promote and establish carbonization research in Canada. Representatives of the major cokemaking steel producers, an independent coke producer, major metallurgical coal miners, coal tar users and the Federal Government Department involved with these Industries were at the table.

The Association's original members were Algoma Steel Corporation, Canmore Mines Ltd, Crows Nest Industries, Dominion Foundries and Steel Limited, Dominion Tar & Chemicals Ltd, Dosco Steel Ltd, The Steel Company of Canada Ltd and The Mines Branch of Energy, Mines and Resources (EMR).

CCRA is a unique co-operative Research and Development effort between Industry and Government, which has become a model for many other industry/government R&D joint efforts. CCRA members and CANMET have a consensus based program that has and continues to meet its members needs over many fruitful years.

The Canadian Carbonization Research Association (CCRA) was formed on September 2, 1965 – 57 years of Research supporting the Canadian Coal and Carbonization Industries

Numerous members have also done and continue to perform many confidential test programs at CANMET to meet their needs directly.

Over the years, CCRA and CANMET have carried out many R&D programs to improve the metallurgical coal and cokemaking operations of its members. Many of these have had far reaching effects which have been well documented in studies carried out by consultants for the government showing the economic effects of the Joint R&D Program (NRCan Audit and Evaluation Branch report, 2001 and PricewaterhouseCoopers report, 2015). The benefits to Canadian industry have been substantial, however, it could not have taken place without the joint efforts of CANMET and CCRA. Having a laboratory to conduct carbonization research is beyond the feasibility of any one company so the single shared Canadian laboratory at Bells Corners in Ottawa, Ontario has allowed the continuation of R&D in this field in Canada.

The fields of R&D covered by the joint CCRA/CANMET program include energy and fuel conservation and efficiency, stabilization of supply, GHG reduction, mining, processing, transportation, production of iron, environment, and safety. At any specific time the R&D program places priority on the most pressing problems while not ignoring the longer term work necessary to progress in the future.

The Early Years

The original members of CCRA and the senior officials of EMR were successful in convincing the Minister of EMR to establish a coal carbonization laboratory in Canada. The first Laboratory was located at The Mines Branch on Booth Street in Ottawa and centered around a 12-inch pilot coke oven and a newly designed sole heated oven. At first, the operation of the equipment was often performed by personnel from CCRA member companies and later CCRA employed personnel for this purpose. In 1968, with the help from CCRA members, a new laboratory facility location was chosen at Bells Corners, 20 km west of downtown Ottawa. EMR provided the building facilities and CCRA members supplied much of the carbonization equipment. A showpiece for the new facility was a new 18-inch movable wall pilot oven. A

30-pound coke oven was also part of the new facilities. In December 1968, the group at the Mines Branch responsible for coal and ironmaking were also relocated to Bells Corners.

Expanding Activities in the 1970s

The coal preparation plant from Booth Street was moved to Clover Bar, just outside Edmonton, AB. Research work was managed by Mr. Jack C. Botham under the direction of the Technical Committee and centered on coal pipelining, additives to coking charges, hot briquetting, formed coke, and petrographic methods for all coals. Arrangements were made to establish a coking facility at Clover Bar to accommodate the Western Canadian Coal producers. Algoma arranged to donate their Koppers pilot coke oven. A mini fluidized bed was constructed for heating coal for hot briquetting as part of the formed coke project and by 1974, this facility was operational. EMR hired Drs. John Gransden and John Price who became the backbone of the Technical program and have gained international recognition as coal carbonization scientists.

In the early 1970s, a major focus for research was the fact that Western Canadian coal contains a significant amount of reactive semi-fusinite compared to traditional Appalachian coals from the USA. During this period, R&D programs focused on petrographic analysis and coking tests helped place Western Canadian coal at the forefront of having excellent coking behaviour and producing excellent coke quality. CCRA has spent much effort explaining the benefits of these coals by using its research program to develop technical projects and has presented numerous papers supporting the technical merits of Western Canadian coals. This work is ongoing today as membership changes.

When the energy crisis developed in 1973-74 concern about energy self-sufficiency and sustainability became very important. This crisis resulted in several oil companies getting involved in the coal mining business. CCRA membership then included Shell Canada, Esso Resources, BP Canada and Gulf Canada.

The organization underwent a substantial change in 1975 when the movable wall coke oven crew switched from being CCRA employees to EMR term employees, to conform with Government policy. CCRA established a new Treasurer system to handle the organization's financial affairs and research funding. This change resulted in the Treasurer's position becoming an appointed officer with full financial authority for the Association. At the time, Mr. George A. Chapman was appointed as Treasurer.

Incorporation of CCRA & Facility Changes – the 1980s

CCRA was incorporated under The Canadian Corporations Act on July 16, 1981, as a non-for-profit Research Association. Letters patent set out the organizational structure with each member company putting forward a representative to the Board of Directors and a Technical Committee member.

The administration of CCRA is the responsibility of the Board of Directors to whom the Officers and other appointed positions report. The objectives of CCRA are set out in the Letters patent:

1. *To conduct Research and Development of importance to the coal and carbonization industries in Canada,*
2. *To co-ordinate and support Canadian carbonization Research in and related to steel, foundry, smelting and coal industries,*
3. *To affiliate with national and international organizations or associations having similar objectives, for the benefit of Canada.*

In the early 1980's, new research studies centered around the correlation of coke and processing conditions from the movable wall oven with that from industrial ovens. Gas and wall pressure measurements in pilot and industrial coke ovens were emphasized. This area of study included a unique study which took place at Algoma Steel's No. 6 coke battery, which was scheduled to be demolished. The study used the battery to carbonize very high-pressure coking blends to determine what the high coking wall pressures would do to an oven and if it could even cause wall failure.

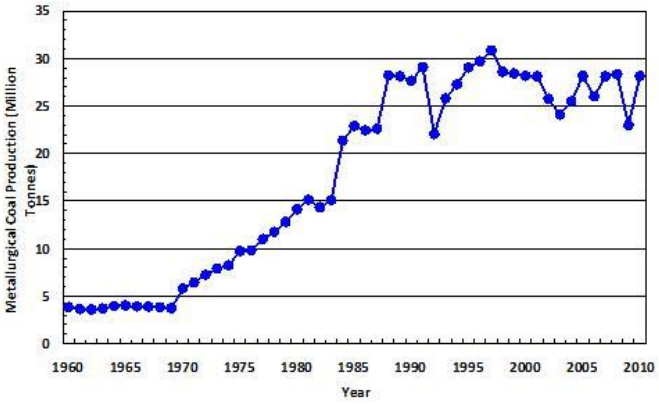
One of the Technical highlights of CCRA at that time was the CCRA/NKK Technical Exchanges between Canada and Japan. Four Technical Exchanges took place, where both sides presented papers on their research work. The delegations generally involved 12 to 15 representatives from each country and was highly successful.

By the latter part of the 1980s, the international energy crisis had subsided, coal and steel prices were dropping, and both industries were entering a period of highly competitive markets. Coal injection into the blast furnace was introduced in Europe and Japan. In that period, many new projects were initiated by the CCRA Technical Committee. Among these were the upgrading of coking quality of Canadian coals through wash plant control, CSR and carbon texture, vertical temperature distribution in a coke oven, and the effect of partial aging/weathering of a component coal on coke quality.

A project to study blast furnace coal injection (PCI) was approved and a special facility was built at Bells Corners. CCRA and Canadian Steel Industries Research Association co-sponsored a study on Strategic Ironmaking with CANMET to review how technologies on ironmaking could evolve in the next 20 years. That study was completed in 1990 and became the road map for the steel industry for many years.

Difficult Times in the Coal and Steel Industries – the 1990s

Canadian coal exports doubled over the 1980s. Research was aimed at reducing the cost of coke and energy for Canadian steelmakers and finding a global niche for Western Canadian coal. With Canadian coke batteries aging, PCI work became very important to coal and steel members. The PCI facilities at Bells Corners was proving its value in the injection program. A CCRA sponsored project at the University of British Columbia on coke oven modeling was completed and the model now resides at CANMET for all to use.



History of Metallurgical Coal Production in Canada

In 1995, CCRA celebrated its 30th anniversary. Because of difficult economic conditions in the Canadian coal and steel industries, membership had declined to eight members and EMR was undergoing a programme review. As a result, CCRA was asked to prepare an impact statement for their review.

By 1997, the CCRA/CANMET fee structure underwent a significant change with confidential oven test work increasing substantially. The Board of Directors approved By-law Number 2 to create a new category of Membership, the Connected Member. This was a category for members who were not financially eligible to join as full members but wished to be part of CCRA.

Consolidation of the Coal Industry and the Challenges of the 2000s

The year 2000 saw another downturn in the steel and coal industries with two of the three Canadian steel members and one coal producer having to discontinue their CCRA memberships because of financial considerations. The reduction in members complicated CCRA's financial situation as the Association had to dip into its limited reserves to maintain its commitments to CANMET. The consolidation of the metallurgical coal producers at the end of 2002 further complicated the financial situation for CCRA as there was now only one coal and one steel member. The Association and CANMET co-operated to keep CCRA as a viable entity and hoped that new members could be attracted when the economy in these industries improved. Dr. Ross Leeder remained as Chairman of the Board of Directors and Mr. Ted Todoschuk as Chairman of the Technical Committee.

The number of metallurgical coal producers was substantially reduced in 2002 with the formation of Elk Valley Coal, which incorporated most of the producers under one organization. That left but only two members to carry the organization with CANMET. The history of important results on coal blend carbonization and the CANMET database that meet members needs made it an easy decision for the remaining ones to carry on.

The CCRA/CANMET R&D program has provided valuable technical information to the Canadian metallurgical coal industry that is accepted by their international customers as reliable, accurate and unbiased. This has allowed Canadian metallurgical coal to compete on the international market against foreign coals and retain jobs in Canada. The export of Canadian coal generates a significant amount of foreign exchange and assists with Canada's balance of payments. Today, Canada is one of the major exporting countries of metallurgical coal globally.

