STANDARDS RESEARCH

DC Microgrids in Buildings

Planning Today for Tomorrow’s Needs

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Executive Summary

Direct Current (DC) microgrids in buildings are evolving and expanding. There is a need, and an industry desire, to see more awareness, tools, education, and standardization in the DC marketplace. The alternating current (AC) market has been in place for over a century. While DC has been around for longer, AC dominates the industry. However, this may change since, over the past decade, new and more efficient DC devices have been introduced to building systems. Further, the lower cost and higher benefits of distributed energy resources (DER) such as photovoltaic (PV) power and battery storage are increasing in popularity. Interconnecting DER with DC technologies is creating microgrids that are evolving beyond the current set of standards documents and safety protocols.

CSA Group published a research report in March 2019 [1], which produced an important knowledge base, as well as a list of high-priority items for standards development. To expand upon the initial research, this report summarizes insights from a workshop involving over 40 Canadian industry stakeholders who were asked to visualize the DC microgrids of the future (2030); explore the DC microgrid value; uncover tools needed to capture that value; and identify solutions to barriers and opportunities. They were also asked to provide their views on the highest priorities for standardization and research needed for DC microgrids to be successful, efficient, and safe. The potential value of DC microgrids; the tools, solutions, and standardization needs; and the further research required as identified in the workshop are summarized herein.

- **Value proposition –** Stakeholder feedback identified several key items that form the value proposition for DC microgrids in buildings. The highest-rated values included energy savings; interoperability of systems; integration of renewable energy, including the reliability/business continuity it provides; and improved experiences.
- **Tools –** Stakeholders identified several value enablers for DC microgrids in buildings, including awareness and education; DC standards documents; government policies and regulations; and demonstration projects and incentive programs.
- **Opportunities and barriers –** Many of the value propositions described earlier are predicated on the ability for DC microgrids in buildings to operate seamlessly with other DC and AC systems. The opportunities identified included return on investment; sustainability, climate change, and renewables; and international economic development opportunities. The barriers to DC microgrids were identified as grid connection rules and regulations; and current AC infrastructure. Solutions for these opportunities and barriers were explored in the workshop and included demonstration projects, case studies, engagement with policymakers and utilities, and expansion of codes and standards.
- **Standardization requirements –** With a clearer understanding of the value and interoperability of DC microgrids, high-priority areas urgently needing standards documents were identified. The highest priority items included standard DC voltages; DC receptacles; DC connector plugs; DC voltage ranges; DC overcurrent protection; and standards for health and safety. In addition, there were several standards identified that should be developed in both the medium to long term.
- **Topics to further the development of DC microgrids –** Other initiatives were raised that could further the development of DC microgrids in the buildings industry, including research activities, pilot programs, and incentives. For example, stakeholders concurred that the industry would benefit from a roadmap exercise that would summarize the current landscape for DC systems and propose a path to integration and transition from AC to DC systems. Further, the implementation of pilot projects in buildings with high-value attributes such as green buildings and electrified mobility could ease adoption of the technology while linking DC with a superior brand.

"Direct current (DC) microgrids are seen to have many benefits, including resiliency, safety, performance, efficiency, stability, and "plug-and-play" capabilities."

1.0 Introduction

As an emerging area, direct current (DC) microgrids are seen to have many benefits, including resiliency, safety, performance, efficiency, stability, and plug-and-play capabilities. They are also a major part of the modernized smart grid power system that incorporates distribution, decentralization, and digitization.

In 2019, CSA Group published a research report on DC microgrids in buildings [1]. As part of the research, 43 recent DC microgrids were evaluated, including commercial, institutional, industrial, and nanogrid residential projects. Further, an analysis of the current standards environment was conducted to determine gaps and identify the most critical steps to enable the adoption of DC power systems.

The report identified seven high-priority items for DC systems:

1. Establishing a standard for DC voltage levels and ranges;
2. Developing approval criteria for DC power metering equipment for revenue billing;
3. Establishing standard receptacle and plug configurations for DC circuits;
4. Updating product standards to enable commercialization of DC lighting, motor drives, and electric vehicle supply equipment;
5. Clarifying the rules for interconnection of distributed energy resources;
6. Determining life-safety installation provisions for DC microgrids; and
7. Developing product standards and installation rules for DC protective devices.

Standardization plays an important role in the growth of many new and emerging technology areas; and having a strong standards base can allow for broader acceptance and uptake of many of these technologies. Also, consensus-based standards can assist in industry acceptance and further the growth of safe, reliable products, technologies, and systems.

The objectives of this project are as follows:

- Confirm that the conclusions of the 2019 report [1] accurately reflect stakeholder perceptions;
- Understand stakeholder perspectives on priority actions; and
- Identify new research needs.

A creative engagement strategy enabled industry stakeholders to provide their perspectives, without leading them to predetermined solutions.

2.0 Methodology

The research was undertaken with the following approach:

1. Identify stakeholder groups interested in, or impacted by, DC microgrids in buildings;

2. Conduct expert interviews with member(s) from each stakeholder group;
3. Convene a workshop building on the initial report [1], seeking additional feedback from the experts; and
4. Review findings and develop conclusions.

2.1. Stakeholders

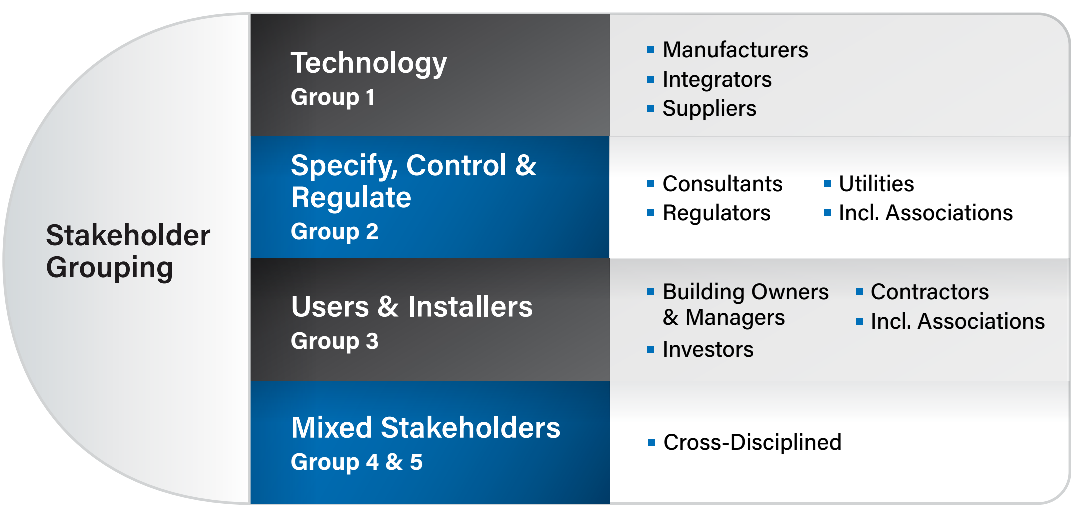
Over 100 potential DC system stakeholders were identified from a broad range of disciplines. After discussions with industry experts, the stakeholder grouping was simplified into three categories of those who may (1) manufacture and distribute; (2) specify, control, and regulate; and (3) use, install, or maintain DC microgrids. This is illustrated in Figure 1.

