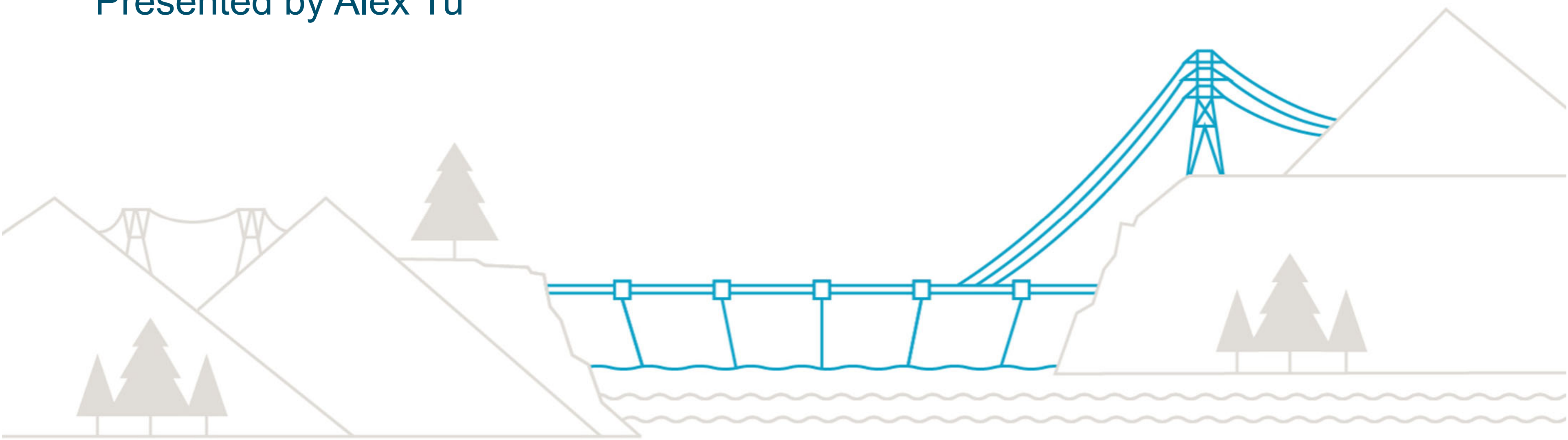
Resource Options Engagement Energy Storage

Presented by Alex Tu



February 4, 2020

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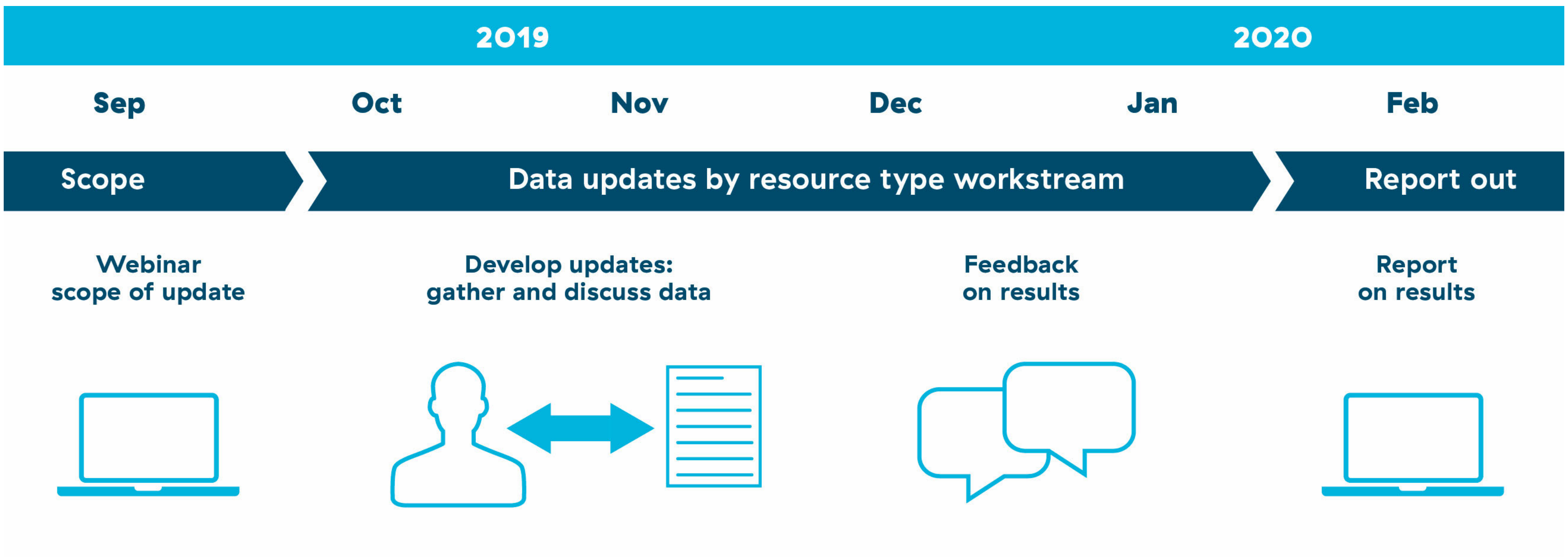
Purpose and Agenda

To solicit input/feedback on BC Hydro assumptions about viability, performance and cost

1. Context – Resource Options in the IRP
2. Narrowing down the viable energy storage types in the BC Context
3. Defining a ‘typical’ configuration for each energy storage type
4. High level technical and cost characteristics of each typical configuration

Resource Option Engagement Schedule



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What is the Resource Option (RO) Inventory

What it is

- A reasonably comprehensive listing of potential supply options in BC
- A high-level representation of each option's technical, financial, social and environmental attributes to allow apples-to-apples comparisons

What it is NOT

- A detailed estimate of what a specific project will cost or produce
- A prelude to any specific energy acquisition program

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What are the relevant attributes?

Attributes describe each option, and are consistent across all resource types

Technical Attributes (examples)

- Location (Latitude & Longitude)
- Installed Capacity (MW AC)
- Energy Storage or Duration (MWh or peak hours)
- Facility Footprint (hectares)
- Round-trip energy efficiency
- Potential secondary applications beyond Supply Capacity

Financial Attributes (examples)

- Overnight Capital Cost
  - Construction Cost
  - Equipment Cost
  - Other Development Costs
- Planning Life
- Project Lead Time
- Fixed OMA (k$/yr)
- Variable OMA ($/MWh)

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Narrowing Down the field of viable energy storage resources

Energy Storage can be defined be defined in so many ways

Technologies	Grid Location	Application	Scale	Duration
Mechanical	Transmission Connected	Supply Capacity	<10 kW	<min
Thermal	Renewable Co-Located	Peak Shaving	<1 MW	<hour
Chemical	Sub-Station	Frequency Reg	<15 MW	1-4 hour
Electro-chemi	Distributed/Community	Voltage Support	<50 MW	4-12 hour
Electrical	BTM - Comm/Industrial	Congestion relief	>50 MW	12-30 hour
	BTM - Residential	Upgrade deferral		weeks
		...		