As CCRA celebrated its 40th Anniversary in 2005, the future looked more promising than it had in the last few years, despite the economic ups and downs of the industries represented by the CCRA. The continued CCRA/CANMET partnership benefited Canada as the participating industries gained new information because of the R&D program. International recognition was achieved for the R&D work performed through the CCRA/CANMET partnership.

International recognition has been achieved for the R&D work performed though the CCRA/CANMET partnership

At the end of 2006, Dr. Ross Leeder, the longest serving member of the Board retired from Elk Valley Coal Ltd. Ross had joined the Technical Committee in 1971 when he was a member of the CANMET staff at Bells Corners. He chaired the Technical Committee before moving to the Board of Directors. Ross became Chairman of the BOD in 1989-90 and again in 1999-2006. During the 35 years of his association with CCRA, Ross presented numerous papers on the industry and on the technical merits of Western Canadian coals at Canadian and international conferences.

In 2007, two new coal companies joined as Connected Members, Anglo American Peace River Coal and Western Canadian Coal Corp. and Dr. Barry Ryan, B.C. government geologist, joined as an Individual Connected Member.

In 2008, George Chapman celebrated his 30th anniversary as Treasurer of the Association. Peace River Coal became a full member of the Association and Essar Steel Algoma Inc. joined as a Connected Member. That same year, after a career spanning 35 years, Dr. John Price took retirement from his position as Senior Research Scientist and Manager of Energy for High Temperature Processes at CANMET.

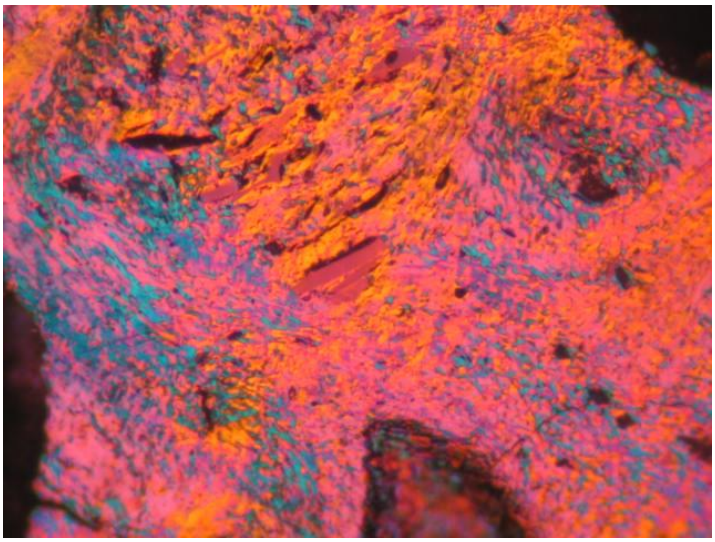
In early 2009, Dr. John Gransden, also Senior Research Scientist in coal carbonization, retired from CANMET. Dr. Gransden received the AIST Joseph Becker Award for career accomplishments in cokemaking research for CCRA and CANMET. The departure of Drs. Price and Gransden, both dedicated research scientists, represented a significant loss to the CCRA within a very short time period. . Furthermore, Dr. Barry Ryan retired from the B.C. Government Ministry of Energy, Mines and Petroleum Resources and, as there was no replacement named, the B.C. Government abandoned its membership.

For several years prior to 2008-09, the Greenhouse gas (GHG) file, as driven by the federal government, became a major thrust of the joint R&D program and the research program reflected that reality.

In 2009, the Technical Committee and the Board of Directors spent a significant amount of time and effort gathering information on the development and financing of a pilot Energy Recovery Pilot coke oven for the joint CCRA/CANMET program to examine this alternative/new cokemaking technology. This endeavour is an excellent example of how CCRA adapts to the changes facing industry.

CCRA's 45th Anniversary - 2010

The 45th anniversary of CCRA's foundation was celebrated in 2010. In 2010-2011, the Association started on a very ambitious project to carry out engineering, design, construction and commissioning of an Energy Recovery Pilot Coke Oven (ERCO) at Bells Corners coal and coke facilities. The ERCO technology is an alternate approach to traditional slot coke oven technology and the fact that pilot facilities using ERCO technology are essentially non-existent, R&D cannot be carried out. CCRA's goal for this project was to put Canada at the leading edge of this technology by having a facility where its members could be able to investigate how coal behaves in this type of oven and generate valuable data to allow the Canadian steel industry to evaluate this alternative technology. This facility would also be used to showcase the cokemaking merits of Western Canadian coals using this technology globally as well as making use of it to conduct research on the incorporating of in coal blends for assessing coke quality.



Due to the capital costs to finance such a large project, CCRA members contributed to a special fund. CCRA also signed a Non-Repayable Contribution Agreement with Natural Resources Canada to assist with the costs. The Canadian Steel Producers Association (CSPA) also contributed to the project. The goal was to secure the funding to enable the construction of the facility. In 2011-12, SunCoke Energy, USA was invited to join CCRA as a strategic partner in developing the energy recovery cokemaking programme as they have owned and operated commercial ovens using this technology for many years.

The 2011–2012 fiscal year saw a growth in CCRA members as US Steel Canada, SunCoke Energy, Inc. joined. Grande Cache Coal Corp., Alberta also rejoined the Association after being absent for some years.

During the 2013/2014 fiscal year, CCRA was obligated to transition from its original letters patent legal structure to comply with the requirements of the new Not-for-Profit Corporations Act. As of January 1, 2013, CCRA received its Certificate of Continuance as Corporation Number 117455-0 Industry Canada.

In 2014-2015, the CCRA with CanmetENERGY's cooperation, provided a website for the Canadian Carbonization Research Association. The website is accessible at *http://www.cancarb.ca/wordpress/* and contains timely information on the CCRA/CanmetENERGY R&D programs and other information related to the Canadian Coal and Coke industry as a whole.

The CCRA celebrated its 50th year milestone of providing research support to the Canadian Coal and Carbonization industries on September 2, 2015.

On September 30, 2016, Mr. George Chapman retired as Treasurer of CCRA. During his 40-year tenure in that function, Mr. Chapman provided important financial and administration stewardship of CCRA and support to the Board of Directors and Members. The Board of Directors appointed Mr. Brian D'Amboise CPA, CA to succeed Mr. Chapman as Treasurer effective October 1, 2017. Mr. D'Amboise has over 25 years of involvement with CCRA as the former external auditor to the Association and provided Mr. Chapman valuable assistance in completing the 2016-17 fiscal year end and related tax returns.

CCRA pursued a number of outside research initiatives during the 2016-17 fiscal year. The Association continued work on the ISO Inter Laboratory Study on Coal Dilatation initiated in 2015-2016 and entered into a new research funding arrangement with Geoscience B.C. to support a study aimed at producing clean coal from Western Canadian Coal Fields using the water-based Roben Jig process. In addition, further studies on coal stamp charging and small-scale coking were developed to meet members future needs.

During 2017-18 fiscal year, the CCRA wrote four papers for presentation at AISTech 2017 in Nashville, USA and a report on Producing Clean Coal from Western Canadian Coalfields using the Water-Based Roben Jig Process in Geoscience BC Summary of Activities 2017. It made a presentation on this work at CoalSMART 2018 and organized two Working Group meetings on use of Biocarbon in Canadian Steel Industry (November 2017 and January 2018).

As well, the new PCI experimental rig at CanmetENERGY-Ottawa was upgraded to allow for better control of coal feeding rate and hot blast composition. A new approach was developed in processing the experimental data including the introduction of two new parameters to quantify the extent of gasification of coal Volatile Matter and Fixed Carbon and a new approach using TGA was developed to quantify the reactivity of combustion residues. Going forward, work will focus on enhancing the rig's capability in terms of NG/COG co-injection, blast gas moisture control and off-gas analysis.

On the use of renewable energy for the steel industry, research was pursued on several fronts including (1) Pyrolysis Technology Evaluation (2) Bio-Carbon for EAF Steelmaking (3) Bio-Briquette Formation (4) Bio-Carbon for Direct Injection in Blast Furnace Ironmaking (5) Biochar Production and Handling.

In 2018-19, the CCRA published three papers in peer-reviewed journals on (i) *"Value-In-Use of Renewable Biocarbon for Direct Injection in Blast Furnace Ironmaking"* in Ironmaking and Steelmaking journal (ii) *"Development of novel method for quantitative determination of carbon chemical reactivity"* in Canadian Journal of Chemical Engineering and (iii) *"Carbonaceous material properties and their interactions with slag during electric arc furnace steelmaking"* in Metallurgical and Materials Transactions B**;** it wrote papers for presentation at AISTech 2018 in Philadelphia, USA, for 8th International Conference on Science and Technology of Ironmaking in Vienna, Austria and a report on Producing Clean Coal from Western Canadian Coalfields using the Water-Based Roben Jig Process: Refining the Process in Geoscience BC Summary of Activities 2018. It made a presentation on this work at Western Canadian Coal Society in February 2019 and organized four Working Group meetings on use of Biocarbon in Canadian Steel Industry (April, June and November 2018 and March 2019).

Again in 2018-19, the CanmetENERGY Bioenegy group was a strong partner and made valuable contributions in assessing existing biomass conversion technologies, in the handling and cleaning and processing and carbonization. The Biocarbon for Iron and Steel production and other large emitters' project successfully secured S&T funding until March 2022.

In 2018-19, four meetings of the CCRA-Biocarbon for Steel Working Group were held at CanmetENERGY-Ottawa. These meetings were successful in advancing the discussion and interest level among the numerous project partners.

In 2021 the CCRA Biocarbon for Steel Working Group has seen the need for further guidance and involvement by other industries. This initiative will be led by CRIBE (Center for Research and Innovation in the Bioeconomy). The concepts remain, but the group will be called Biocarbon for Heavy Industry to include other industries similar to steel in the demand for bio energy. CCRA and its members will continue to be involved and are well engaged.