2.2. Expert Interviews

Six industry experts participated in the interview process. These experts represented building owners and managers; consultants; suppliers and manufacturers; and regulators. The expert interviews provided insight into the range of topics and considerations for DC microgrids in buildings. An array of perspectives and differing opinions emerged on where DC systems may head over the next decade. For example, building owners expressed concern about the uniformity of systems and components and the ability to easily switch between and within alternating current (AC) and DC systems. They also saw an opportunity for increased resilience with DC systems by having their own renewable generation and battery storage. Manufacturers indicated that there was a strong value proposition for DC microgrids in buildings, however, the message has not been well articulated and communicated to all stakeholders. They stated it would be helpful to have a proof of concept through demonstration and pilot projects, perhaps even an innovation lab that enabled switching from conventional AC to DC. Regulators expressed concern that the rapid evolution of DC and the proliferation of simple communication protocols could quickly transform products and systems. This could open the door to unforeseen safety hazards if codes, standards, and regulatory requirements do not adapt to the swiftly changing technology.

> *I envision that voltages across wires will change based on a device's needs as communications are built into the power lines. So, how do we protect the lines and keep the system safe when voltages constantly change?*
>
> *—REGULATOR*

Figure 1: *Stakeholder Grouping*



2.3. Workshop Development

Overall, the responses from the expert interviews demonstrated the need to begin the workshop discussion at a high level before addressing the seven priorities identified in the first research report. The workshop was designed to first probe stakeholders on their perspectives of the DC microgrid building of the future. To provide a sense of reality, the future was defined as the year 2030. Presentations by key industry leaders were given to inspire the participants with their perspectives on the future DC building. After each presentation, the participants broke into five pre-arranged groups – three were stakeholder specific, and two were cross-disciplined (Figure 1). Three breakout sessions flowed from high-level discussions down to specific actions. Within the sessions, participants were asked to provide input as follows:

- **Session 1: The 2030 Vision and Today's Needs –** If the future potential is understood, today's needs can be identified.
  - Provide input on the value proposition for DC microgrids by brainstorming potential value drivers;
  - From the value drivers identified, select the items with the greatest value; and
  - Identify what tools are needed now to enable the value proposition.
- **Session 2: Interoperability –** Future systems will need to interact for the benefits to be realized.
  - Identify the opportunities and barriers for DC microgrids;
  - Identify, review, and prioritize solutions to realize opportunities and resolve barriers.
- **Session 3: Connecting the Pieces –** Consolidating the discussion with practicality in mind allows a prioritization of action items.
  - Develop a list of areas where standardization would be of benefit;
  - Identify the standardization priorities for the short, medium, and long term.

Throughout the workshop, participants were also invited to provide suggestions and insights on DC projects currently underway in Canada; potential pilots and demonstration projects; and other research needed in the DC field.

2.4. Analysis

The workshop results were compiled and tabulated for analysis as presented in this report. The DC microgrid value assessment was based on the number of similar responses from the stakeholders. Enabling tools and interoperability opportunities and barriers were brainstormed and reported back with appropriate context. The solutions were tabulated and cross-referenced to the identified opportunities and barriers. And finally, a prioritization formula was used on needed standardization based on the frequency of an item and the relative importance expressed by the stakeholders.

The workshop provided an inventory of ideas, concepts, and actions that will be explored further in this report.

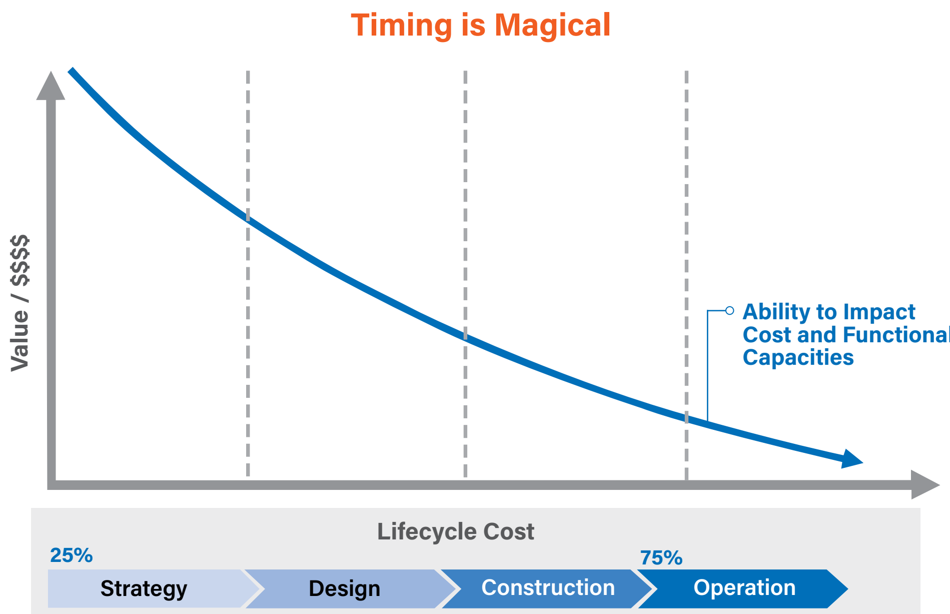
3.0 DC Microgrids – Defining the Value Proposition and Value Enablers

3.1. DC Microgrids

DC microgrids in buildings is a generic term used to describe the incorporation of DC electrical systems into buildings. Over the past century, most buildings have been designed to operate on AC. Electricity is typically received over powerlines from centralized generating stations in each province and territory across Canada. However, a greater focus on resiliency and an increase in alternatives to fossil-fuel-based energy has reintroduced DC power as an attractive option for all, or a part, of the building. Local decentralized power generation from photovoltaic (PV) cells are DC based, battery storage is DC based, and manufacturers are developing DC end devices, such as LED lighting systems. One of the workshop's presenters noted that 'the timing is magical', as the ratio of value to investment cost for DC microgrids decreases the later systems are incorporated in the building development process (Figure 2).

The term microgrid has various definitions across the industry; however, it is generally used to describe the interconnection of multiple DC systems within a local

Figure 2: *Effect of DC System Implementation Timing on Value to Cost Ratio*



environment, such as a building. It reinforces that the highest value for DC is created when systems are interconnected to create microgrids. These microgrids can eliminate numerous DC to AC conversions as illustrated in Figure 3. Stakeholders were asked to further explore their views on the value proposition of DC microgrids in buildings, which are presented in Sections 3.2 and 3.3.