For the purposes of the IRP and long term supply planing, we are interested in only the Energy Storage resources that are compatible with providing **Supply Capacity**

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Narrowing Down energy storage resources compatible with Supply Capacity

In terms of Technologies – this means CAES, Li-Ion, and Flow,

Technologies	Grid Location	Application	Scale	Duration
Mechanical	Transmission Connected	Supply Capacity	<10 kW	<min
Thermal	Renewable Co-Located	Peak Shaving	<1 MW	<hour
Chemical	Sub-Station	Frequency Reg	<15 MW	1-4 hour
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		…		

- Hydrogen (via power-to-gas) and back to electricity (via combustion or fuel cells) is notionally viable, but is not sufficiently mature to include at this time
- Pumped storage is considered independently
- Question: is CAES a technically feasible option in BC?

Narrowing Down energy storage resources compatible with Supply Capacity

In terms of Grid Location – we are interested in all of them as they all can contribute to supply capacity

Technologies	Grid Location	Application	Scale	Duration
Mechanical	Transmission Connected	Supply Capacity	<10 kW	<min
Thermal	Renewable Co-Located	Peak Shaving	<1 MW	<hour
Chemical	Sub-Station	Frequency Reg	<15 MW	1-4 hour
Electro-chemi	Distributed/Community	Voltage Support	<50 MW	4-12 hour
Electrical	BTM - Comm/Industrial	Congestion relief	>50 MW	12-30 hour
	BTM - Residential	Upgrade deferral		weeks
		…		

- Of course, not all technologies are viable at all grid locations (eg CAES is dependent on specific geography, and Flow Batteries not typical at residential scale)

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Narrowing Down energy storage resources compatible with Supply Capacity

In terms of Applications – the primary application we require is Supply Capacity…

Technologies	Grid Location	Application	Scale	Duration
Mechanical	Transmission Connected	Supply Capacity	<10 kW	<min
Thermal	Renewable Co-Located	Peak Shaving	<1 MW	<hour
Chemical	Sub-Station	Frequency Reg	<15 MW	1-4 hour
Electro-chemi	Distributed/Community	Voltage Support	<50 MW	4-12 hour
Electrical	BTM - Comm/Industrial	Congestion relief	>50 MW	12-30 hour
	BTM - Residential	Upgrade deferral		weeks
		…		

- …and the ability to provide additional value through secondary applications will depend on grid location and technology

Narrowing Down energy storage resources compatible with Supply Capacity

In terms of Scale – we are interested in all sizes

Technologies	Grid Location	Application	Scale	Duration
Mechanical	Transmission Connected	Supply Capacity	<10 kW	<min
Thermal	Renewable Co-Located	Peak Shaving	<1 MW	<hour
Chemical	Sub-Station	Frequency Reg	<15 MW	1-4 hour
Electro-chemi	Distributed/Community	Voltage Support	<50 MW	4-12 hour
Electrical	BTM - Comm/Industrial	Congestion relief	>50 MW	12-30 hour
	BTM - Residential	Upgrade deferral		weeks
		…		

- Scale is primarily determined by Grid Location

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Narrowing Down energy storage resources compatible with Supply Capacity

In terms of Duration – we are interested in longer duration storage to meet our fairly long flat system peak (morning through evening) during winter cold snap

Technologies	Grid Location	Application	Scale	Duration
Mechanical	Transmission Connected	Supply Capacity	<10 kW	<min
Thermal	Renewable Co-Located	Peak Shaving	<1 MW	<hour
Chemical	Sub-Station	Frequency Reg	<15 MW	1-4 hour
Electro-chemi	Distributed/Community	Voltage Support	<50 MW	4-12 hour
Electrical	BTM - Comm/Industrial	Congestion relief	>50 MW	12-30 hour
	BTM - Residential	Upgrade deferral		weeks
		…		

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Questions on approach?

Defining a Typical Bulk Transmission Connected Energy Storage Facility

Consider Lithium Ion Batteries @ Burrard Thermal Generating Station

Power Rating: 50 MW

Duration: 4 hours

Usable Energy: 200 MWh (100% DoD)

Footprint: 3,000 sq meters (15 m^3 / MWh)

Roundtrip Energy Efficiency: 88%

Project Lifetime: 20 years

Project Lead Time: 2 years

Potential Secondary Value Streams:

- Arbitrage
- Spinning Reserve
- Frequency Response

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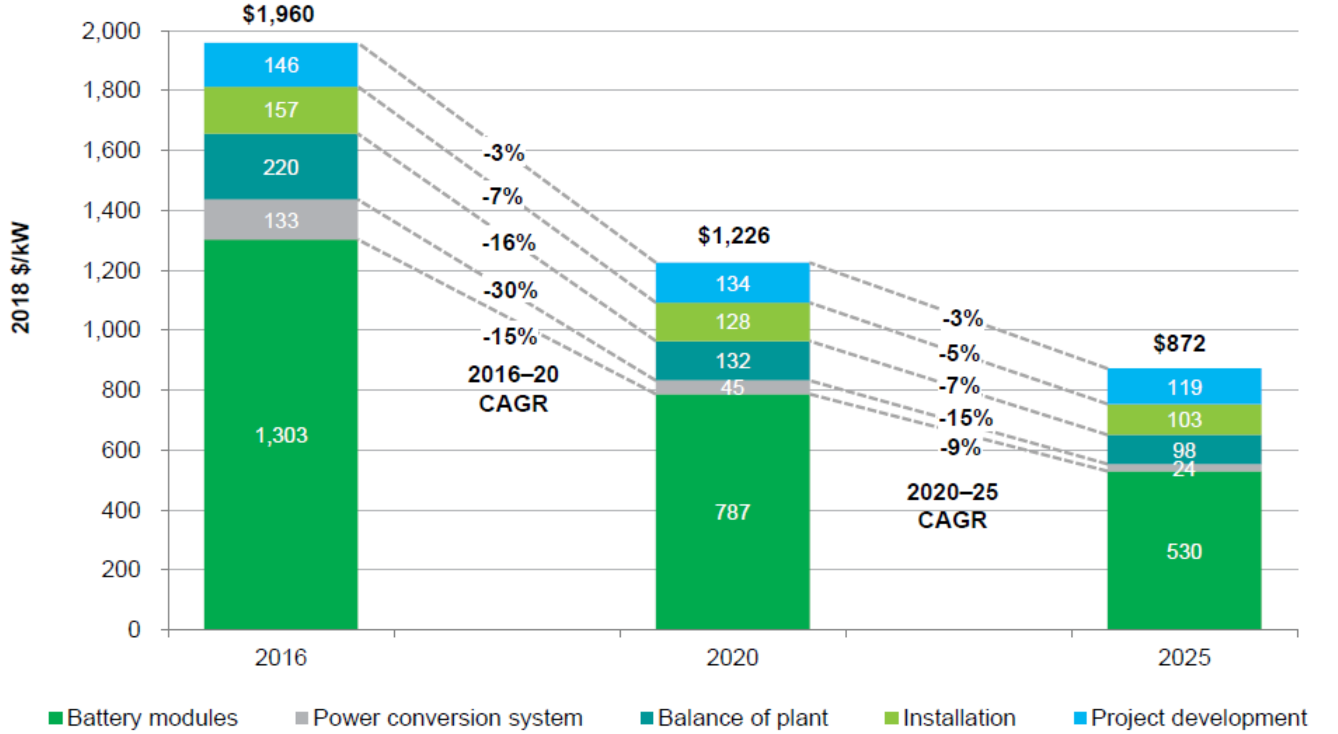
Costs of Bulk-Connected Li-Ion Batteries

The largest component of up-front Capital costs is modules (63%)

US utility-scale BESS benchmark capital cost (four hour)



Note: Benchmark refers to an average cost across regions for a utility-scale project of 50 MW. CAGR = compound annual growth rate.
Source: IHS Markit

Costs of Bulk-Connected Li-Ion Batteries

Battery OMA composed of fixed OMA, augmentation, and energy charges

OMA category	Cost ($US 2018)	Description
Fixed O&M	$22/kW-yr	Basic site maintenance (checking electrical connections, cleaning, software recalibration, etc), warranty and site monitoring/security
Augmentation	2% / yr of module costs	Essentially accounting for 2% annual degradation of the cells
Charging	88% efficiency	Based on energy prices

Costs of Bulk-Connected Li-Ion Batteries

Total Costs for Bulk Connected Li-Ion Batteries (50 MW, 200 MWh) in $2020 Canadian

Category	Cost	Description
Upfront Capital	$85M $1,700 / kW	Includes Containerized Battery Energy Storage systems, bi-directional high power inverter, cabling, installation, land costs, permitting, shipping, developer fees
Fixed O&M	$1.5M / yr	Includes Site Maintenance, Monitoring and Warranties
Augmentation	$1.1M / yr	Replacement of battery cells over 20-yr life
Energy Charges	N/A	Based on round trip efficiency of 88% and cost of energy during charging

Defining a Typical Bulk Transmission Connected Energy Storage Facility

Consider Flow Batteries @ Burrard Thermal Generating Station

Power Rating: 100 MW

Duration: 4 hours

Usable Energy: 400 MWh (100% DoD)

Footprint: 6,000 sq meters (15 m^3 / MWh)

Roundtrip Energy Efficiency: 75%

Project Lifetime: 20 years

Project Lead Time: 2 years

Potential Secondary Value Streams:

- Arbitrage
- Spinning Reserve

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Cost of Bulk-Connected Flow Batteries

Limited public information on large scale flow batteries

Lazard 4.0 describes costs of 100 MW 400 MWh VFRB ($2017 US):

- BESS & PCS: $314-550 / kWh
- EPC: 14-20% of equipment costs
- Fixed OMA: 1.35% - 2.36% of total capital
- Warranty: 3.5% of total capital
- Augmentation: ??
- Cost reductions to 2020?

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Costs of Bulk-Connected Flow Batteries

Total Costs for Bulk Connected Flow Batteries (100 MW, 400 MWh) in $2020 Canadian

Category	Cost	Description
Upfront Capital	$280 M ($2,800 / kW)	Includes BESS, cabling, installation, inverters, land costs, permitting, shipping, developer fees
Fixed O&M	$15M / yr	Includes Site Maintenance, Monitoring and Warranties
Augmentation	??	Electrolyte needs replacement, but do cells?
Energy Charges	N/A	Based on round trip efficiency of 75% and cost of energy during charging

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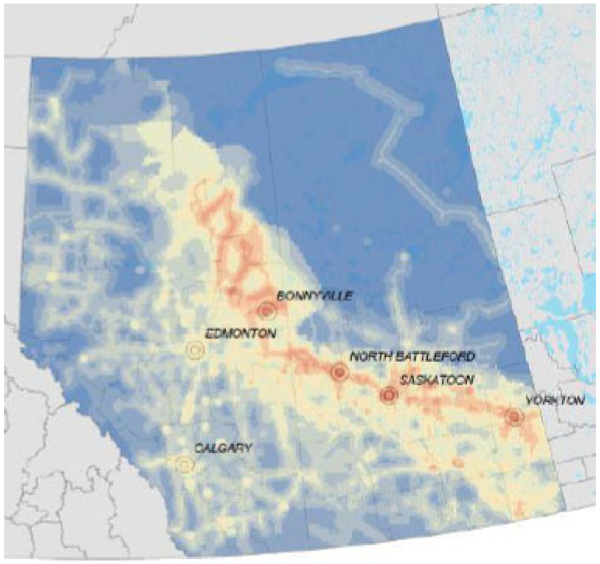
Defining a Typical Bulk Transmission Connected Energy Storage Facility