CCRA's key accomplishments through the years

The CCRA and its members can be very proud of its accomplishments over the five decades since its inception. It is difficult to list all the accomplishments, but numerous papers and presentations have been made available to interested research organizations. Significant highlights include:

- The 2015 PricewaterhouseCoopers report showed the value of the research program and the significant positive financial impact of CCRA research on the Canadian GDP.
- Enhancing the understanding of the technical merits of Western Canadian coals in international markets leading to significant sales globally.
- Metallurgical coal resource development in Canada using CanmetENERGY-Ottawa pilot scale coal and coke facilities, equipment, and expertise.
- Development of unique coal and coke testing techniques to support CCRA member needs.
- Lower fuel rates and GHG reductions in the Canadian steel industry with coke quality improvements.
- Improved energy efficiency for Canadian Ironmakers with the use of pulverized coal injection.
- Development of a biocarbon strategy to significantly reduce GHG emissions in the steel sector through multiple pathways.
- Engagement with strategic biocarbon supply chain producers to initiate a bio economy with the steel sector.
- Ensuring the development of suitable coal and coke quality standards to support the competiveness of the Canadian coal and steel industries.
- Engagement of CanmetENERGY's various researchers in GHG reduction initiatives to support industrial receptors for GHG reduction.

Going Forward

The uniqueness of the CCRA program is that it is able to adapt well to current and future needs of its members. The CCRA has recently embarked on R&D projects with international researchers in Australia, France, Japan, Sweden, USA and this has allowed the development of global partners and programs. In

addition, the CCRA is pursuing significant GHG reduction initiatives with both the coal and steel sectors as this is fast becoming a very significant global directive for these industries. In brief, the CCRA is examining ways to achieve carbon-neutral ironmaking in the middle to long-term (2030-2040) by partnering with Canadian and international partners.

Aligning the R&D Program with current and future needs of its members and industry, the CCRA has developed the following program areas:

Program Title	Program Objectives
Fundamentals of Coal Science	• To understand the fundamental science of metallurgical coal for supporting efficient exploration and product quality improvement to improve global competiveness of Western Canadian Coal.
Blast Furnace Ironmaking Carbon Efficiency Enhancement	• To advance pulverized coal injection technology for improving carbon efficiency of blast furnace ironmaking. • To improve quality of metallurgical coke by understanding the fundamental science of cokemaking and coke utilization for supporting high carbon efficiency blast furnace ironmaking.
Substitution of Fossil Carbon by Renewable Biocarbon in Pyrometallurgy Processes	• To reduce GHG emissions associated with pyrometallurgical metal production processes in Canada. • To develop technology for enabling substitution of fossil carbon by biocarbon in pyrometallurgical sectors. • To develop biocarbon supply chain to support metal production sectors.
Carbon Neutral Ironmaking Technology Development	• To develop technology for achieving carbon neutrality ironmaking in Canada by embracing different technologies (BioCarbon, H_2, Electron, CCUS).

These changes will ensure that the CCRA continues to meet the needs of industry and align with Government Policies. As can be seen in Appendix 1, much work is already underway and will continue to evolve.

1965-2022 CHAIR OF BOARD OF DIRECTORS

Year	Name	Company
1965 – 1966	C.W. Draker	Algoma Steel Limited
1967 – 1968	F.J. Pearce	The Steel Company of Canada Limited
1969 – 1970	J.E. Ludberg	Dominion Foundries and Steel Limited
1971 –1972	J.S. Anslow	The Steel Company of Canada Limited
1973 – 1974	J.O. Thomas	DEVCO
1975 –1976	A.M. Cameron	Algoma Steel Limited
1977-1977	J.T. Collier	DEVCO-SYSCO
1978 – 1979	W.A. Riva	Kaiser Resources Limited
1980 – 1980	J.E. Ludberg	Dofasco Limited
1981 – 1982	A. Johnson	Gulf Resources Limited
1983 –1984	A.W. Kay	Stelco Inc.
1985 – 1986	R. Sagi	Denison Mines Limited
1987 – 1988	W. Becken	Dofasco Inc.
1989 – 1990	W.R. Leeder	Denison Mines Limited
1991 – 1992	K. Carnes	Fording Coal Limited
1993 – 1994	H. Stelmach	Line Creek Resources Limited
1995 –1996	T. Benner	Dofasco Inc.
1997 –1998	W. Jonasson	Algoma Inc.
1999 – 2000	W.R. Leeder	Teck Corporation
2001 – 2002	W.R. Leeder	TeckCominco Corp.
2003 – 2006	W.R. Leeder	Elk Valley Coal Limited
2007 – 2022	T. Todoschuk	ArcelorMittal Dofasco Inc.

2021-2022 BOARD OF DIRECTORS

COMPANY	NAME	PHONE (FAX)
Algoma	Cory Evans Superintendent, Cokemaking Algoma 105 West Street Sault Ste. Marie, ON, P6A 7B4 cory.evans@algoma.com	(705) 297-0555 (705-945-4189)
ArcelorMittal Dofasco Inc.	Ted Todoschuk Programme Leader ArcelorMittal Dofasco Global R&D - Hamilton 1390 Burlington St. E Hamilton, ON, L8N 3J5 ted.todoschuk@arcelormittal.com	(905) 548-4796 Cell:(905-520-4451)
CanmetENERGY	Dr. Brian Farnand S&T Director, Industrial Innovation Group CanmetENERGY Natural Resources Canada 1 Haanel Drive Ottawa, ON, K1A 1M1 bfarnand@nrcan.gc.ca	(613)-996-7977 (613-995-9728)
Elkem Métal Canada Inc.	M. Jean-Denis Tremblay Engineering/Maintenance Manger Elkem Chicoutimi, Foundry Products 2020, chemin de la resérve Chicoutimi, QC G7J 0E1 jean-denis.tremblay@elkem.com	(418) 549-9917 ex. 260 Cell: (418) 820-6612
Stelco	John D'Alessio Director - Process Technology Stelco - Lake Erie Works BF Control Building, 2nd Floor 2330 Regional Road #3 Nanticoke, ON N0A 1L0 john.dalessio@stelco.com	(519) 587-4541 Ext. 5270 Cell: (905) 308-1253
SunCoke Energy, Inc.	Dr. John Quanci Vice President, Engineering and Technology SunCoke Energy, Inc. Suite 600, 1011 Warrenville Road Lisle, IL USA 60532 jfquanci@suncoke.com	(630) 824-1941 Cell: (610) 496-5989
Teck	Jason Halko Global Manager Technical Marketing Teck Resources Limited/Teck Coal Limited Suite 1400, 500 Centre Street SE Calgary, Alberta T2G 1A6 jason.halko@teck.com	(403) 767-8600 Cell: (403) 671-3798

2021-2022 CORPORATE OFFICERS

CCRA Position	COMPANY	NAME	PHONE (FAX)
Chairman	**ArcelorMittal Dofasco Inc.**	Ted Todoschuk Programme Leader ArcelorMittal Dofasco Global R&D - Hamilton 1390 Burlington St. E Hamilton, ON, L8N 3J5 *ted.todoschuk@arcelormittal.com*	(905)-548-4796 Cell (905)-520-4451
Vice Chair	**Teck**	Jason Halko Global Manager Technical Marketing Teck Resources Limited/Teck Coal Limited Suite 1400, 500 Centre Street SE Calgary, Alberta T2G 1A6 jason.halko@teck.com	(403) 767-8600 Cell (403) 671-3798
Secretary	**CanmetENERGY**	Ka Wing Ng Research Scientist CanmetENERGY Natural Resources Canada 1 Haanel Drive Ottawa, ON K1A 1M1 *kawing.ng@canada.ca*	(613) 996-8712
Treasurer	**Brian G. D'Amboise Chartered Professional Accountant**	Brian D'Amboise, CPA, CA Chartered Professional Accountant *CCRA-Treasurer@bell.net*	(905) 938-2984

2021-2022 TECHNICAL COMMITTEE MEMBERS

COMPANY	NAME	PHONE (FAX)	ALTERNATE OR CO-MEMBER
CanmetENERGY	**CHAIR:** Dr. Pierre Martin Manager Metallurgical Fuel Lab CanmetENERGY-Ottawa Natural Resources Canada 1 Haanel Drive Ottawa, ON K1A 1M1 pierre.martin@canada.ca	(613) 944-4330	Ka Wing Ng Research Scientist CanmetENERGY Natural Resources Canada 1 Haanel Drive Ottawa, ON K1A 1M1 (613) 996-8712 kawing.ng@canada.ca
ArcelorMittal Dofasco Inc.	***VICE CHAIR:*** Ted Todoschuk Programme Leader ArcelorMittal Dofasco Global R&D - Hamilton 1390 Burlington St. E. Hamilton, ON L8N 3J5 ted.todoschuk@arcelormittal.com	(905) 548-4796 Cell: (905) 520-4451	Graeme Scott Senior Researcher ArcelorMittal Dofasco Global R&D - Hamilton (905) 548-7200 x6619 graeme.scott1@arcelormittal.com
CanmetENERGY	***SECRETARY:*** Xianai Huang Research Scientist Metallurgical Fuels Lab CanmetENERGY-Ottawa Natural Resources Canada 1 Haanel Drive Ottawa, ON K1A 1M1 xianai.huang@nrcan-rncan.gc.ca	(613) 947-6584	Kirby Wittich Research Engineer CanmetENERGY Natural Resources Canada 1 Haanel Drive Ottawa, ON K1A 1M1 (613) 943-8235 kirby.wittich@canada.ca
Teck	Dr. Qun Zhang Senior Researcher Teck Metals Ltd. PO Box 2000 Trail, BC V1R 4S4 qun.zhang@teck.com	(250) 364-4422 Cell: (250) 921-4269	Michelle Latosinsky Sr. Eng. Coal &Coke Quality Teck Resources Limited Suite 1400, 500 Centre St. SE Calgary, AB T2G 1A6 (403) 767-8552
Stelco	Mr. John D'Alessio Director - Process Technology Stelco - Lake Erie Works BF Control Building, 2nd Floor 2330 Regional Road #3 Nanticoke, ON N0A 1L0 john.dalessio@stelco.com	519-587-4541 Ext. 5270 Cell: 905-308-1253	Ms. Nancy Ward Process Engineer - Process Technology Stelco - Lake Erie Works BF Control Building, 2nd Floor 2330 Regional Road #3 Nanticoke, ON N0A 1L0 519-587-4541 Ext. 5012 Cell: 519-410-3453 nancy.ward@stelco.com
Algoma	Mr. Jarred Kapush Graduate Engineering Trainee 105 West Street Sault Ste. Marie, ON P6A 7B4 jarrad.japush@algoma.ca		TBD
SunCoke Energy, Inc.	Dr. Jonathan Perkins Senior Scientist SunCoke Energy, Inc.	(630) 824-1938 Cell: (610) 858-7706	Dr. John Quanci Vice President, Engineering and Technology

