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Resilient Energy and Transportation Infrastructures

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Acknowledgement to members at Smart Energy Systems Lab, Ontario Tech University
Talk Summary

• Energy Transitioning
• Smart Energy Grids for Marine and Waterfront Applications
• Resilient Interconnected Infrastructures
• Fast Charging for Marine and Waterfront Applications
• Nuclear-Renewable Hybrid Energy Systems for Marine and Waterfront Applications
• Smart Energy Networks
Energy Transitioning

Module-1: Energy Transitioning Scenario Modeling

Module-2: Energy Computational Modeling and Simulation

Module-3: AI, Optimization, Data Analytics

Module-4: Smart Sensors, Monitoring, Diagnosis, Data Centers

Module-5: Transactive Energy, Performance, and LCC

Module-6: Energy Transitioning Projects for Communities

Task-1: Analysis of Energy Grids for a Given Region or Application

Task-2: Low-Carbon Energy Transition Scenario Assessment

Task-3: Integrated Hybrid Energy Modeling and Simulation

Task-4: Supply Side Design and Control Strategies for Smart Energy Grids

Track-1: Electricity Grids and Storage Technologies

Track-2: Gas and Hydrogen Grids and Storage Technologies

Track-3: Thermal Grids and Storage Technologies

Track-4: Smart Energy for Transportation Infrastructures

Track-5: Smart Energy for Water Networks

Track-6: Demand Side Design and Control Strategies for Smart Energy Grids

Task-5: Demand Side Design and Control Strategies for Smart Energy Grids

Task-6: Optimization of Smart Energy Grids Design and Control

Task-7: Data Analytics of Smart Energy Grids Operation with Co-Simulation

Task-8: Energy Transition Planning, Technology Deployment and Business Modeling
Energy Transitioning

- Policies, Procedures, and Regulations
- Region, Application, and Integration
- Business Models and Management Scheme Strategies
- Control Strategies

Clean Energy Technologies

- Transportation Load
- Infrastructure Load
- Water Load
- Gas/H2 Load
- Electrical Load
- Thermal Load
- Water Storage
- Gas/H2 Storage
- Electrical Storage
- Thermal Storage
- Water Sources
- Gas/H2 Generation
- Power Generation
- Thermal Generation
- WTE
Hybrid Energy Infrastructures – Marine and Waterfront Regions

- Hydro Power Plants
- Wind Mill
- Solar
- Thermal Power Plants
- Nuclear Power Plants

Classify Energy Use & Supply as per Amounts / Risks / Environmental Impacts.

Analyze and Evaluate Current & Future Energy Needs in each Geographical Area using LCA/LCC Index

Clustering, Data Mining for Optimized Energy Production/Supply Chain

Risk/LCA Index

- Environmental Integrated Index
  - Endpoint
    - Human Health
    - Social Welfare
    - Productivity
  - Influence Area
    - Global Warming
    - Acidification
    - Air Pollution
  - Cause Item
    - CO2
    - SOx
    - NOx
Planning of Resilient Energy-Water-Food-Health-Transportation Infrastructures – Marine and Waterfront Regions
Energy Conversion Technologies

- Energy Supply
- Food Supply
- Health Supply
- Water Supply
- Transportation Network

Diagram:
- Thermal → EM1 → Thermal
- Thermal → EM3 → Work
- Work → EM5 → Thermal
- Work → EM7 → Electricity
- Fuel → EM9 → Work
- Fuel → EM11 → Electricity
- Electricity → EM2 → Thermal
- Electricity → EM4 → Light
- Thermal → EM6 → Electricity
- Electricity → EM8 → Electricity
- Fuel → EM10 → Thermal
- Electricity → EM12 → Work
Smart Energy Grid Superstructure

HENSU: hybrid energy supply system
Interconnected Micro Energy Grids

Transportation Network - RN

Water Network - WN

Thermal Network - TN

Electric Network - EN

Gas Network – GN

Adaptive Interconnected Micro Energy Grid Superstructure
Micro Grid

MEG Demonstration at UOIT

- Energy Supply
- Food Supply
- Health Supply
- Water Supply
- Transportation Network

- AC Power Flow
- DC Power Flow
- Heat Flow
- H2 Flow
- NG Flow

Smart Meters / Sensors

Utility Grid

Transformer

Waste-to-Energy
AC Voltage Bus

Micro Gas Turbine

Wind

Coal/Diesel Plant

Hydro Power

Grid loads

AC Load
DC Load
Thermal Load

Integrated Grid Management

AC/DC Converter

DC Voltage Bus

Battery

PV

Fuel Cell

H2 or NG

Heat

H2 or NG

Plug-in Hybrid Vehicle

Heat

H2 Storage

Electrolyzer

H2

NG Water

Energy Supply

Food Supply

Water Supply
Performance Modeling

• Quality
• Reliability
• Safety
• Security
• Resiliency
• Economy
• Technical
• Environmental
• Human Interface
• Social / Cultural
• Regulation Compliance

KPIs

Real Time
Steady State
Transient
Seasonal
KPI Modeling

- EWFHT (Generation / Storage / Loads)
- KPI Modeling
  - Socio-cultural
  - Economic
  - Environmental
  - Reliability / Safety / Security
  - Technical