3.2. Value of DC Microgrids

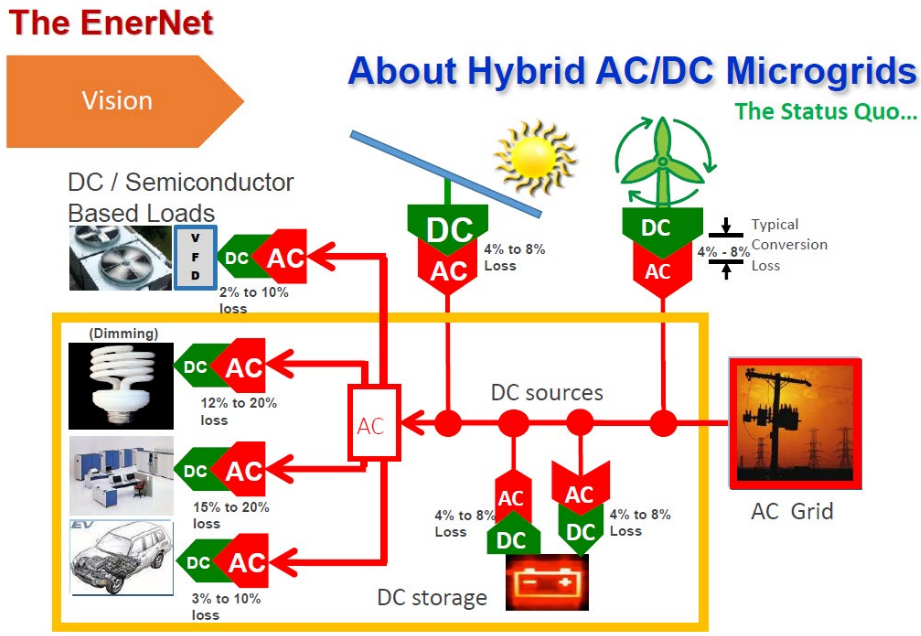
In considering the future of DC microgrids in buildings, stakeholders listed many value propositions that could lead to an increased adoption of DC systems. Figure 4 demonstrates a tree map of various value drivers that were raised in the workshop. The size of each block (and associated percentage) represents the proportionate weighting of the identified value, which corresponds to the items that participants selected as the most compelling.

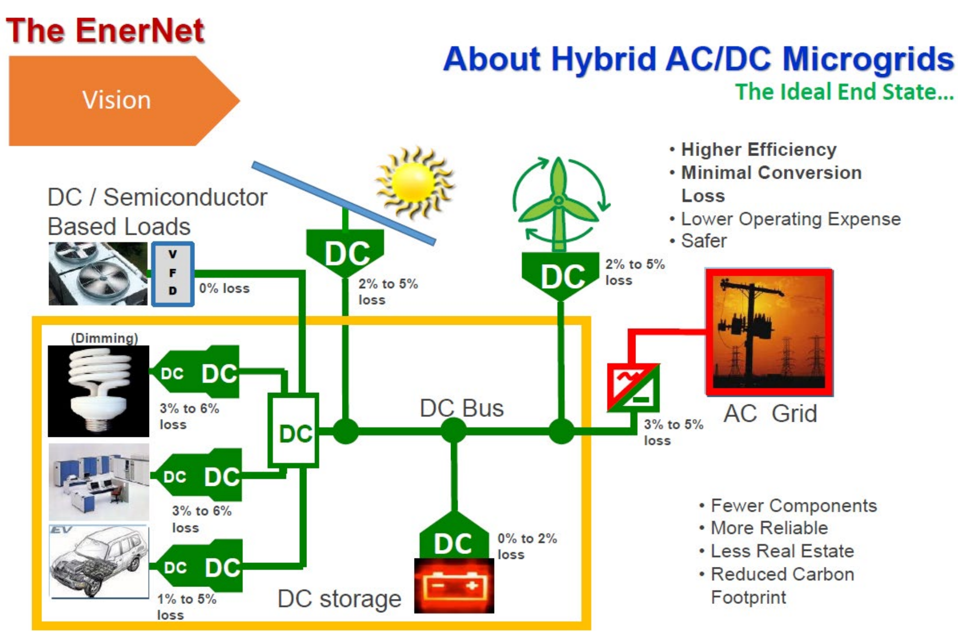
Energy savings (15%) was the most popular value proposition. The primary driver for energy savings is the reduction in energy used when converting AC to DC. This conversion is needed for numerous regularly used devices in AC buildings, such as ballasts in LED lighting, adaptors for information technology (IT) systems (phones, laptops, monitors, etc.), and EV charging systems, to name a few. Further, these AC to DC conversions also create unnecessary heat, which, when eliminated, further reduces energy use in the building, as well as wear and tear on the adapters.

Interoperability (15%) ranked close to energy savings. DC microgrids are already being installed in buildings today. They are often islands that operate independent of other building systems. Creating a seamless operation between DC and AC systems enables opportunities for system efficiencies and flexibility. This interoperability will also open the door to revenue opportunities, or simply reduce operating costs, by appropriately integrating distributed energy resources (DER) into daily operations.

> *The horse has left the barn—the demand for DC is here now.*
>
> *—TECHNOLOGY STAKEHOLDER*

Figure 3: *Hybrid AC/DC Microgrids vs. Full DC Microgrids Solutions [1]. Reproduced with Permission from EMerge Alliance.*





Renewable energy integration (12%) ranked closely behind interoperability. Renewable energy at the building level is often generated by PV, which is a DC source. These systems need to be converted to AC using an inverter. Having a pure DC system or microgrid enables that simple integration. This is less of a concern with large rooftop PV installations. However, as building-integrated PV (BIPV) evolves, there will be DC generation sources disbursed throughout the building that will be most effective connected to a DC microgrid. Renewable energy generation at the building level may negatively impact the electricity utilities; as the utility will see lower, and perhaps less predictable, consumption in each building.

Improved experiences (12%) were an important value noted by stakeholders. The perception is that trades will have a better understanding of DC as regulatory requirements and best practices become clearer. Further, having plug-and-play functionality will create a simplified connectivity experience for users; improving usability and flexibility of DC technology.