COMPANY	NAME	PHONE (FAX)	ALTERNATE OR CO-MEMBER
	Suite 600, 1011 Warrenville Road Lisle, IL USA 60532 jhperkins@suncoke.com		SunCoke Energy, Inc. Suite 600, 1011 Warrenville Road Lisle, IL USA 60532 Cell: (610) 496-5989 jfquanci@suncoke.com
Elkem Métal Canada Inc.	M. Jean-Denis Tremblay Engineering / Maintenance Manager Elkem Chicoutimi Foundry Products 2020, chemin de la réserve Chicoutimi, QC G7J 0E1 jean-denis.tremblay@elkem.com	(418) 549-9917 ext. 260 Cell: (418) 820-6612	TBD
CCRA Guest Member	Ms. Melanie Mackay Professional Geoscientist 3360 Georgia Street Richmond, BC, V7E 2R6 mmackaygeo@gmail.com	(604) 323-6692	Not Applicable
CCRA Consultant	Dr. John Price 28 Nanook Crescent Ottawa, ON K2L 2A7 j.t.price@rogers.com	(613) 592-4397	Not Applicable
Sr Technical Consultant Teck Coal Ltd.	Dr. Ross Leeder 12686 Ocean Cliff Drive Surrey, BC V4A 6N1 ross.leeder@teck.com	(604) 531-1944 Cell: (604) 317-7412	Not Applicable

Appendix 1 – 2021-2022 CCRA Technical Committee Planning Table		
Program	**Program Objectives**	**Projects**
Fundamental of coal science	• To understand the fundamental science of metallurgical coal for supporting efficient exploration and product quality improvement to improve global competiveness of Western Canadian Coal	CCRA 54: ISO and ASTM Coal and Coke Standards
		CCRA 90: Exploration Sample Assessment for Current and New Coal Mines in Canada
		CCRA 81: Mineral Matters in Western Canadian Coal
		CCRA 80: Characterization of Coal Washing Plant Streams and Product Quality Upgrade
		CCRA 86: Performance of Canadian Coals in High Inert Blends (review for next step)
		CCRA 87: Technical Merits of Western Canadian Coals
		CCRA 93: Performance of Western Canadian Coal in Stamp Charge
Blast furnace ironmaking process carbon efficiency enhancement	• To advance pulverized coal injection technology for improving carbon efficiency of blast furnace ironmaking. • To improve quality of metallurgical coke by understanding the fundamental science of cokemaking and coke utilization for supporting high carbon efficiency blast furnace ironmaking.	CCRA 91: Blast Furnace Energy Reduction Initiatives using Auxiliary Fuel Injection
		CCRA 82: Factors Affecting Coke Bed Permeability (1)
		CCRA 88: Application of Small-Scale Coking
		CCRA 77: Energy Recovery Cokemaking Technology
		CCRA 84: Coke Degradation Mechanisms
		CCRA 94: High Temperature Properties of Coke (Need some background)
Substitution of fossil carbon by renewable biocarbon in pyrometallurgy processes	• To reduce GHG emissions associated with pyrometallurgical metal production processes in Canada. • To develop technology for enabling substitution of fossil carbon by biocarbon in pyrometallurgical sectors. • To develop biocarbon supply chain to support metal production sectors	CCRA 70A: Raw materials, Pyrolysis technology and Transportation
		CCRA 70B: Substitution of blast furnace pulverized coal injection and EAF slag foaming injection by bio-carbon
		CCRA 70C: Incorporation of bio-carbon in cokemaking by densification and utilization of bio-coke in blast furnace ironmaking
		CCRA 70D: Bio-Carbon for non-ferrous metal production
Carbon neutral ironmaking	• To develop technology for achieving carbon neutrality ironmaking in Canada through	CCRA 95A: Alternate Ironmaking Technology
		CCRA 95B: Gaseous Reducing Agent Supply

technology development	embracing different technologies (Biocarbon, H2, Electron, CCUS)	CCRA 95C: Renewable Electricity
		CCRA 95D: Application of CCUS
		CCRA 95E: Process Analysis and Assessment
CanmetENERGY MFL Facilities	• To ensure the reliability and repeatability of CanmetENERGY facilities • To develop new research facilities in	Benchmarking of Movable Wall Ovens
		Quarterly LQSI Round Robin

Program	Projects	Team	Project Objectives	Project Tasks	
Fundamentals of Coal Science	CCRA 54: ISO and ASTM Coal and Coke Standards	AM Dofasco T. Todoschuk Stelco J. D'Alessio N. Ward CanmetENERGY Xianai Huang	• Development of standards and procedures pertaining to Canadian Coal and Steel industries	**Identify both ASTM and ISO up for review**	• On-going
				ISO Inter Lab Study on Dilatation	• Normalization of dilatation measurement results to reference mass ○ Final Report: Inter Laboratory Study on Coal Dilatation under ISO/TC27 ○ METEC 2019: Findings of inter laboratory study on coal dilatation under ISO/TC27 and importance of correcting experimental dilatation results to a reference coal mass
				Effect of coal particle size on rheology measurement	• Fluidity and dilatation measurement of US coal samples at different size (A3) ○ METEC 2019: Coal rheology - A Practical Approach for Industry ○ AIST 2019: Coal Rheology — A Practical Approach for Industry
					• Fluidity and dilatation measurement of Canadian coal samples at different size (A3) ○ Teck select 4 WCC sample and send to Canmet for analysis ○ *Sample prepared following standard procedures

Gieseler Fluidity

Size (Mesh)		WCC 1		WCC 2		WCC 3		WCC 4	
Min	Max	ddpm	T_{Range}	ddpm	T_{Range}	ddpm	T_{Range}	ddpm	T_{Range}
0	**40***	**415**	**71**	**97**	**59**	**39**	**60**	**2**	**43**
60	40	526	73	207	66	34	63	4	52
80	60	541	74	155	67	45	65	3	51
100	80	488	75	143	64	48	69	3	49
140	100	409	77	98	63	50	73	3	51
200	140	397	74	59	60	47	66	2	45
0	200	221	70	16	57	25	65	1	39

Ruhr Dilatation

Size (Mesh)		WCC 1		WCC 2		WCC 3		WCC 4	
Min	Max	SD2.5	T_{Range}	SD2.5	T_{Range}	SD2.5	T_{Range}	SD2.5	T_{Range}
0	**60***	**125**	**83**	**37**	**80**	**40**	**75**	**-14**	**68**
80	60	147	85	51	83	24	81	-18	68
100	80	143	83	44	86	29	72	-16	74
140	100	142	85	40	82	32	66	-16	70
200	140	132	83	26	81	30	69	-23	65
0	200	90	86	11	79	21	67	-23	51

Sapozhnikov plastometry	• Equipment Commissioning (A3) ○ Equipment Handover: Completed

- Operating Procedure Development
  - Draft SOP and THA completed
- Measurement Repeatability Establishment
  - 4 repeated tests with WCC (27686)
  - 4 repeated tests with high max fluidity US coal (27687)
    - Cannot obtain valid X measurement. Test plan aborted
  - 4 repeated tests with 2020 Oven Benchmarking US Blend (27738)

	X		Y	
Sample	**Ave**	**Stdev**	**Ave**	**Stdev**
WCC (27686)	28.1	0.9	12.6	0.2
US (27687)	Abort	Abort	Abort	Abort
US Blend (27738)	25.6	0.7	19.0	0.4

- Benchmarking with other lab for establishing reproducibility
  - 3 coal samples was collected
    - 100% US Blend: 2020 Oven Benchmarking US Blend (27738)
    - 65%US-35 %WCC Blend: same as WCC blend in CCRA 82 (27740)
    - 100% WCC (STDBL): same as WCC for CCRA 82 (27734)

	X		Y	
Sample	**Canmet**	**External Lab**	**Canmet**	**External Lab**
US Blend (27738)	25.6	26.1	19.0	19.4
US-WCC Blend (27740)	28.7	29.6	19.1	16.8
WCC (27734)	28.0	30.4	12.6	11.3

- Report: Commissioning of CanmetENERGY Automatic Sapozhnikov Plastometer
  - Report: CCRA 54:001/2020 Commissioning of CKIC Automatic Sapozhnikov Plastometer
  - Report: CCRA 54:002/2020 Automatic Sapozhnikov Plastometry Parameters Determination

- Effect of Fines Content on Sapozhnikov Plastometry Measurement for ISO Standard Development
  - * Sample prepared following standard procedure

	WCC 1		WCC 2		WCC 3		WCC 4	
%Fines	X	Y	X	Y	X	Y	X	Y
32*	**21.00**	**13.35**	**31.5**	**11.15**	**25.20**	**10.2**	**23.0**	**8.10**
0	41.35	15.45	47.65	10.0	46.30	9.3	40.6	9.1
40	13.25	13.75	28.35	10.5	25.35	12.05	20.8	7.40
50	12.70	15.30	27.00	10.6	22.25	11.0	23.1	8.90
100	25.60	17.75	41.10	9.5	37.20	13.85	39.2	10.2