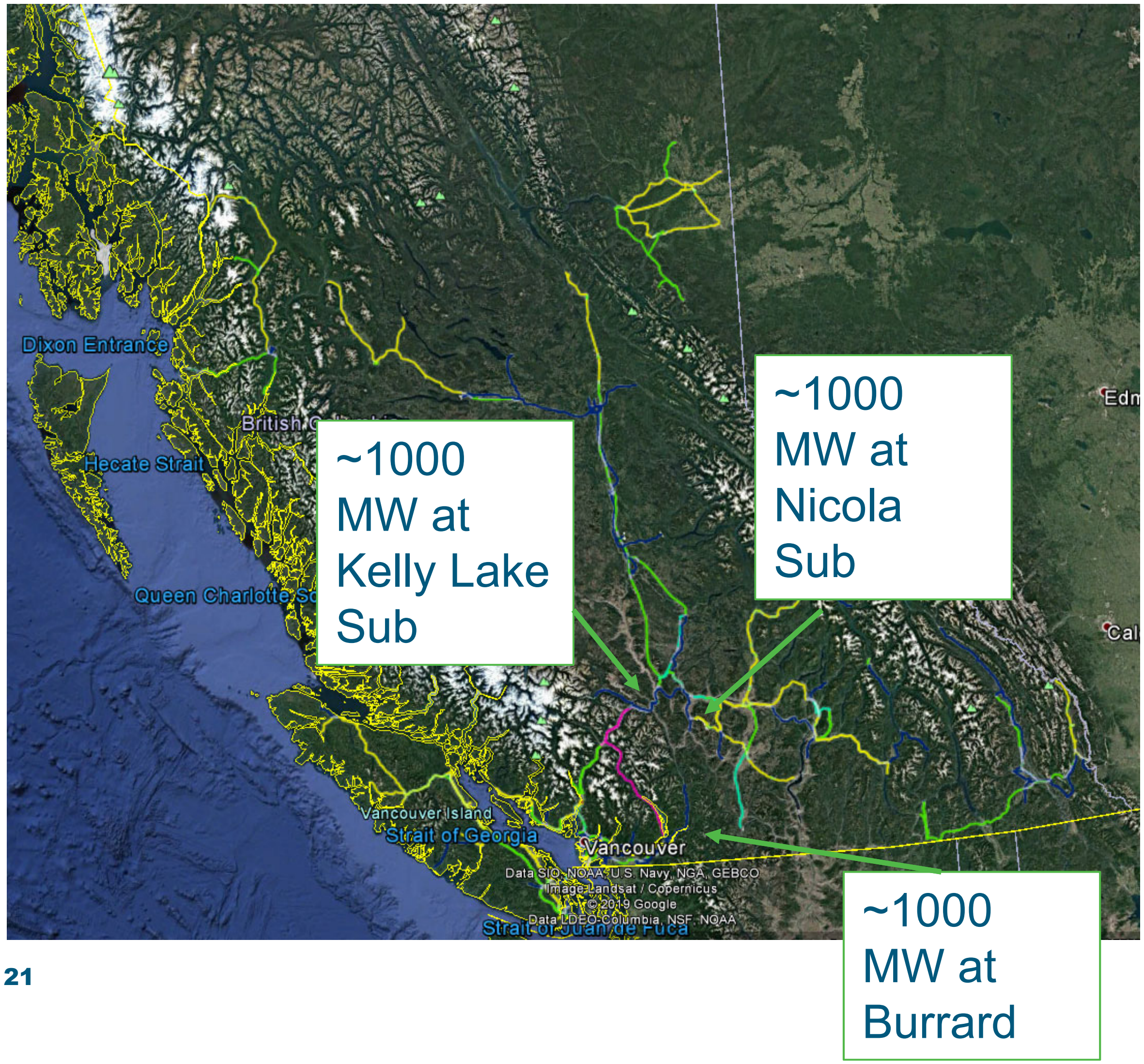
?



Consider Compressed Air Energy Storage

- Generally require salt cavern or permeable reservoir
- While they certainly exist in BC – especially in Sedimentary Basin – their viability and location is not confirmed
- Remove CAES from Dataset?

Bulk Transmission Connected Energy Storage Potential



>3,000 MW (4 hours) available at 3 locations

- 50-100 MW modular blocks
- Each site has more 100,000 sq meters of notionally available space nearby

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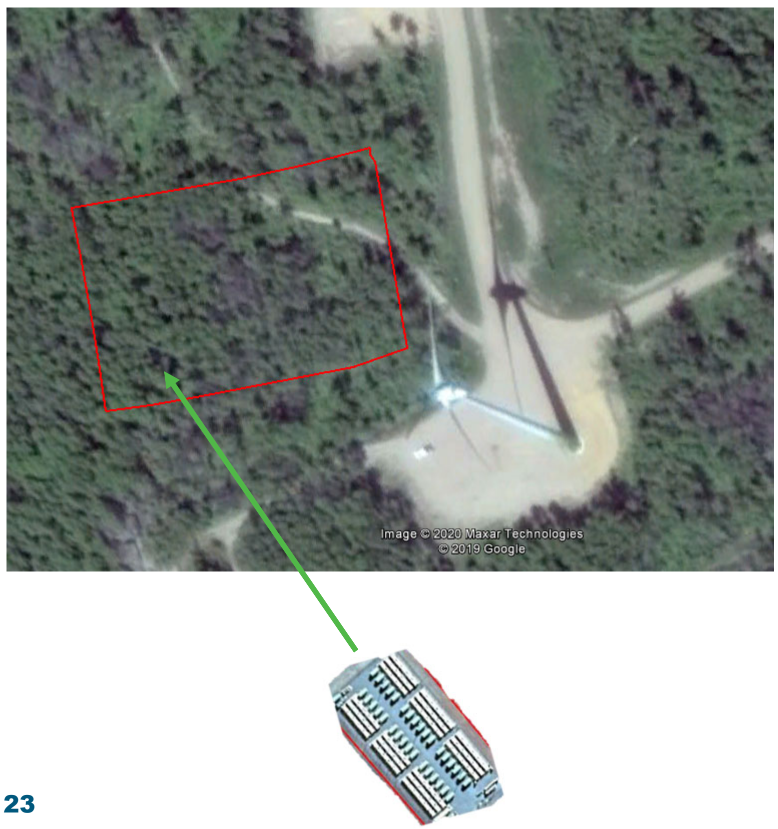
Questions on Bulk T-Connected Resources?