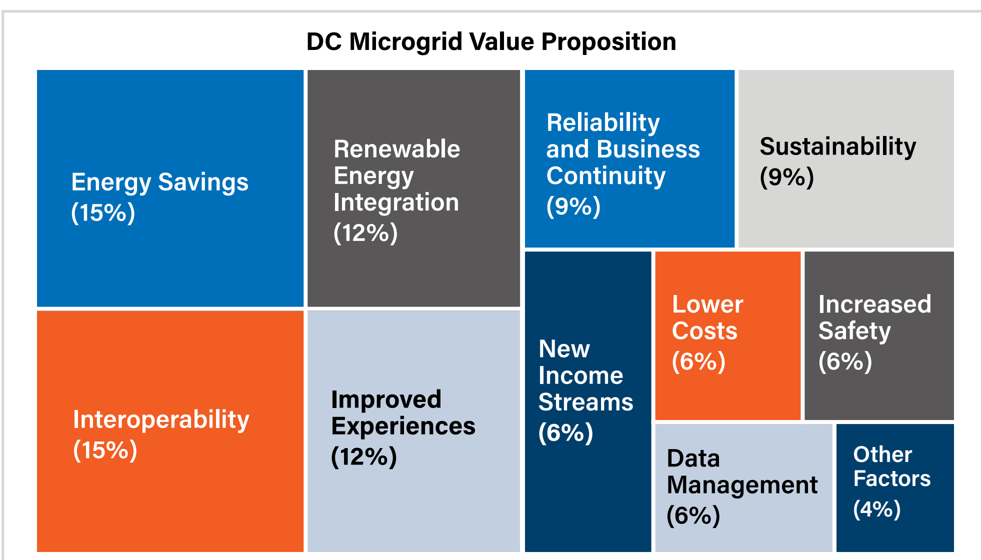
Reliability and business continuity (9%) were lower in the ranking. This is likely because DERs in the market today are insufficient to provide the scale of power needed for full business continuity. Further, where buildings need reliability, most building owners will convert from DC back to AC, as most users and enforcement officials are accustomed to AC. This last point increases the importance of the interoperability and integration values described earlier.

> *DC microgrids in buildings "threaten to make things simple."*
>
> *—CONSULTANT STAKEHOLDER*

Sustainability (9%) and **new income streams (6%)** were also valued. Environmental sustainability is important to many stakeholders. The integration of renewable DC energy provides the opportunity to sell power to the grid, which provides a revenue for the PV owner, while offsetting energy supplied by the higher greenhouse gas (GHG) content of the grid.

Additionally, **lower costs (6%)**, **increased safety (6%)**, and **data management (6%)** were value drivers. The removal of AC-DC and DC-AC conversions should reduce initial construction costs, as well as ongoing

Figure 4: *Stakeholders' Perspectives on DC Microgrid Value Proposition, Weighted by Quantity of Responses*



maintenance costs. Safety and data management require proper standardization for DC systems.

Stakeholders indicated that having clear regulations, codes, and standards in place would ease the uncertainty associated with emerging technologies entering the market. Also, DC microgrids, which are often networked and interconnected, would enable better control of devices and plug loads, which could, in turn, lead to optimized energy use in the building and in the community.

3.3. Enabling DC Microgrids

An understanding of the value of future DC microgrids leads to uncovering the tools needed to enable the value. Tools include guidelines, standards, regulations, voluntary programs, and any other enabling tool. Four tools emerged as important for enabling value of DC microgrids in buildings: Awareness and education, DC standards documents, government policies and regulations, and demonstration projects and incentive programs.

Awareness and education were identified as being strategically important to the growth of the DC microgrid environment. Creating awareness programs based on known benefits would help overcome perceived barriers and hurdles in the industry. The programs need to be tailored to each specific target audience, where manufacturers will require a different education program than consumers. There is a need to augment the curriculum for electrical and communication trades to include DC systems from application to safety requirements. Developers, owners, and property managers should be aware of the cost savings and resiliency benefits in a well-functioning DC microgrid.

The need for **DC standards documents** was identified as an important tool by the workshop stakeholders. Stakeholders stressed that these documents should go beyond traditional standards to also include guidelines, testing methodologies, and specifications and that codes, standards, specifications, and other documents need to be enhanced to include DC systems. The regulator stakeholders identified that it would be helpful to create a landscape and roadmap for how and when standards documents will incorporate DC systems. This will be discussed in Section 6.1 of the report. Within that plan, there should be consideration for standards documents to be flexible and adaptable to flow with DC systems as they rapidly evolve.

> *SPEED OF EXECUTION—there is an urgency to bring everyone on side and find a happy middle ground.*
>
> *—CONSULTANT STAKEHOLDER*

Workshop stakeholders expressed that **government policies and regulations** need to evolve to include DC microgrids. For example, it was noted that regulations around DERs and interoperability between the grid and DC microgrids are lacking. Currently, only electric utilities are permitted to transmit power across property lines. DC microgrids and storage may be desired at a community level, which cannot be provided by real estate developers due to these regulations.

Demonstration projects and incentives programs geared towards DC microgrids were raised by stakeholders as potential tools for enabling value for DC microgrids. Having proofs of concept, published benefits of pilot projects, and incentives, will help the industry understand how DC systems are evolving. This topic will be expanded later in Sections 6.2 and 6.3 of this report.

The current AC grid has an infrastructure with over a century of history and an impressive legacy. **DC infrastructure development** would help to equalize opportunities for DC microgrids. An example raised by stakeholders included the government investing in its own buildings to create critical mass and spawn local economic development.

Overall, stakeholders felt that work needs to begin as soon as possible on tools to support DC microgrids in buildings.

4.0 High-Level DC Microgrid System Interoperability Solutions

Many of the value propositions described earlier are predicated on the ability for DC microgrids in buildings to operate seamlessly with other DC and AC systems. This interoperability has opportunities and barriers that require solutions. Stakeholders identified several opportunities and barriers in the workshop and then explored the possible solutions. Those solutions were then ranked and mapped to the barriers, opportunities and value drivers as presented in Table 1.

4.1. Opportunity: Return on Investment

The most significant opportunity identified for DC microgrids was the potential to generate a reasonable return on investment (ROI) for the building owner and manager. In addition to cost savings, DC microgrids are often associated with green buildings, which in turn often achieve higher lease rates or higher lease/sales velocities (the ability to quickly fill vacancies). This is also supported with higher perceived customer satisfaction, which also increases the building's asset value.

4.2. Opportunity: Sustainability, Climate Change, and Renewables

Government policies, and many stakeholders, often focus on climate change mitigation and adaptation. DC microgrids that integrate renewable energy generation and electricity storage provide reduced GHGs by displacing fossil-fuel-based grid electricity. Having an independent source of power also provides resilience for all, or a part, of the building's electricity needs.

4.3. Opportunity: International Economic Development Opportunities

DC microgrids are being deployed internationally and many stakeholders are proud that Canada is a high-tech leader and innovator. There is economic growth potential for Canadian manufacturers and their supply chain to expand on an international basis. By participating in international forums, Canada may be able to effectively expand its DC infrastructure and grow its economy.