  - Report: CCRA 54:001/2021 Effect of Fines Content on Sapozhnikov Plastometry Parameters

				Examination of coal oxidation information	• CCRA Publications ○ 2001: Determination of organic oxygen in coals with application to the study of coal weathering ○ 2003: Application of TG-FTIR to the determination of oxygen content of coals ○ 2004: Detection of natural oxidation of coking coal by TG-FTIR-Mechanistic implications ○ 2006: Application of Thermogravimetric Fourier Transform Infrared Spectroscopy (TG-FTIR) to the Analysis of Oxygen Functional Groups in Coal ○ 2006: Application of TG-FTIR to the determination of organic oxygen and its speciation in the Argonne Premium Coal samples ○ 2006: Storage of small samples of coking coal for thermal rheological tests ○ 2011: Deterioration of coking coal quality in samples and stockpiles
					• Current research status ○ Ross to prepare a report to summarize oxidation work to date • Determination of Oxidation Boundary ○ Detail project plan to be developed by Melanie
	CCRA 90: Exploration Sample Assessment for Current and New Coal Mines in Canada	CCRA Consultant Melanie Mackay CanmetENERGY Ka Wing Ng Teck Jason Halko Ross Leader	• To investigate alternative environmental friendly methods to produce exploration coal samples for further assessment.	**Exploration technology**	• Relationship between Geophysical Density Response and Laboratory Analysed Raw Ash ○ Detail project plan to be developed by Melanie
				Effect of clean coal composite preparation (CCC) by float/sink with organic liquid on coal properties	• Effects of Organic Liquids on Western Canadian Coking Coals ○ Fuel Processing Technology 2017: Effects of organic liquids on coking properties of a higher-inert Western Canadian Coal
					• Effect of Float/Sink with Perchloroethylene on HGI ○ Detail project plan to be developed by Melanie
				Development of CCC Preparation by water base Roben Jig Technology	• Preliminary evaluation of Australian Boner Jig facility performance on WCC ○ Completed: The jig worked (2016)
					• Phase 1: Roben Jig Facility Setup in Canada ○ Completed: Commissioning with 4 coal samples (3SEBC and 1 NEBC) (2017)
					• Phase 2a: Performance of Roben Jig on clean coal sample preparation ○ Completed ○ Able to make a clean coal composite that matched the plant sample ○ Misplace material in the Jig was found and measured

- Jigging with narrow size fraction was impractical
- Re-jigging helped to remove some misplaced material. +1.54SG material decreased from 6% to 2%

- Phase 2b: MWO evaluation of coking performance of sample prepared by Roben Jig
  - Single seam plant coal samples collection
    - Raw coal feed and clean coal
  - Raw coal feed process
    - Create organic liquid and Roben jig CCC (Dec 9-13, 2019)
    - Coal properties comparison: Plant clean coal vs Organic liquid vs Roben jig (Dec 16-20, 2019)
  - MWO carbonization
    - MWO carbonization of plant clean coal, sample prepared by organic liquid float/sink and Roben jig CCC completed Jan 2020.
  - Final Report and Publication
    - Producing Clean Coal from Western Canadian Coal Fields using the Water-based Boner Jig Process – Coal SMART presentation February 2017
    - Producing clean coal from western Canadian coalfields using the water-based Roben Jig process – Geoscience BC Summary of Activities 2017
    - Producing Clean Coal from Western Canadian Coal Fields using the Water-based Boner Jig Process 2018 update – Coal SMART presentation February 2018
    - Producing clean coal from western Canadian coalfields using the water-based Roben Jig process: refining the process – Summary of Activities 2018: Minerals and Mining, Report 2019-01
    - Geoscience BC Report 2019-05: Producing Clean Coal from Western Canadian Coal Fields using the Water-based Roben Jig: Refining the Process
    - Fuel 306 (2021) 121729: Preparation of Clean Coal Samples Using Roben Jig

- Phase 3: Using Roben Jig to Wash 'Difficult to Wash' Coals
  - Detail project plan to be developed by Melanie

Alternate liquid for Float/Sink coal washability study

- Phase 1: Evaluation of Alternate Float-Sink Liquid (3M FC-770 and Novec 7700) for Clean Coal Composite Preparation (A3)
  - Clean coal composite preparation (GWIL)
    - Float-Sink with perchloroethylene (PCE)
    - Float-Sink with 3M FC-770 and Novec 7700 (NOVEC)
    - Roben Jig (JIG)
  - Clean coal composite properties(GWIL)

	PCE	NOVEC	JIG
Canmet Index	28152	28153	28151
%Ash	8.11	7.69	7.87
Basicity Index	0.216	0.191	0.202
Cl (ppm)	1580	414	177
Max Fluidity (ddpm)	203	256	241
SD2.5	87	91	103
FSI	8	7	8

- SHO Carbonization Coke Properties (Canmet)

	PCE	NOVEC	JIG
Canmet Index	28152	28153	28151
E/C	-8.57	-8.37	-8.02
ASG	0.979	0.951	0.978
CSR	62.2	60.2	62.4
CRI	23.9	25.0	23.6
%Ash	10.32	10.42	10.34
%S	0.55	0.58	0.55
Isotropic	2.20	2.50	1.80
%Binder Phase	88.90	84.1	88.40
%Inert Phase	8.90	13.40	9.80
Calculated Ro	0.97	1.01	1.04
CSMI	1.97	1.97	2.05

- Phase 2: Evaluation of Alternate Float-Sink Liquid (3M FC-770 and Novec 7700) for Clean Coal Composite Preparation
  - Detail project plan to be developed by Melanie

CCRA 81: Mineral Matters in western Canadian coal

Teck
Anelda van Staden

CanmetENERGY
Kun Liu

CCRA Consultant
John Price

- To understand the effect of mineral type and size in coal on resultant coke quality
- To understand the characteristics of western Canadian coal in-situ mineralogy and transformation of minerals in carbonization

Preliminary Study

- Publications
  - ISS-AIME Ironmaking 1994: Minerals in Coal and High Temperature Properties of Coke
  - AIST 2014: Mineral Matter Transformation in Small-Scale Coke Oven for Evaluation of CSR/CRI
  - CCRA Report: Coal and Coke Mineralogy Influences on Coke Properties and Behavior in Blast Furnace

Effect of mineral type and size on coke quality

- Mineral Addition Tests
  - Completed: SHO carbonization of WC MV and US HV with 1% mineral addition at different size
    - AIST 2017 Effect of Coal Mineral Type and Size on Coke Strength After Reaction
    - AIST 2019: Effect of Coal Mineral Type and Size on Coke Strength After Reaction
- Role of in-situ mineral type and size on CSR prediction
  - Phase 1: Coals with resultant coke CSR do not align with prediction (A3)
    - Carbonization of selected coal samples and measurement of CSR
    - Comparison of measured CSR with predictions

	US LV	WCC	US HV
Canmet Index	**27410**	**27211**	**27992**
Measured CSR	49.9	70.6	76.3
Predicted CSR	64.5	58.4	64.9

    - Mineral analysis of both coal and resultant coke
      - Coal Mineralogy Characterization: Completed
      - Coke Mineralogy characterization: Completed
    - Observations

- Distribution of inorganic elements between crystalline and glassy phases in coke
- Distribution of inorganic elements between catalytic and non catalytic groups in coke

- Phase 2: Coals and resultant cokes in 2022 Annual Oven Benchmarking Project
  - Coal and corresponding resultant coke samples collection

Index	28324	28325	28326	28327	28337	TBD	TBD	TBD	TBD
US 1	100%					25%	25%	15%	15%
US 2		100%				30%	30%	10%	10%
US 3			100%			25%	25%	25%	25%
US 4				100%		20%	20%	20%	20%
WCC					100%	--	--	30%	30%
Coke Oven	SHO	SHO	SHO	SHO	SHO	SHO	18 in	SHO	Carbolite

  - Mineralogy characterization of component coals and blends and corresponding resultant cokes
    - TBD

	CCRA 80: Characterization of Coal Washing Plant Streams and Product Quality Upgrade	TBD	• To characterize the metallurgical properties of mine circuits to better understand how to improve coke quality and hence energy efficiency for both the coal and steel industries. • To determine which "oxidation/aging" parameters best reflect the caking/coking	**On Hold**	**On Hold**

			ability of each circuit and coal.		
	CCRA 86: Performance of Canadian Coals in High Inert Blends	TBD	• To understand how Western Canadian coals behave/work in high inert blends.	**On Hold**	• Current status ○ Report: CCRA 86:001/2021 Hi Inert Blends Performance Program Update
	CCRA87: Technical Merits of Western Canadian Coals	TBD	• To develop fundamental studies that show the technical merits of Western Canadian coals. • To package existing technical information/data and gather new analysis data for highlighting the fact that Canadian coals prove to make high quality coke for modifying perception of marketing representatives.	**MOF Diagram**	• MOF Diagram Modification ○ Publications ○ AIST 2013: Predictive Model for Blending Coking Coals Part 1 Canadian Coal ○ AIST 2015: Predictive Model for Blending Coking Coals Part 2 US Coal ○ METEC 2015 Predictive Model for Blending Coking Coals to Produce High Strength Coke ○ Preparation for next phase ○ Test Plan ○ Letter to ARCAP ○ Summary of test program with Australian coal including all phases
				Sapozhnikov Plastometry	• Application of Sapozhnikov Plastometry in Coal Blend Design ○ Literature review: ○ TC 248 Sept 2019: Application of Sapozhnikov Plastometry in Coal Blend Design ○ Project Scope definition ○ TBD ○ Experimental Plan ○ TBD
	CCRA 93: Performance of Western Canadian Coal in Stamp Charge	Teck Jason Halko CanmetENERGY Keith Ludlow	• To understand the effect of incorporating Western Canadian Coal in stamp charge blend on resultant	**Canmet Stamp charge capability development**	• Benchmark single compartment box stamp charge with gravity charge results (A3) ○ Completed: Gravity charge (BD: 810 kg/m3) vs Box stamp charge (BD: 925 kg/m3) • Stamping apparatus development ○ Small scale coal blend densification test to understand compaction behavior of coal: ○ 1x1x1 ft wooden box ○ Coal particle size 85% <3mm ○ 10% Moisture

coke quality and coal blend stampability

- Achieve 978 kg/m3 dry BD
- 8" ID metal cylinder
  - Coal particle size 100%<3mm; 73%<1mm; 43%<0.5mm
  - 10% Moisture
  - Achieve 1003 kg/m3 dry BD
- Proctor test equipment developed for soil compaction
  - Report CCRA93: 001/2020 Coal Stampability by Compaction with Adapted Soil Proctor Method (ASTM D1557)
- Examine the effect of coal particle size distribution on compaction energy
  - Identify suitable particle size distribution and equipment to allow reaching 1000 kg/m3 dry BD for conducting MWO test