Defining a typical Renewables co-located energy storage resource



Consider a Li-Ion Energy Storage facility co-located with new wind resources

Power Rating: 50 MW

Duration: 4 hours

Usable Energy: 200 MWh (100% DoD)

Footprint: 3,000 sq meters (15 m^3 / MWh)

Roundtrip Energy Efficiency: 88%

Project Lifetime: 20 years

Project Lead time: N/A

Potential Secondary Value Streams:

- Arbitrage
- Renewable Integration

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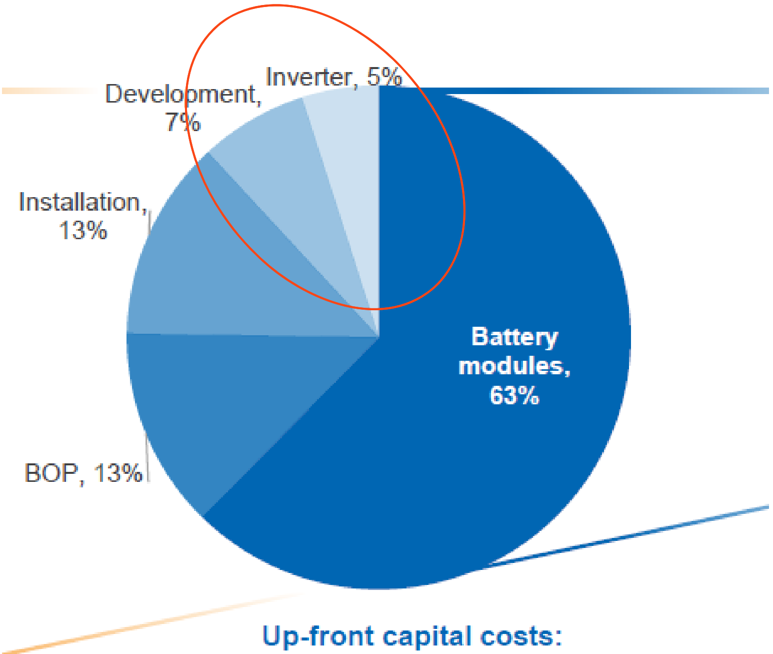
Cost of Renewable Co-located Li-Ion Battery System



Up-front capital costs:
Capital costs reflect all the costs associated with installing a BESS, including hardware (battery modules, PCS, and BOP) and soft costs (installation and project development). The largest component of up-front capital costs are battery modules.

Co-location allows savings on shared infrastructure

- Main driver for co-location in BC is shared infrastructure with renewables
  - inverter (5% of total costs)
  - permitting, site acquisition and interconnection (~2% of total costs)

Costs of Co-located Li-Ion Batteries

Total Costs for Renewables Co-located Li-Ion Batteries (50 MW, 200 MWh) in $2020 Canadian

Category	Cost	Description
Upfront Capital	$80M $1,600 / kW	Includes Containerized Battery Energy Storage systems, ~~bi-directional high power inverter,~~ cabling, installation~~, land costs, permitting~~, shipping, developer fees
Fixed O&M	$1.5M / yr	Includes Site Maintenance, Monitoring and Warranties
Augmentation	$1.1M / yr	Replacement of battery cells over 20-yr life
Energy Charges	N/A	Based on round trip efficiency of 88% and cost of energy during charging

Costs of Co-located Flow Batteries

Total Costs for Renewable Co-located Flow Batteries (100 MW, 400 MWh) in $2020 Canadian based on same ~7% Capital cost reductions

Category	Cost	Description
Upfront Capital	$260 M ($2,600 / kW)	Includes BESS, cabling, installation, ~~inverters, land costs, permitting~~, shipping, developer fees
Fixed O&M	$15M / yr	Includes Site Maintenance, Monitoring and Warranties
Augmentation	??	Electrolyte needs replacement, but do cells?
Energy Charges	N/A	Based on round trip efficiency of 75% and cost of energy during charging

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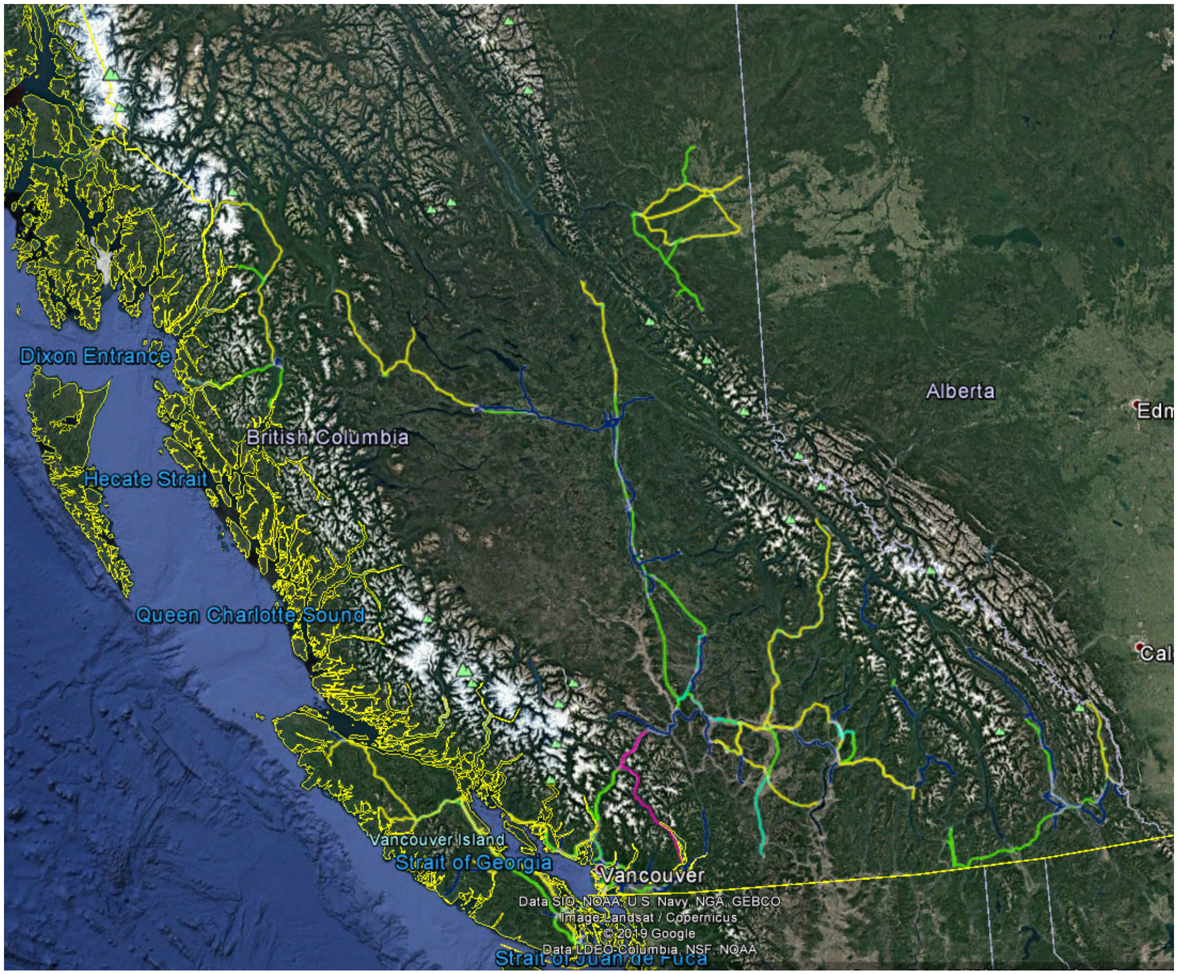
Renewable Co-located Energy Storage Potential



Based on new Renewable growth

- Assume 50-100 MW modular blocks
- Notionally sized to match Renewable Capacity

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Questions on Renewable Co-Located Resources?