4.4. Barrier: Grid Connection Rules and Regulations

In order to maximize the value of DC microgrids in buildings, there is a need for integration of DC systems into the larger connected grid and the community. This would require a review of the current regulations and government policies. Electricity cannot be transmitted across property lines without a distribution licence, which is currently held by local distribution companies. Utilities would need to be part of any solution, as changes to regulations may impact their business model. Utilities could be a catalyst to drive productive change in the DC microgrid market. The utility business model changes could be viewed negatively if the regulator precludes utilities from competing in the DC microgrid space. However, it could also lead to a very positive outcome if utilities are enabled to drive a new DC microgrid business line, leveraging their knowledge and customer base.

> *Investor sentiment is important and should be sought out.*
>
> —*INVESTOR STAKEHOLDER*

4.5. Barrier: Current AC Infrastructure

The current AC infrastructure is well established, making it an easy choice for expansion. As a result, the efficiencies and other benefits offered by DC microgrids may be overlooked. With an increase in DC infrastructure within and between buildings, many believe DC will be the future choice. The challenges are how to create new infrastructure and how to fund the transition from AC to DC.

Some utilities are well positioned to increase the needed DC infrastructure at a community level; however, there are regulatory restrictions, noted previously, preventing expansion. Overall, the lack of, or clarity of, regulations is challenging for all stakeholders. Regulatory uncertainty is also a barrier for investors looking to expand the DC infrastructure.

The regulators noted that safety standards are well established for AC systems. DC systems need to be integrated into the current codes and standards to promote a safer building environment.

4.6. Solutions

Stakeholders identified several potential solutions for the opportunities and barriers identified. From a high-level system perspective, the following solutions were offered:

1. Create demonstration projects to quantify GHG reductions and increase public buy-in. Being selective in the geographic location of the building may assist in highlighting higher value based on electricity-grid carbon content and utility pricing.
2. Publish case studies showcasing the value of the DC systems, including energy savings, improved customer experience, and lower GHG impact.
3. Create consistent messaging around DC microgrids in buildings in a similar fashion to, and associated with, leading movements such as green buildings, electrified mobility, and other high-value attributes.
4. Develop a new business model such as energy-as-a-service to help drive the future of DC microgrids. This concept is an expansion of energy performance contracting whereby the energy-as-a-service company would benefit from the value created, such as energy savings and GHG offsets.
5. Review configurations for enabling a new and transitional infrastructure to create a mechanism for the cost to be offset (incentives) or captured in the future (financing).
6. Clarify regulations and establish new, or update existing, standards to provide a higher degree of certainty for investors.
7. Promote and expand DC infrastructure by engaging manufacturers and control vendors early. Multistakeholder participation in infrastructure discussions could enhance product availability and identify where DC can be economically deployed.
8. Focus on transitioning larger building portfolios first. One suggestion was for a large entity, such as the federal government building portfolio, to transition to DC in order to create the infrastructure and positive messaging needed for the private sector to begin the shift.
9. Engage with policymakers to explore updates to regulations as a catalyst for unlocking the value of DC microgrids in buildings.
10. Engage with utilities to encourage non-wires alternatives (NWAs)[1] that support needed infrastructure, acknowledging that energy regulators and provincial/territorial governments will also need to be engaged.
11. Expand codes and standards, including stretch[2] codes, to include DC systems in higher performance stretch portions. For example, high-performance codes could incorporate CSA C22.3 No. 9 [2] as the standard for distributed energy resource interconnections.
12. Increase cooperation between standards development organizations (SDOs) internationally.
13. Enable Canadian DC technology and service organizations to expand into international markets and participate in international work.

Table 1 cross references the solutions to the respective opportunities, barriers, and value propositions.

5.0 Connecting the Pieces: Standardization for DC Microgrids in Buildings

After stakeholders reflected on and discussed the value and interoperability of DC microgrids in buildings, they were asked to explore the specific needs for standardization. This exercise brought the discussion to a detailed level focusing on the relative importance and priority of each standardization element. These elements were then ranked from multiple brainstormed lists. From a timeline perspective, urgent items represented those that should be addressed in the next two years; timely items in the next five; and items to be considered by 2030.

[1] NWAs is an industry term used to describe the alternative solutions to utilities installing transmission and distribution system infrastructures. These can be energy efficiency, DER, distributed generation, demand response programs, pricing strategies, etc.

[2] A stretch code is a locally mandated code or alternative compliance path that is more aggressive than base code, resulting in buildings that achieve higher energy savings, see https://newbuildings.org/code_policy/utility-programs-stretch-codes/stretch-codes/

***Table 1:** High-Level Solutions to Effectively Grow DC Microgrids in Buildings*

	OPPORTUNITY			BARRIER		VALUE ALIGNMENT
SOLUTIONS	**Capture ROI**	**Sustainability, Climate Change, and Renewables**	**International Efforts and Economic Development**	**Current AC Infrastructure Dominance**	**Grid Connection Rules and Regulations**	
Create demonstration projects to quantify GHG reductions and increase public buy-in	Yes	Yes	No	No	Maybe	Sustainability
Publish case studies showcasing the value of DC systems	Yes	Yes	Maybe	No	No	All
Create consistent messaging around DC microgrids in buildings	No	Yes	No	No	Yes	Sustainability Interoperability Improved Experience
Develop a new business model such as energy-as-a service to help drive the future of DC microgrids	Yes	Yes	No	No	Yes	Energy Savings New Income Streams Renewable Integration Improved Experiences
Engage with policymakers to explore updates to regulations as a catalyst for unlocking the value of DC microgrids in buildings	No	Yes	No	Yes	Maybe	All
Engage with utilities to encourage NWAs that support needed infrastructure (include energy regulators and provincial/territorial governments)	Maybe	Yes	No	Yes	Yes	Lower Costs New Income Streams Interoperability
Expand codes and standards to include DC systems in higher performance stretch portions	No	Yes	No	Yes	No	Energy Savings Increased Safety
Review configurations for enabling new and transitional infrastructure to create a mechanism for costs to be offset (incentives) or captured in the future (financing)	Yes	No	No	Yes	No	Lower Costs Renewable Integration
Clarify regulations and establish new, or update existing, standards to provide a higher degree of certainty for investors	Yes	No	Yes	Yes	No	Increased Safety Lower Costs Interoperability
Promote and expand DC infrastructure by engaging manufacturers and control vendors early	Yes	No	Yes	Yes	No	Increased Safety Lower Costs Improved Experiences
Focus on transitioning larger building portfolios first	Yes	Maybe	No	Yes	No	Energy Savings Reliability and Business Continuity
Increase cooperation between standards development organizations (SDOs) internationally	No	Maybe	Yes	No	No	Lower Costs
Enable Canadian DC technology and service organizations to expand into international markets and participate in international work	No	Maybe	Yes	No	No	Lower Costs

***Yes** = Solution will help address the opportunity or barrier; **Maybe**= Solution may address the opportunity or barrier;*
***No** = Solution will not address the opportunity or barrier.*

5.1. Urgent Items

Table 2 lists six high-priority items expressed by a majority of stakeholders; they are therefore considered urgent items.