Effect of WCC in stamp charge on resultant coke quality

- Formulation of base case stamp charge coal blend
  - Lit review: CCRA 93:001/2019: A Review of Literatures on Stamp Charge Technology
  - Coal blend formulation: CCRA TC 249 Dec 2019
    - **Base blend**: 45% PCI - 15%LV - 40% HVA
    - **WCC Blend**: 40% PCI - 35% HVA - 25% WCC

- MWO carbonization test plan (A3)
  - Carbonization Test Plan
    - Test 1: Gravity charge **BASE BLEND** at 820 kg/m3 dry BD and 2.5% moisture
    - Test 2: Box charge **BASE BLEND** at 1000 kg/m3 dry BD and 10% moisture
    - Test 3: Gravity charge **WCC BLEND** at 820 kg/m3 dry BD and 2.5% moisture
    - Test 4: Box Charge **WCC BLEND** at 1000 kg/m3 dry BD and 10% moisture

Test	1	2	3	4
Blend	Base	Base	WCC	WCC
Charge Method	Gravity	Box	Gravity	Box
Particle Size	80%<3mm	TBD	80%<3mm	TBD
BD(dry)	820	1000	820	1000
Moisture	2.5%	10%	2.5%	10%

  - Carbonization Test Results
    - TBD

Program	Projects	Team	Project Objectives	Project Tasks	
Blast furnace ironmaking process carbon efficiency enhancement	CCRA 91: Blast Furnace Energy Reduction Initiatives using Auxiliary Fuel Injection	AM Dofasco T. Todoschuk Stelco J. D'Alessio N. Ward CanmetENERGY K.W. Ng X. Huang	• To develop analytical method for monitoring the combustion efficiency of pulverized coal injection in industrial blast furnace • To determine the roles of coal rheology and petrographic properties on pulverized coal combustibility	**Preliminary Study**	○ AIST 2015: Evaluation of PCI Coals in New Injection Facility at CanmetENERGY-OTTAWA
				PCI rig setup	• Standard rig test procedure ○ Establish repeatability of PCI rig test: Completed ○ Apply carbon type differentiation (CTD) TGA technique to rig combustion residues: Completed ○ Develop new methodology to examine reactivity of combustion residues: Completed ○ Validate ash tracer assumption for burnout calculation: Completed ○ Report ○ CCRA Report (CCRA 91:001/2018): CanmetENERGY Pulverized Coal Injection Rig Repeatability Tests

					• Rig capability enhancement
					○ Natural gas/Coke oven gas- Coal co-injection (A3)
					  ○ CCRA Report (CCRA 91:003/2019): Re-Commissioning of Natural Gas-Coal Co-Injection Capability
					  ○ CCRA Report (CCRA 91:004/2019): Effect of Natural Gas Co-Injection on Pulverized Coal Combustion
					  ○ CCRA Report (CCRA 91:005/2019): Comparison between Combustion of Coke Oven Gas and Natural Gas
					○ Blast moisture control
					  ○ Completed
					○ Off gas sampling
					  ○ On hold

				Develop relationship between coal properties (petrography, rheology) and combustion behaviour	• Collection of coal properties data and combustion behavior ○ CCRA Report (CCRA91:002/2019): Carbonaceous Materials Transformation during Pulverized Coal Injection ○ AIST 2019: Carbonaceous Materials Transformation in Pulverized Coal Injection ○ METEC 2019: Effect of Coal Properties on Combustion Behavior during Pulverized Coal Injection
	CCRA 82: Factors Affecting Coke Bed Permeability	Teck Jason Halko CanmetENERGY Ka Wing Ng	• To understand the effect of coke size and shape on bed permeability • To understand the effect of western Canadian coal on resultant coke size and shape	**Analytical technique to development size and shape of coke**	• Equipment setup for coke bed permeability measurement ○ Completed • Image analysis technique development for coke size and shape characterisation ○ Completed ○ AIST 2013 Coke Size and Shape Characterisation for Bed Permeability Estimation

Relationship between coke size and shape and bed permeability

- Completed
- AIST 2017 Factors Affecting Coke Bed Permeability

Effect of WCC on coke size and shape evolution in stabilization

- Effect of WCC in coal blend on resultant coke size and shape 2020 (A3)

- Carbonization for coke sample preparation
  - **US Blend**: 25% US LV(CB30)- 35% US HVA (LR)- 15% US HVB (CW)- 25%US HVC (MY)
  - **WCC Blend**: 16% US LV (CB30)- 23% US HVA (LR) -10% US HVB (CW)- 16% US HVC (MY)- 35% WCC
- Effect of Oven and WCC on Degradation
  - Extended IRSID completed
  - Test data to be discussed in Dec 2020 meeting
- Effect of WCC on size and shape evolution in stabilization
  - Procedures
    - Collect 50kg IRSID sample for image analysis
    - Drop sample from 10 ft
    - Re-screen stabilized sample
    - Redo image analysis on stabilized sample

	18-2983			
Drops	Sieve	Dia	Shape	RI
1	65.7	61.59	1.81	28.9
2	61.1	53.3	1.727	35.1
3	58.6	52.49	1.717	42.8
4	56.3	50.3	1.688	66.8
5	54.5	50.1	1.677	62.2
	C-2919 (w/o WCC)			
Drops	Sieve	Dia	Shape	RI
1	67.8	64.11	1.923	31
2	61.8	56.33	1.821	46.4
3	59.4	53.36	1.773	40.2
4	56.5	51.13	1.742	55.8
5	55.3	49.72	1.713	57.7
	C-2920 (w/ WCC)			
Drops	Sieve	Dia	Shape	RI
1	62.2	63.98	1.982	17.4
2	60.2	55.62	1.874	25
3	57.6	52.87	1.822	35.1
4	54.8	50.62	1.748	63.3
5	53.5	51.16	1.724	102

- Report: CCRA 82:001/2021 Effect of Coal Blend Composition on Resultant Coke Size and Shape Characteristics and Degradation Behavior

					• Effect of WCC in coal blend on resultant coke size and shape 2022 (A3) ○ Coke Sample Preparation ○ US Blend: 25%CB30-35%LR-20%CRM-20%LGCB ○ WCC Blend: 25%CB30-35%WCC-20%CRM-20%LGCB ○ Effect of WCC on size and shape evolution in stabilization ○ Procedures ○ Collect 50kg IRSID sample for image analysis ○ Drop sample from 10 ft ○ Re-screen stabilized sample Redo image analysis on stabilized sample
				Effect of coal properties on coke size and shape	• To be developed
	CCRA 77: Energy Recovery Cokemaking			**On-Hold**	
	CCRA 84: Coke Degradation Mechanisms	TBD	• To understand the effect of coal properties, carbonization conditions and handling on coke degradation mechanism	**On-hold**	○ AIST 2005 Stabilization of Blast Furnace, Sampling Station, Wharf And Pilot Oven Cokes from Canadian Steel Mills ○ AIST 2011 Implementation of Coke Stabilization at ArcelorMittal Dofasco ○ AIST 2017 CanmetENERGY's Experience on Performing High-Temperature Dilatation Measurements ○ CCRA Report: CCRA84:001/2019 Review of CCRA Research on Coke Degradation
	CCRA 88: Application of Small Scale Coking		• To develop and demonstrate carbonization methods for small (<350kg) coal samples	**SHO CSR**	• Publication: Fuel 2013: Small scale determination of metallurgical coke CSR
				Canmet multi-compartment box charge capability development	○ Equipment Fabrication for Box Charge ○ Completed ○ Multi-compartment box charge capability demonstration (A3) ○ Completed: First set of MWO tests ○ Gravity, 1 compartment, 2 compartment and 3 compartment charge with same coal blend ○ Demonstrate capability to conduct multi-compartment box charge ○ Observations ○ No significant variation in coke quality between compartments in 2 compartments box charge and similar to gravity charge ○ Coke quality in 3 compartment box charge varies between compartments ○ Current setup does not allow gas pressure and center temperature measurement in each compartment ○ Needs to design new equipment for gas pressure and center temperature measurement

				Benchmarking of multi-compartment box charge with gravity charge	• Combined gas pressure and center temperature measurement ○ Two Compartment Box Charge ○ Design and fabrication: Completed ○ Functionality test: CCRA TC 246 March 2018 ○ Three Compartment Box Charge ○ TBD • Benchmarking of two compartment box charge with gravity charge (A3) ○ TBD • Benchmarking of three compartment box charge with gravity charge ○ TBD
	CCRA 94: High Temperature Properties of Coke	TBD	• To understand the high temperature (>1100C) properties of coke	**On Hold**	