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Defining a typical Substation energy storage resource

Consider a Li-Ion Energy Storage facility co-located within substation boundaries

Power Rating: 10 MW

Duration: 4 hours

Usable Energy: 40 MWh (100% DoD)

Footprint: 600 sq meters (15 m^3 / MWh)

Roundtrip Energy Efficiency: 88%

Project Lifetime: 20 years

Project Leadtime: 1 year

Potential Secondary Value Streams:

- T&D deferral
- Peak shaving

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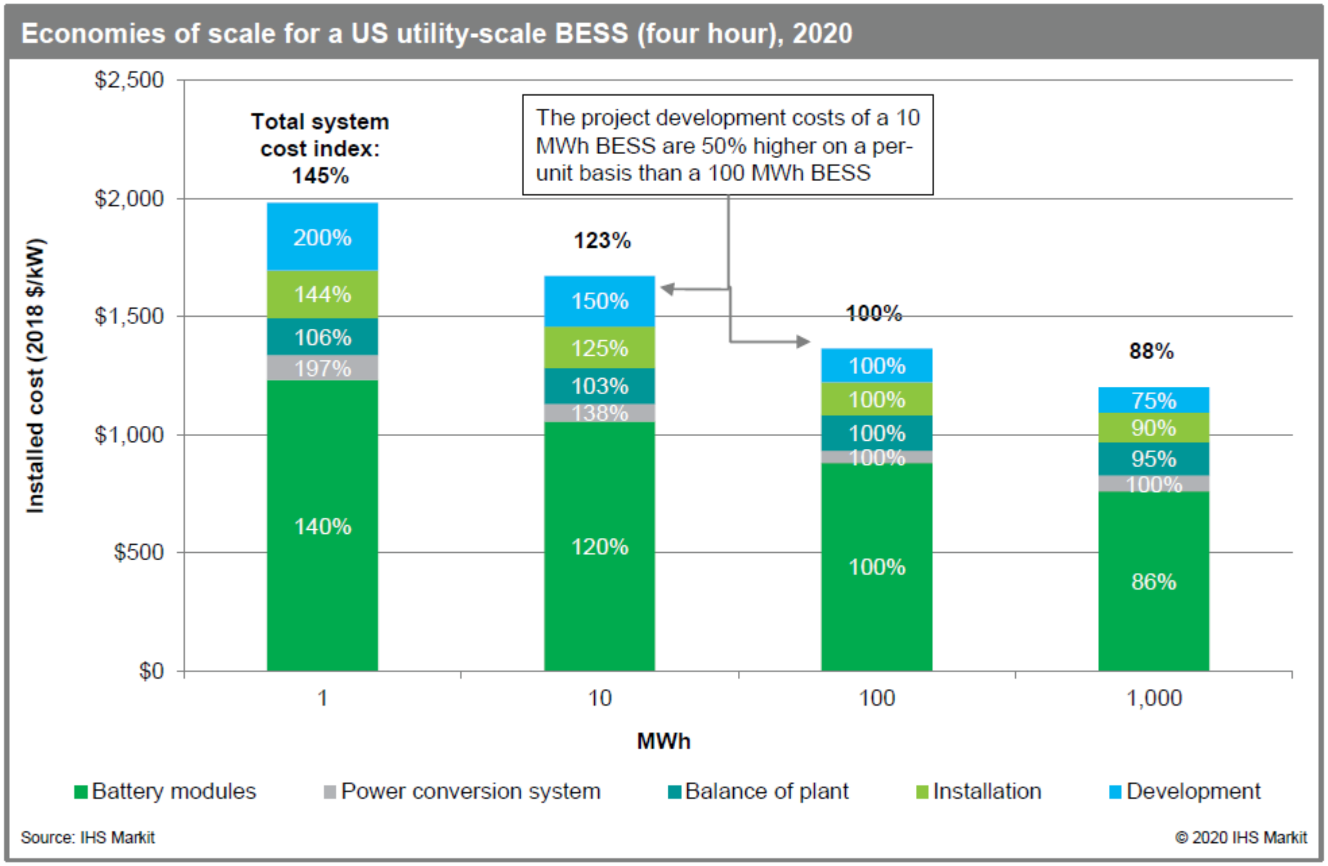
Costs of Substation Li-Ion Batteries

Moderate loss of economies of scale in all areas from 200 MWh to 40 MWh



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Costs of Substation Li-Ion Batteries

Total Costs for Renewables Co-located Li-Ion Batteries (10 MW, 40 MWh) in $2020 Canadian

Category	Cost	Description
Upfront Capital	$19M $1,900 / kW	Includes Containerized Battery Energy Storage systems, bi-directional high power inverter, cabling, installation, ~~land costs, permitting~~, shipping, developer fees
Fixed O&M	$0.3M / yr	Includes Site Maintenance, Monitoring and Warranties
Augmentation	$0.25M / yr	Replacement of battery cells over 20-yr life
Energy Charges	N/A	Based on round trip efficiency of 88% and cost of energy during charging