Table 2: *Urgent Items Requiring Standardization. Numbering Relates to the Priority Level Identified*

Urgent High-Priority Items	
1. Standard DC voltages	**4.** DC voltage ranges
2. DC receptacles	**5.** DC overcurrent protection
3. DC connector plugs	**6.** Standards for health & safety

To ease market confusion and deliver consistency of DC microgrids in buildings, there is a need to develop common voltages and voltage ranges. This is consistent with one of the key observations from the initial research report. As noted in the report, "Standardization of DC voltage levels for building power distribution is a key early [need] and high priority [item] affecting both product and installation standards" [1]. Further, the report states, "Specifying the acceptable range of voltages for each standard nominal level is as important as selecting the level itself" [1]. Examples of voltages would be 5V, 48V, and 380V; while hypothetical ranges could be 3-7V, 40-55V, and 360V-400V. The industry is challenged to move forward without voltages and voltage ranges being specified. If industry fails to do so, each manufacturer could propose a different voltage and range, creating proprietary systems that are not desired by end users.

Also concurring with the initial report, having standard configurations for DC plugs and receptacles is another urgent need, which follows closely from standard voltage definitions.

Once voltages are consistent, the plugs and receptacles can be appropriately configured. On the component side, standards are needed for DC overcurrent protection.

The users and installers group also pointed to the need for DC standards on health and safety, insurance, and environmental issues. This request for standards and guidelines was echoed by the cross-discipline stakeholder groups; though, the highest urgency request was an update to health and safety standards to address DC systems.

5.2. Standardization Required in a Timely Manner

Fourteen additional items were identified as high priorities by a number of participants. While the urgency of these items may not be as time-sensitive, their importance is still high. To better identify the needs, the items are broken down into component-level standardization; updates to existing electrical standards documents; other standard documents; and other important areas (Table 3).

Stakeholders identified that, regarding components, standards are needed for DC cable sizing and runs, as well as standards for arc- and ground-fault circuit interrupters (AFCI and GFCI). This view was held most predominantly by stakeholders in the users and installers group and in the technology group.

The specify, control, and regulate group provided specific recommendations to update current standards with DC content. The stakeholders in this group focused on the CSA C22.2 Canadian electrical standards and the CSA C22.1 Canadian Electrical Code [3], with an addition of DC as a power source and updating the inverter and interconnection parts/sections.

Several other issues were identified as important, such as developing guidelines that inform the industry. These include environmental considerations, insurance needs, and system standards. The latter item is a pivot from component-level standards to broader objective-based requirements for various DC systems. Another important issue was the development of guidelines or other documents that would prepare first responders for approaching a building with a DC microgrid. This could include amendments to natural gas and AC electrical system guidance for first responders. Also, there is a need for broader industry alignment to address the urgent items first, particularly for harmonizing DC voltages.

Finally, a need to develop a DC integration roadmap was raised, including a full landscape of current DC standards activity. This research need will be discussed in Section 6.1 of the report.

Table 3: *Important Items to Be Addressed in a Timely Manner. Numbering relates to the priority level identified.*

New Component-Level Standardization	Updates to Electrical Standards Documents	Other Standards Documents	Other Important Areas
7. DC cable intelligence, size, runs	**12.** Update to all CSA 22.2 Canadian electrical standards	**16.** Standard for environmental considerations	**9.** First-responder education
10. DC ground-fault circuit interrupter (GFCI) standards	**13.** Update to the CSA 22.1 Canadian Electrical Code	**8.** Standard for insurance	**17.** Standardization authority needs to be receptive, responsive, and adaptable
11. DC arc-fault circuit interrupter (AFCI) standards	**14.** Canadian Electrical Code new section – power sources	**20.** Develop system standards	**18.** Set landscape for DC (international, regional, industry, etc.)
	15. CSA to update inverters and include interconnection requirements		**19.** Gain consensus with key developers/manufactures on standard DC voltages

5.3. Items to Be Considered in Due Course

Table 4 sets out the lower-priority items identified by stakeholders in the workshop. Most of these items target future technology or having operational guidelines in place by 2030.

6.0 Additional Support for DC Microgrids in Buildings

Throughout the workshop, stakeholders were asked to provide their input on what efforts need to be taken to support DC microgrids in buildings. This section provides insight into the stakeholders' perspectives, grouped by research needs, pilot programs, and incentives.

6.1 Research Needs

Roadmap for DC microgrid in buildings – Stakeholders indicated that there is significant current and upcoming activity for DC systems and that it would be helpful to examine the current DC landscape and create a roadmap that extends to 2030, or beyond. The roadmap could investigate two trends: (1) the evolution of products, technologies, and solutions; and (2) a forecast of the type and timeline for buildings to implement partial and full DC microgrid integration. The building integration could also factor in the green building movement of the past, along with its future potential. It could include how a desire for resiliency and climate mitigation/adaptation would impact the speed of DC transformation. The roadmap exercise would prove beneficial in understanding the critical timelines for regulations, standards, and guidelines. It could also be used as a communication tool for the industry.

Business cases for DC microgrids in buildings – Participants agreed that the value proposition for DC microgrids is growing and that business cases need to be developed to demonstrate how value is created. This would include net incremental costs; energy savings; greenhouse gas savings; and operations cost impacts. The business cases should also compare the DC system (hybrid and full) to conventional AC systems.

Table 4: *Lower-Priority Items. Numbering relates to the priority level identified.*

New Component Level Standardization	Other Standards Documents	Operational Guidelines
35. Switches	**36.** DC appliances	**39.** Installation training
	37. DC HVAC systems	**40.** Maintenance procedures
	38. Standards for coexistence of AC/DC products/infrastructure	

DC battery storage evaluation and life-safety impact – It was noted that battery technology is evolving and will likely play an important role in distributed energy resources and DC microgrids. Having a well-documented life-cycle analysis, including disposal and recycling options, would help the industry understand the merits and challenges of battery technology. Further, many organizations will be looking towards battery technology for backup power. Therefore, understanding what systems could use DC battery technology as a backup with consideration of reliability and duration would be helpful, particularly where these systems back up life-safety equipment.

Validation of DC load voltage tolerances and arc-fault safety requirements – Workshop participants indicated that validation for various types of systems could help standards development. Currently, wiring, equipment, heating elements, and other components and systems have tolerances based on AC voltages. It was raised that the impact of DC should also be tested and validated. Similarly, arc-fault safety requirements need to be tested and validated for DC systems. This could expand to appropriate coordination study guidelines that consider DC only and DC-AC hybrid systems for overcurrent and arc-fault protection.