Program	Projects	Team	Project Objectives	Project Tasks	
Substitution of fossil carbon by renewable biocarbon in pyrometallurgy processes	CCRA 70A: Raw materials, Pyrolysis technology and Transportation	AM Dofacso T. Todoschuk Stelco J. D'Alessio N. Ward Algoma C. Evans A. Talati CanmetENERGY K.W. Ng X. Huang	• To develop raw biomass supply and pyrolysis technology for producing suitable biocarbon for steel production	**Preliminary Study**	• METEC 2011: Biofuel Ironmaking Strategy from a Canadian Perspective: Short-Term Potential and Long-Term Outlook • AIST 2010: Direct Injection of Biofuel in Blast Furnace Ironmaking • Iron and Steel Technology 2012: Combustibility of Charcoal for Direct Injection in Blast Furnace Ironmaking • SCANMET IV 2012: SELECTION OF BIOFUEL FOR DIRECT INJECTION IN BLAST FURNACE IRONMAKING • AIST 2012: Incorporation of Charcoal in Coking Coal Blend – A Study of the Effects on Carbonization Conditions and Coke Quality • Fuel Processing Technology 2011: Reactivity of bio-coke with CO2 • AIST 2011: Biofuel Use in Ironmaking From a Lifecycle Analysis Perspective • AIST 2012: Wood Pellets for Ironmaking From a Life Cycle Analysis Perspective
				Raw Biomass Supply	• Evaluate feedstock type, location, quality, and quantity ○ Forestry Biomass ○ Quebec forestry residue supply: Quebec woodchip association report ○ Ontario forestry residue supply: CRIBE Nextfor Innovation Hub ○ C&D wood ○ Potential Supply: Ecostrat report ○ ISO Grade Standard ○ Rail Ties and Decommissioned Poles ○ Supply assessment: To be completed by Bioenergy • Biomass Feedstock Physico-Chemical Properties Database ○ Enhance CE-O biomass database and its functionalities to identify the biomass sources, volume, availability, costs etc.
				Pyrolysis Technology Assessment and Development	• Assessment of existing pyrolysis technologies ○ Completed: Bioenergy Group Report: Biomass Carbonization Technology, Producers and Products
					• Establish benchmark reference on effect of feedstock (Saw dust, Roadside, Barks and C&D Wood) and pyrolysis technology (torrefaction, fast pyrolysis and HTC) on product properties ○ Completed: CCRA Report (CCRA70:001/2018): Pyrolysis Technology Benchmarking Research Report

					• Pre-Treatment Protocols ○ Drying, chipping, hammer milling, sieving ○ Biomass Feeding System • Pre-Treatment by Steam Explosion ○ Ash content control ○ Binding potential in Densification ○ Densified product durability and weathering resistance
					• Hydrothermal Carbonization Process Development ○ Literature Review ○ Focus on using waste materials as feedstock ○ To be completed by student from Polytechnic Mtl in summer 2020 ○ Will share results with CCRA ○ CanmetENERGY 20L HTC Reactor ○ On Hold
					• Pyrolysis of Rail Ties/Decommissioned Poles (A3) ○ Literature Review on Pyrolysis of Creosote Treated Wood ○ Report to be written ○ Benchmarking between CPM Jenkner Retort and Canmet Rotary Drum for Biomass Pyrolysis Heat and Mass Balance study (A3) ○ Continuous Screw Reactor Slow Pyrolysis Facility ○ Equipment capability ○ 10-20 kg/hr feed ○ Temp: Up to 800C ○ Residence time: 5-30 min ○ Recovering of gas and liquid pyrolysis products ○ Commissioning Test ○ Rail Ties Pyrolysis using the Continuous Screw Reactor ○ TBD
					• Pyrolysis of C&D Wood ○ Heat & Mass balance study of C&D "A" and "B" grade wood pyrolysis ○ Conclusions ○ Major challenge in C&D wood pyrolysis arises from foreign materials contamination ○ It affects operation of the pyrolysis process and also quality of final product ○ Development of standard grading system for consistent description of C&D feedstock cleanliness is essential ○ Bioenergy Group Reports

					○ Assessment of CHAR TECH Carbonization Process ○ Small Scale Batch Carbonization of C&D Wood
				Pyrolysis Product Properties Beneficiation	• Integrated slow pyrolysis and Densification ○ Densification of biocarbon using pyrolysis oil binder ○ Raw Biomass Densification ○ Report: NRC C&D Densification Report ○ Pyrolysis product densification ○ For transportation and handling ○ For nut coke replacement in blast furnace ironmaking ○ For EAF steelmaking
					• Develop technology for ash content control ○ Acid washing of CHAR biocarbon sample produced from C&D "A" grade wood with Acetic Acid (1.3% and 8.0%) and synthetic wood vinegar (Acetone + Methanol) ○ Na, K and P content not significantly affected by acid washing ○ CCRA Report (CCRA70:009/2019) Effect of washing biochar with various acidic media on ash content and composition ○ CCRA Report (CCRA70:010/2019) Effect of Biocarbon Acid Washing on Blast Furnace Operation ○ Study the mineral form of ash in before and after wash samples ○ Mineral form analysis by MLA was completed by TECK (Report) ○ Alkali and P in are in clay minerals ○ Not soluble in common acid ○ Feedstock Pre-Processing Followed by Pyrolysis ○ Pre-processing of feedstock by acid washing ○ Literature review of acid washing is ongoing in Bioenergy group. Tracking of both internal work and literature results ○ Review of Bioenergy group database on potential of raw feedstock acid washing ○ Pre-processing of feedstock by HTC ○ Pre-processing of feedstock by steam explosion
					• Biocarbon Properties Characterisation Standards ○ Comparison between Coal/Coke (ASTM D05 and ISO: TC27) Analysis Standard Procedures with Solid Biofuel (ISO: TC 238) Analysis Standard Procedures

					○ Proximate, Ultimate, Calorific value determination ○ Benchmarking between analysis procedures (A3) ○ ISO/TC238/TG1 Focus Group ○ Members: ○ Chris Wiberg (Timber Products Inspection / Biomass Energy Lab) (Group Leader) ○ Maurice Douek (consultant) ○ Brett Spigarelli (University of Minnesota Duluth) ○ Ka Wing Ng and Guy Tourigny (CE-O) ○ Graeme Scott (AMD) ○ Tasks: ○ Identify properties of biocarbon relevant to metallurgical applications ○ Ensure tools are available to measure the required properties reliably
	CCRA 70B: Substitution of blast furnace pulverized coal injection and EAF slag foaming injection by bio-carbon		• To develop technology for substituting	**Biocarbon VIU in Evaluation**	• Biocarbon VIU evaluation methodology development ○ Completed ○ AIST 2017: Suitability of Bio-Chars from Different Production Technologies for Direct Blast Furnace Injection ○ Ironmaking and Steelmaking 2018: Value-In-Use of BioCarbon Fuel for Direct Injection in Blast Furnace Ironmaking
				Grinding of Biocarbon	• Grinding Test with HGI Apparatus (A3) ○ AIST 2019: Grindability of Solid Bio-Carbon ○ CCRA Report (CCRA 70:007/2019): Rolling Mill Co-Grinding of Biocarbon and Coal ○ Conclusion: Follow ASTM HGI procedure for Biocarbon or Coal-Biocarbon mixture
				Direct Injection of Solid Biocarbon in Blast Furnace	• Bio-char injection rig test: ○ Substitution of HV PCI Coal (A3) ○ Completed ○ CCRA Report (CCRA 70:002/2019): 25% Substitution of High Volatile PCI Coal by Biocarbon ○ CCRA Report (CCRA 70:004/2019): 50% Substitution of High Volatile PCI Coal by Biocarbon ○ Substitution of HV vs LV in HV-LV PCI Coal Mixture (A3) ○ Completed ○ Effect of Biocarbon Composition on Suitability for PCI Substitution ○ Completed ○ Effect of Biocarbon Densification on PCI Substitution Performance ○ Completed

- CCRA Report (CCRA 70:008/2019): Effect of Physical and Chemical Properties of Biocarbon on Suitability for Direct Injection in Blast Furnace Ironmaking
- Summary Report: CCRA 70:002/2020

- Commercial Biocarbon Sample Evaluation (Overview A3)

Base Case (50%HV/50%LV)	%Burnout	50.30%			
	HGI	74			
	BD (kg/m3)	565.6			
	GHG	1520 kg/thm			
Biocarbon	**%Bio**	**25%**	**50%**	**75%**	**100%**
Airex Pellet (27363)	%Burnout	58.60%	--	--	--
	HGI	45.5	--	--	--
	BD (kg/m3)	--	--	--	--
	GHG	30.7	--	--	--
BC Biocarbon (27475)	%Burnout	40.70%	37.80%	3.80%	-131.30%
	HGI	71	75.6	Insufficient	Insufficient
	BD (kg/m3)	423.9	393.4	310.2	387.3
	GHG	-132.1	-240.8	--	--
Elkem Loose (26837)	%Burnout	57.20%	54.30%	Insufficient	Insufficient
	HGI	74.6	90	Insufficient	23.2
	BD (kg/m3)	416.6	344.9	Insufficient	234.8
	GHG	-94.4	-193.9	--	--
Elkem Briquette (26859)	%Burnout	54.10%	50.00%	57.00%	54.90%
	HGI	52.8	44.5	45.2	42.9
	BD (kg/m3)	592.5	548.8	556	537
	GHG	-90.6	-179.8	-283.4	-419.6
National Carbon Tech (27732)	%Burnout	60.10%	58.40%	Poor Flow	
	HGI	53.3	38.1	36.7	36.1
	BD (kg/m3)	532.9	440		
	GHG	-115.2	-232.5		

- Observations
  - Carbon content in Airex pellet is too low. Substituting PCI coal by Airex biocarbon results in overall GHG emissions increases.
  - The ash fusion temperature of BC Carbon sample is low (1137 C). Lost of ash by slagging during rig test leads to unreliable burnout determination.
  - The low ash fusion temperature is anticipated problematic at high degree of substitution in industry scale operation