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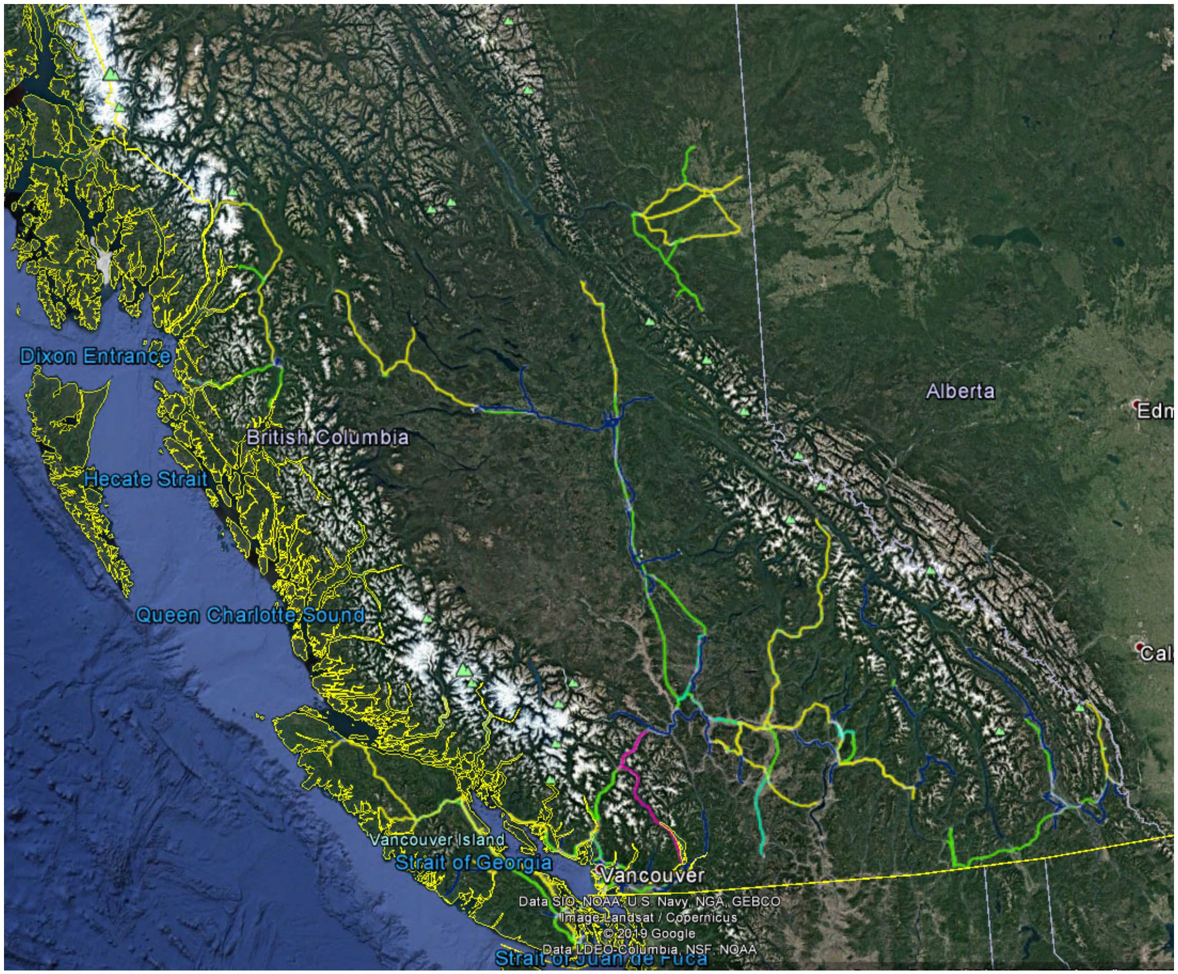
Costs of Substation Flow Batteries

Total Costs for Renewable Substation Flow Batteries (10 MW, 40 MWh) in $2020 Canadian based on same loss of economies of scale

Category	Cost	Description
Upfront Capital	$30 M ($3,000 / kW)	Includes BESS, cabling, installation, inverters, ~~land costs, permitting~~, shipping, developer fees
Fixed O&M	$1.6M / yr	Includes Site Maintenance, Monitoring and Warranties
Augmentation	??	Electrolyte needs replacement, but do cells?
Energy Charges	N/A	Based on round trip efficiency of 75% and cost of energy during charging

Substation Energy Storage Potential



~600 MW of capacity available on distribution system

- Total of 300 BCH substations
- ~20% have sufficient available space to host 10 MW facility
- 50% of resource in Lower Mainland

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Questions on Substation Resources?

Defining a typical Behind The Meter energy storage resource

Consider a Li-Ion Energy Storage facility located behind the customer meter

	Commercial	Residential
Power Rating	150 kW	7 kW
Duration	2 hr	2 hr
Usable Energy	300 kWh	14 kWh
Footprint	??	??
Round Trip Efficiency	88%	88%
Project Life	10 years	10 years
Project Lead Time	<1 year	<1 year
Potential Secondary Value Streams	• Demand Charge Reduction • Customer Reliability	• Customer Reliability

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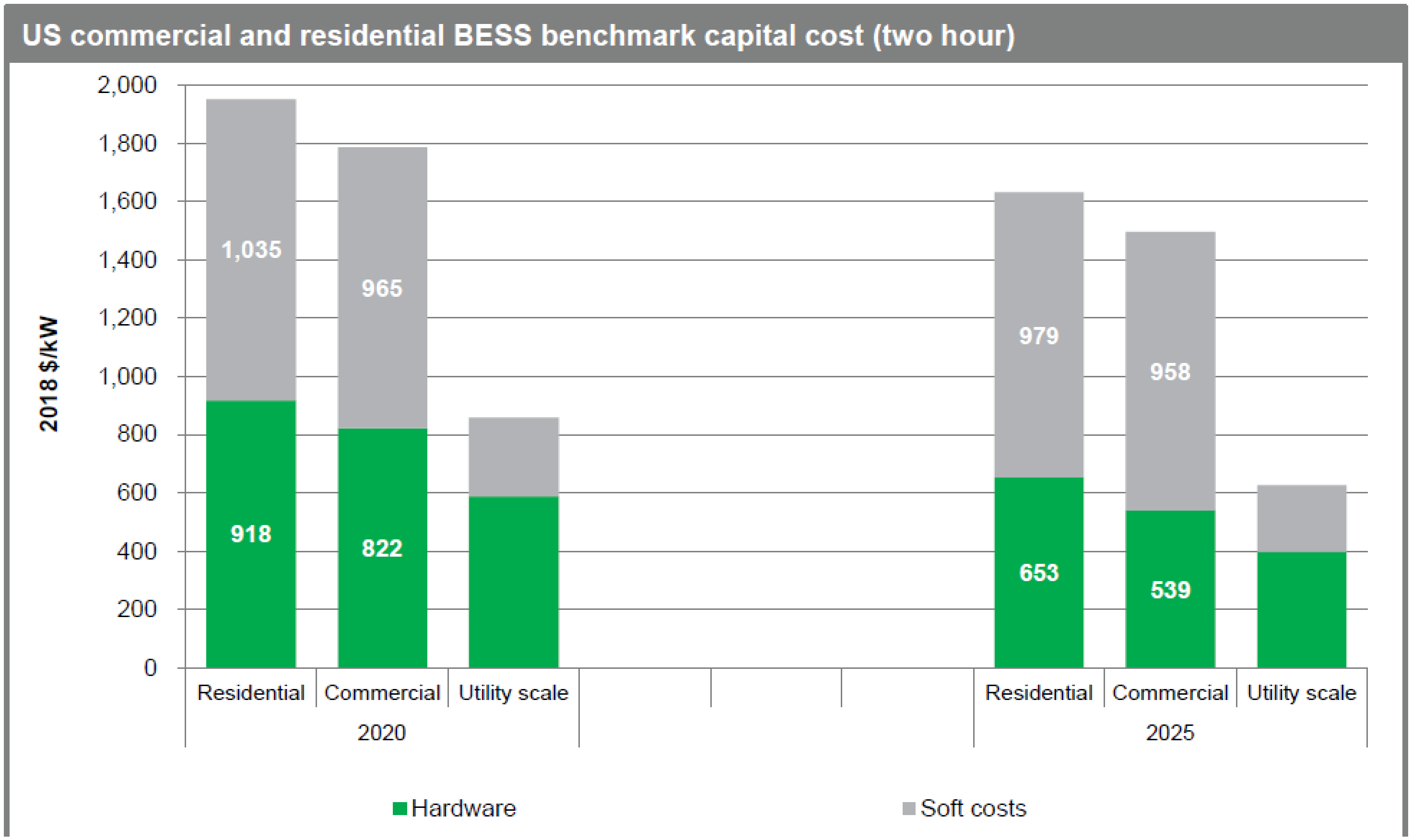
Costs of BTM Li-Ion Batteries