> *R&D is needed around implementation.*
>
> *—BUILDING OWNER STAKEHOLDER*

6.2 Pilot Programs

Stakeholders indicated that there is a desire for examples of DC microgrids in buildings, as pilot programs and demonstration projects would be valuable for communicating the benefits of DC microgrids in buildings. The following are examples of potential pilot or demonstration projects were suggested by participants:

- The Intelligent Structural Panel (ISP) [4] was introduced in 2018 and could demonstrate the value of integrated DC microgrids in buildings;
- A project to update CSA C22.2 107.x[3] to meet the interconnection requirements of a new CSA Standard CSA C22.3 No. 9[4];
- A pilot project for northern Indigenous communities and air force bases;
- A small residential duplex built to provide a side-by-side comparison, one with DC and the other with AC, to demonstrate the business case (capital expenditure, energy, operational costs, etc.). This is similar to the National Research Council's Canadian Centre for Housing Technology [5] research facility;
- A small-scale pilot project integrating various key DC elements, including meter, heat pump, lighting, PV, storage, appliances, EV charging (vehicle-to-home or vehicle-to-grid), rectifier at service entrance, DC-DC converters (i.e., step-up or step-down), load management, fault protection. This could be used as a safety testbed as well.

6.3 Incentives

Workshop participants noted that, as with many new growth areas, incentives can play a vital role in encouraging market transformation, or balancing inequities between legacy infrastructure and advanced technology. This is also true for DC microgrids in buildings. Incentives and investment opportunities, which should involve electric utilities and others, would be best tailored to assist with the following:

- Costs to develop standards;
- Demonstration projects;
- Sharing in capital costs;
- Updates to utility mandates; and
- Developer rebate offers.

> *We need to understand where DC fits in, as it may not fit in at all.*
>
> *—CONSULTANT STAKEHOLDER*

[3] *CSA C22.2 107.x includes CSA C22.2 107.1-16 – Power conversion equipment; CSA C22.2 107.2:01 (R2016) – Battery Chargers; and CSA C22.2 107-3:14 (R2019) – Uninterruptible power systems.*

[4] *CSA C22.3 No 9:20 – Interconnection of distributed energy resources and electricity supply systems. .*

7.0 Discussion and Analysis

7.1. Comparison with the Original DC Microgrids Report

The foundation research report [1] provided a recommended list of high-priority items, acknowledging that there were many other elements that also required investigation. In this follow-up exercise, workshop stakeholders concurred that all previously-identified items were needed for DC microgrids to succeed, and they expanded further on the list. Table 5 highlights alignment between the items identified in the first report and the results of this workshop. Alignment according to rank, priority level and demand (frequency) is presented.

7.2. Priority Work – High-Level Perspective

The stakeholder perspectives gained through the workshop demonstrated that DC microgrids in buildings are gaining marketplace traction and that work is needed in several areas to ensure a smooth integration and transition. The most commonly raised issue was the need for awareness, as it was felt that there are numerous benefits to DC microgrids that are not well communicated in the industry.

Further, there are many components to consider, therefore the industry would benefit from a roadmap exercise that would summarize the current landscape for DC systems and propose the path to integration and transfer from AC to DC systems. The roadmap could provide insight into timelines for future codes, standards, guidelines, and other resources to be developed.

In addition to awareness and roadmap work, the following high-level recommendations were provided:

- Create consistent messaging around DC microgrids in buildings;
- Engage policymakers and utilities to explore updates to regulations, as well as encourage NWAs that support needed DC infrastructure;
- Increase cooperation between SDOs internationally;
- Encourage Canadian DC technology and service organizations to expand into international markets and participate in international work.

Table 5: *DC Microgrids in Buildings Report Priorities versus Stakeholder Perspectives*

Original Report Priorities	Workshop Stakeholder Perspectives		
	Rank	Priority	Demand
1. Establishing standard DC voltage levels and ranges	1	High	High
2. Developing approval criteria for DC power metering equipment for revenue billing	31	Medium	Low
3. Establishing standard receptacle and plug configurations for DC circuits	2	High	High
4. Updating product standards to enable commercialization of DC lighting, motor drives, and electric vehicle supply equipment	29	Medium	Low
5. Clarifying rules for interconnection of distributed energy resources	15	Medium	Low
6. Determining life safety installation provisions for DC microgrids	6	High	High
7. Developing product standards and installation rules for DC protective devices	32	Medium	Low

***High priority** – should be done within the next 2 years; **Medium priority** – should be done within the next five years.*
***High demand** – identified by a large number of stakeholders; **Low demand** – identified by few stakeholders.*

7.3 Priority Work – Standardization

With respect to activity that should be taking place in the standards community, stakeholders identified a need for updated codes, standards, and guidelines to address DC systems in a similar fashion to that of AC systems.

The findings are summarized in Figure 5 and outlined in Section 5. Note that demand on the x-axis represents the frequency in which stakeholders recommended a standardization, and the priority is based on the average priority sentiment expressed by the participants. The workshop data tables can be found in Appendix A.

> *The order of standards development is important (codes—guidelines—certifications—education—etc.) and this needs to be communicated.*
>
> *—CONSULTANT STAKEHOLDER*