					○ Incorporation of NCT biocarbon in pulverized coal results in flowability decreases. Frequent blockage of injection lance occurred during rig tests and required frequent cleaning of gas line to continue the rig test. ○ Report: Injection Rig Evaluation of Commercial Biocarbon for Direct Injection in Blast Furnace Ironmaking
				EAF Steelmaking	• Substitution of Charge carbon by biocarbon ○ Completed: No effect on steel and slag composition • Substitution of Injection carbon by biocarbon ○ Poor wetting results in very limited foaming ○ Injection test on hold until wetting issue is resolved ○ CCRA Report (CCRA 70: 005/2019): Biocarbon for EAF Steelmaking ○ Met Trans B 2019: Carbonaceous Material Properties and their Interaction with Slag during Electric Arc Furnace Steelmaking ○ AIST 2019 Biocarbon Materials in EAF Steelmaking • Cause of Poor Foaming between EAF slag and biocarbon ○ Effect of raw biomass feedstock and densification on wetting behavior ○ Softwood biocarbon shows better wetting by slag than hardwood biocarbon ○ Densification further enhance wetting behavior of softwood biocarbon ○ Investigation on hold • Injection facilities setup in CMAT ○ Review of research activities and results with AMD ○ Small scale tensiometer test procedure needs to be further refined for proper interpretation of observations. ○ Future effort will be focused on setting up injection experiments in CanmetMATERIALS ○ CCRA 70:001/2020 Meeting Minutes ○ Discussion with CMAT ○ CCRA 70:003/2020: Meeting Minutes
					• Pilot Scale Evaluation of Biocarbon Performance in EAF (Project Overview A3) ○ Benchmarking of CMAT Melting Facilities with Industrial Furnace ○ Effect of Biocarbon Properties on Performance as Charge Carbon ○ Effect of Biocarbon Properties on Performance as Injection Carbon

	CCRA 70C: Incorporation of bio-carbon in cokemaking by densification and utilization of bio-coke in blast furnace ironmaking		• To develop coal and biocarbon densification technology for facilitating incorporation of biocarbon in cokemaking coal blend	**Incorporation of Solid Biocarbon in Cokemaking by Briquetting with Coal**	• Incorporation of biocarbon via partial briquetting SHO carbonization (A3) ○ Completed ○ Optimal bio-briquette composition: 50%Coal-38%Biochar-12%Bio-oil binder ○ Optimal oven charge composition: 80% Loose coal-20%Briquette ○ AISTech 2019: Incorporation of BioCarbon in Cokemaking via Partial Briquetting • MWO test with 20% biocarbon/coal briquette 2021 (A3) ○ Material Logistic ○ AM Dofasco ship required component coals to Canmet ○ AM Dofasco ship Biocarbon to Canmet ○ Canmet collect fast pyrolysis bio-oil binder from Bioenergy group ○ Canmet prepare 100 kg of bio-briquette (50%Coal; 38%Biocarbon; 12%Bio-Binder) ○ Canmet carry out pilot scale MWO using loose biocarbon and bio briquette ○ Oven Test Results

	Test 1	Test 2	Test 3
Index No	**28009**	**28116**	**28118**
Oven Test No.	**18-3013**	**18-3022**	**18-3023**
Loose Coal Blend	100%	92.4%	80%
Bio-Briquette	--	--	20%
Loose Biocarbon	--	7.6%	--
Coking Time	17:12	17:49	20.52
Max Wall Press	6.21	7.17	5.58
Max Gas Press	11.72	2.55	2.48
Yield	71.5	72.4	72.9
Mean Size	48.3	55.9	38.4
Stability	63.8	52.1	45.9
Hardness	70.0	63.2	65.1
IRSID-10	19.20	24.08	25.08
IRSID-20	79.04	72.32	66.88
IRSID-40	50.68	43.64	20.80
CSR	61.4	36.8	54.6
CRI	25.7	40.8	31.5
ASG	0.927	0.920	0.926

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td>
○ Distribution of input Solid Biochar in Resultant Coke
<table>
<tr><th>Oven Test No</th><th>18-3022</th><th>18-3023</th></tr>
<tr><th></th><th>%Biocarbon</th><th>%Biocabon</th></tr>
<tr><td>>3in</td><td>17.3</td><td>1.4</td></tr>
<tr><td>>2in</td><td>31.0</td><td>15.5</td></tr>
<tr><td>>1.5in</td><td>15.6</td><td>17.0</td></tr>
<tr><td>>1in</td><td>8.3</td><td>15.6</td></tr>
<tr><td>>0.75in</td><td>4.4</td><td>11.7</td></tr>
<tr><td>>0.5in</td><td>3.5</td><td>9.2</td></tr>
<tr><td>breeze</td><td>19.9</td><td>29.6</td></tr>
</table>
• MWO test with 20% biocarbon/coal briquette 2022 (A3)
○ Reduce biocarbon particle size to 100%<35M
○ Preparation of bio briquette with US blend and WCC blend
○ Bio briquette composition: 50%Coal-38%Biocarbon-12%Bio-oil
○ Perform MWO tests
○ 80%US blend-20%Biobriquette
○ 80%WCC blend-20%Biobriquette
</td></tr>
<tr><td></td><td></td><td></td><td></td><td>Incorporation of biocarbon in cokemaking by stamp charge</td><td>
• Effect of biocarbon on stamping energy to achieve desire BD
• Effect of biocarbon on coal cake strength at desire BD
• Effect of biocarbon on properties of stamp charge resultant cokee
</td></tr>
<tr><td></td><td></td><td></td><td></td><td>Nut coke replacement</td><td>
○ Small Scale Bio-Pellet Strength Evaluation (A3)
○ Completed
○ CCRA Report (CCRA70: 003/2019): Bio-Pellet for Nut Coke Replacement
○ Large Scale Bio-Pellet Strength Evaluation
○ Bio-Pellet Compressive strength
○ Completed: Bio-Pellet compressive strength is about 1/2 of conventional nut coke
○ 1/5 MICUM tumbling test with iron ore pellet
○ Completed: Break down and fine generation is similar between iron ore with 5% nut coke and 5% Bio-Pellet
○ Performance of Biocoke and Densified Biocarbon on Iron Ore Reduction (A3)
○ Densified Biocarbon Pellet Characterization
○ HTF Test for Biocoke Performance
○ HTF Test for Densified Bio Pellet as Nut Coke Replacement
</td></tr>
<tr><td></td><td>CCRA 70D: Bio-Carbon for non-ferrous metal production</td><td></td><td>• TBD</td><td></td><td>○ Not started yet</td></tr>
</table>

Program	Projects	Team	Project Objectives	Project Tasks	
Carbon neutral ironmaking technology development	CCRA 95A: Alternate Ironmaking Technology		•	**Direct Reduced Iron Technology**	○ High Pressure Oxy-Fired (HiPrOx) Metallization ○ Mohammad Asiri and Marc Duchesne, CE-O
			•	**Electrolytic Ironmaking Technology**	○ Molten Oxide Electrolysis (TBD) ○ Electrowinning (TBD)
	CCRA 95B:Gaseous Reducing Agent Supply		•	**Hydrogen Production and Delivery**	○ H2 Production from NG using High Temp Slag ○ Haining Gao and Allan Runstedtler, CE-O ○ "Green" H2 Production (TBD) ○ H2 Storage and Delivery (TBD)
			•	**Bio-Syngas production and Delivery**	○ Assessment of Existing and Emerging Biomass Gasification Technologies ○ Aqueous Reforming of Organics Derived from Biomass ○ Ammonia as a Vehicle/Carrier for Blue or Green Hydrogen ○ Peter Gogolek and Andrew McFarlan, CE-O ○ Hydrogen Production via Low-Temperature Aqueous Phase Reforming of Biomass-Derived Oxygenates ○ Yi Zhang and Jacques Monnier ○ Renewable Syngas Storage and Delivery (TBD)
	CCRA 95C: Renewable Electricity		•	**Renewable Electricity**	○ Assessment of the potential for integrating renewable energy technologies into the steel-making process ○ Wind energy ○ Tom Levy, CE-O ○ Solar PV / Solar thermal energy ○ Reda Djebbar, CE-O ○ Hydro-electric and marine energy ○ Ghanashyam Ranjitkar, CE-O
	CCRA 95D: CCUS Application		•	**CO2 Capture**	○ Canadian Steelmaking Facilities Baseline data gathering and Assessment of Emerging Carbon Capture Technologies ○ Kelly Atkinson and Marc Duchesne, CE-O ○ H2 Production by Pressurized Chemical Looping Steam Methane Reforming with Carbon Capture ○ Robin Hughes, CE-O
				CO2 Utilization	○ Assessment of Emerging Carbon Utilization technologies ○ Kelly Atkinson and Marc Duchesne, CE-O
	CCRA 95E: Process Analysis and Assessment		•	**Techno-economic analysis for assisting technology and location selection**	○ Analyze CO2 capture and conversion options (including co-feedstock supply) in iron and steel industries ○ Investigate biocarbon and renewable hydrogen applications using process simulation and life cycle analysis ○ Process simulation and techno-economic analysis of bioenergy pathways and technologies ○ Sara Eskandarifar and Hamed Bashiri, CE-V
				Life Cycle Analysis	○ TBD

Program	Projects	Team	Project Objectives	Project Tasks	
CanmetENERGY MFL Facilities	Benchmarking of Movable Wall Ovens		• To ensure the reliability and repeatability of CanmetENERGY pilot scale coke ovens	• Conduct 3 carbonization tests in 18in oven and 3 carbonization tests in Carbolite with same coal blend	• 2020 (A3) ○ Report • 2021 (A3)
					• 2022 (A3)
	Quarterly LQSI Round Robin		• To ensure the reliability of CanmetENERGY coal and coke analysis	• Participate in quarterly LQSI Round Robin	○ On going
	High Temperature Furnace Re-Commissioning		• To upgrade the high temperature furnace	• Re-configuration of auxiliary facilities	○ Re-configuration of power supply, control and cooling water supply system ○ Completed
				• Re-commissioning	○ System Functionality Test ○ Completed (CCRA TC 255 June 2021) ○ Work Instruction and Task Hazard Analysis ○ Completed ○ Commissioning Test ○ Completed (CCRA TC 256 September 2021)