Costs of small batteries systems (in $US) dominated by development and installation costs



Costs of BTM Li-Ion Batteries

Total Costs for BTM Li-Ion Batteries in $2020 Canadian

Category	Commercial	Residential	Description
Upfront Capital	$360k ($2,400 / kW)	$18.5k ($2,640 / kW)	Includes BESS, cabling, installation, inverters, shipping, developer fees
Fixed O&M	$0	$0	Assumes warranty and maintenance included
Augmentation	$0	$0	Electrolyte needs replacement, but do cells?
Energy Charges	N/A	N/A	Based on round trip efficiency of 88% and customer tariff for charging

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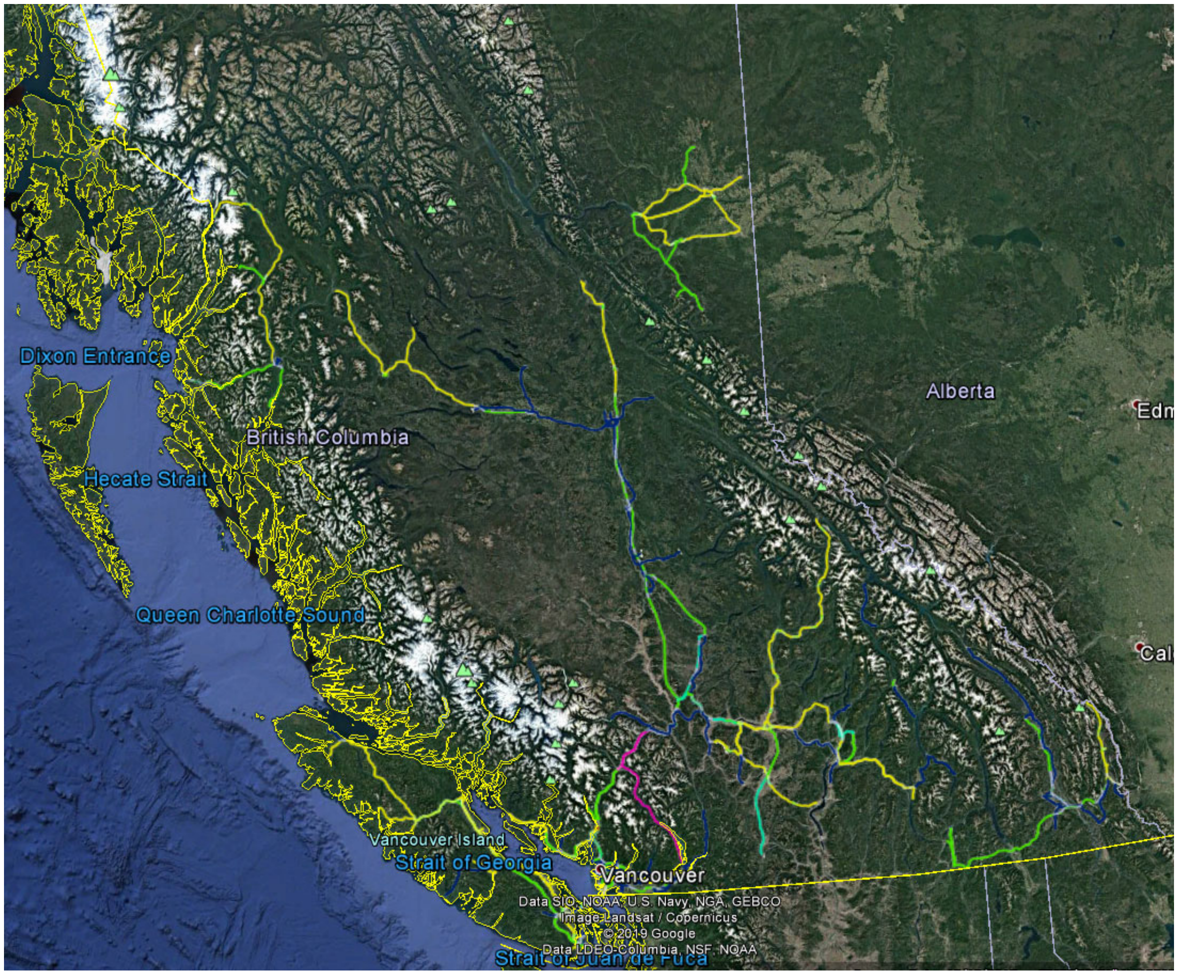
BTM Energy Storage Potential



Uncertain – Will require structural tariff changes

- Under current tariff structure, minimal value to customer from BTM storage

Questions on BTM Resources?

Feedback and Discussion

Reflect on these topics and please provide written feedback

1. Technical Characteristics of Energy Storage Resources.
    - Round trip efficiency, footprint, typical sizes?
2. Cost Characteristics of Energy Storage Resource
    - Hardware costs, Soft Costs, OMA costs
3. Available Resources in the Province
    - Transmission-connected resources, renewable co-located resources, substation resources, BTM resources

Is there anything missing?

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