Figure 5: *Standardization Items – Workshop Findings*

REQUIRED BY MANY

7. DC cable intelligence, size, runs

8. Standard for insurance

9. First-responder education

10. DC GFCI standards

11. DC AFCI standards

12. Update to all CSA 22.2 standards

13. Update CSA 22.1 code

14. CEC new section – power sources

15. CSA to update inverters and incl. interconnection requirements

16. Standard for environmental

17. Standardization authority needs to be receptive, responsive, and adaptable

18. Set landscape for DC (int'l, regional, industry, etc.)

19. Gain consensus with key developers/ manufacturers on standard DC Voltages

20. Develop "system" standards

21. DC-DC converters

22. DC rectifiers

23. Battery safety

24. Battery installation

25. Battery code

26. BC amperage ranges

27. DC labeling

28. Device intelligence

29. Product standards

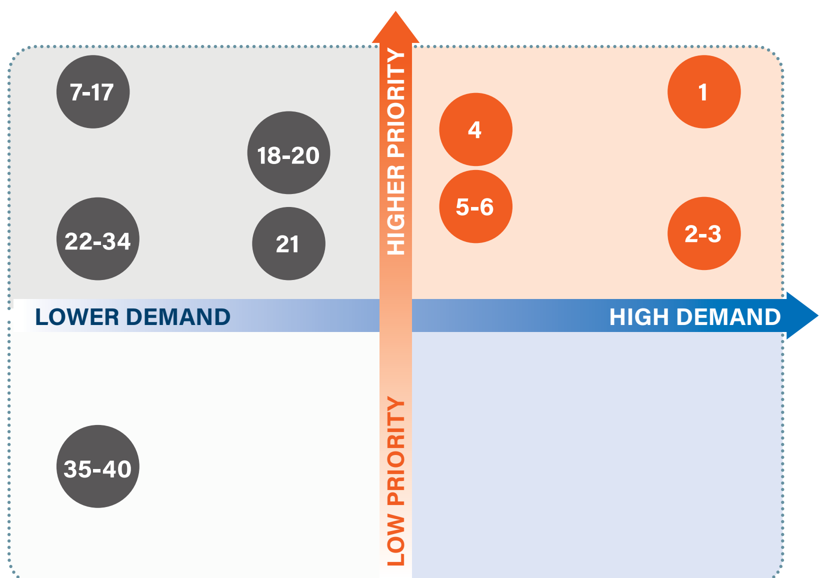
30. DC panels

31. Metering

32. Installation rules for DC protection

33. Installer certification

34. Grid supplies and contracts



URGENTLY REQUIRED

1. Standard DC voltages

2. DC receptacles

3. DC connector plugs

4. DC voltage ranges

5. DC overcurrent protection

6. Standard for health & safety

LOWER PRIORITY

35. Switches

36. DC appliances

37. DC HVAC systems

38. Standards for coexistence of AC/DC products/ infrastructure

39. Installation training

40. Maintenance procedures

"DC microgrids in buildings are advancing quickly and the marketplace is looking for clear information, standards, guidelines, and test procedures."

8. Conclusions

This report summarizes a workshop that engaged stakeholders in an exploration of the future of DC buildings. A productive and valued transformation to DC microgrids in buildings will require evidence and financial support. Demonstration projects, case studies, business cases, and incentive programs should be sought, highlighted, and rewarded.

Knowing that green building systems are leading the building development industry, there could be a benefit to enhancing the messaging around those leading developments when DC microgrids are installed. Case studies could be developed for those currently offering DC microgrids, and business cases developed for green building owners who are considering whether or not to pursue DC.

Further, a commonly successful process for market transformation is to incent early adopters. Creating incentives for DC microgrids, tied to the value provided to building owners and occupants, would send a strong positive message to all stakeholders. Incentives can take the form of cash, pay-for-performance, or support for investment financing. Non-financial incentives, such as capacity building, could also enhance the overall understanding and uptake of DC microgrids in buildings.

> *We're talking amongst friends; however, we need to get to the non-believers.*
>
> *—TECHNOLOGY STAKEHOLDER*

DC microgrids in buildings are advancing quickly and the marketplace is looking for clear information, standards, guidelines, and test procedures. Stakeholders provided a significant amount of intelligence on the needs and priorities, and the roadmap to success by 2030 is becoming clearer. Many items will require additional details and action planning. Overall, increasing awareness while creating and expanding standards documents will improve consistency and help to promote safer DC microgrids in buildings.

References

[1] I. Gal, B. Lipson, T. Larsen, and A. Tsisserev, "DC Microgrids in Buildings", Canadian Standards Association, Toronto, ON, CAN, 2019.

[2] CSA Group, "CSA C22.3 NO. 9:20 Interconnection of Distributed Energy Resources and Electricity Supply Systems", 2020. [Online]. Available: https://store.csagroup.org/ccrz__ProductDetails?viewState=DetailView&cartID=&portalUser=&store=&cclcl=en_US&sku=CSA%20C22.3%20NO.%209%3A20

[3] CSA Group, "CSA 22.1-18 Canadian Electrical Code, Part I (24th edition), Safety Standard for Electrical Installations", 2018. [Online]. Available: https://store.csagroup.org/ccrz__ProductDetails?viewState=DetailView&cartID=&portalUser=&store=&cclcl=en_US&sku=C22.1-18

[4] Doug Picklyk, "Intelligent Structural Panels," Canadian Consulting Engineer, Dec. 20,2018. [Online]. Available: https://www.canadianconsultingengineer.com/features/intelligent-structural-panels/

[5] National Research Council Canada, "Canadian Centre for Housing Technology Research Facility." Accessed: Aug. 4, 2020. [Online]. Available: https://nrc.canada.ca/en/research-development/nrc-facilities/canadian-centre-housing-technology-research-facility

Appendix A – Workshop Results

Items with at Least One **High-Priority** Ranking

COMPONENTS	GROUP				
Standardization	**1**	**2**	**3**	**4**	**5**
Standard DC voltages	H		H	H	H
DC voltage ranges			M	H	H
DC receptacles DC connector plugs	H		L	H	M
DC overcurrent protection	H		M		M
DC cables intelligence, size, runs	H		M		
DC GFCI DC AFCI	H				

Group 1: Technology
Group 2: Specify, Control Regulate
Group 3: Users and Installers
Groups 4 & 5: Mixed

DOCUMENTS	GROUP				
Standardization	**1**	**2**	**3**	**4**	**5**
Update to all C22.2 standards		H			
Update C22.1 code		H			
Canadian Electrical Code new section – power sources		H			
CSA to update inverters and incl. interconnection requirements					H
Standard for health & safety			H	M	M
Standard for insurance			H		M
Standard for environmental			H		

OTHER	GROUP				
Standardization	**1**	**2**	**3**	**4**	**5**
Standardization authority needs to be receptive, responsive, and adaptable			H		
Stds landscape for DC (int'l, regional, industry, etc.)		H			
Gain consensus with key developers / manufacturers on standard DC voltages				H	
First-responder education			M		H

Items with Only **Medium-Priority** Rankings

COMPONENTS	GROUP				
Standardization	**1**	**2**	**3**	**4**	**5**
DC-DC Converters					M
DC rectifiers					M
Battery safety					M
Battery installation					M
Battery code					M
DC amperage ranges			M		
DC labelling			M		
Device intelligence	M				
Product standards				M	
DC panels			M		
Metering			M		

OTHER	GROUP				
Standardization	**1**	**2**	**3**	**4**	**5**
Installation rules for DC protection				M	
Installer certification			M		
Grids supplies and contracts			M		
Develop "system" standards	M	M			

Items with Only **Low-Priority** Rankings

COMPONENTS	GROUP				
Standardization	**1**	**2**	**3**	**4**	**5**
Switches	L				
DC appliances					L
DC HVAC systems					L

OTHER	GROUP				
Standardization	**1**	**2**	**3**	**4**	**5**
Standards for coexistence of AC/DC products/infrastructure		L			
Installation training					L
Maintenance procedures			L		

CSA Group Research

In order to encourage the use of consensus-based standards solutions to promote safety and encourage innovation, CSA Group supports and conducts research in areas that address new or emerging industries, as well as topics and issues that impact a broad base of current and potential stakeholders. The output of our research programs will support the development of future standards solutions, provide interim guidance to industries on the development and adoption of new technologies, and help to demonstrate our on-going commitment to building a better, safer, more sustainable world.

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