<table>
<thead>
<tr>
<th>Socio-Cultural</th>
<th>Economic</th>
<th>Environmental</th>
<th>Reliability</th>
<th>Technical</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Public Acceptance</td>
<td>• Capital Cost</td>
<td>• Greenhouse Gas Emissions</td>
<td>• System average interruption distribution index (SAIDI)</td>
<td>• Power Balance</td>
</tr>
<tr>
<td>• Diversity of Supply</td>
<td>• Replacement Cost</td>
<td>• Pollutant Emissions</td>
<td>• System average interruption frequency index (SAIFI)</td>
<td>• Power Losses</td>
</tr>
<tr>
<td></td>
<td>• Operational Cost</td>
<td>• Noise</td>
<td>• Average service availability index (ASAI)</td>
<td>• Total Harmonic Distortion</td>
</tr>
<tr>
<td></td>
<td>• Payback Period</td>
<td>• Waste</td>
<td>• Expected energy not served (EENS)</td>
<td>• Capacity Factor</td>
</tr>
<tr>
<td></td>
<td>• Life Cycle</td>
<td></td>
<td>• Customer average interruption duration index (CAIDI)</td>
<td>• Load Factor</td>
</tr>
</tbody>
</table>

Diagram: Diagram of component interactions with equations.
Risk-based Energy Systems
LOPA (Layer of Protection Analysis)

- **LOPA Definition**: is to determine if there are sufficient layers of protection against the consequences of an accident scenario (can the risk be tolerated?).
LORPA: Layers of Resiliency and Protection Analysis

IRL-Independent Resiliency Layers

IPL-Independent Protection Layers

Hazards

IE 1

IE 2

IE 3
Interconnected Infrastructures

- Transportation Systems
- Health Systems
- Interface Systems
- Waste Systems
- Food Systems
- Water Systems
- Social Systems
- Hybrid Energy Systems

Interconnected Systems
Energy Loads Coupling with Interconnected Infrastructures

- Electric Load
- Water Load
- Transportation Load
- Social Load
- Waste Load
- Thermal Load
- Gas Load
- Health Load
- Food Load
Interface Design for Interconnected Systems, Application on Energy-Water-Transportation Networks

Health Interface  F1
Material Interface  F2
Electricity Interface  F3
Gas Interface  F4
Thermal Interface  F5
Environmt. Interface  F6
Water Interface  F7
Transport Interface  F8
Data Interface  F9
Social Interface  F10
Policy Interface  F11

Vehicle

Health Interface  F1
Material Interface  F2
Electricity Interface  F3
Gas Interface  F4
Thermal Interface  F5
Environmt. Interface  F6
Water Interface  F7
Transport Interface  F8
Data Interface  F9
Social Interface  F10
Policy Interface  F11

Water Pumps

Machine
Regional Gas-Power MEG Planning

1. Regional Zone
2. Sub-regional Zone
3. Extra-regional Zone
4. Cell
5. Interconnection
6. Interface
Evaluation and Optimization of Interconnected Micro Energy Grids with Gas-Power, CHP, and Renewable Technologies

- **CHP system with optimal prime mover, it is found that:**
  - Return on investment of the system could be as high as **13%**
  - Minimum payback period found is **7.8 years**
  - Maximum possible CO₂ emission saving is **15%**
  - Maximum NOx savings found is **61%**
Mobile Microgrid Trailer

- **2.4 kW Solar Array**
  - Sides of array fold out for deployment. Dual-axis sun tracking can increase power production by 40%.

- **Optional Turbine Tower**
  - Lowered by actuators for transport.

- **8 kW Output Inverter & Electrical Components**
  - Are proven and best-in-class.

- **90 kWhrs Battery Storage**
  - Lithium Ion. Tubular gel available.

- **Available small diesel or gas generator**
  - For redundancy.

- **Rugged aluminum purpose-built trailer**
  - R20 rated insulation, NEMA 4X enclosure equivalent.

- **Internet on-board for remote monitoring & control**
  - WiFi Hotspot available.
Multiple Resources and Multiple Products-based Coupling
Fig: Multiple Resources and Multiple Products-based Coupling

Fig: Energy Management Algorithm
Hybrid Energy System
Nuclear-Renewable Hybrid Energy System Simulator

In direct coupling method, electricity is generated from different RESs and reactors, and the resources simultaneously serve the electric and thermal requirements.
Deployments of Nuclear-Renewable Hybrid Energy Systems

- Renewable Energy and Energy Storage Systems
- Nuclear Power Technologies
- Nuclear-Renewable Hybrid Energy Systems
- Demand Side Management
- Micro Hybrid Energy Systems
- Techno-Economic Analysis
- Group Discussions and Individual Work
Resilient Interconnected Micro Energy Grids for Sustainable Railways
Typical Topology of an AC Railway Electrification
Resilient Interconnected Micro Energy Grids for Sustainable Railways

![Diagram showing supply lines and overhead lines for sustainable railway power supply.](image)

![Graph showing power supplied and consumed by train from different sources.](image)
Interconnected Micro Grids for Transportation Charging
Schematic of Hybrid AC-DC RIMG Including Power and Energy Sources
Integrated Control of Charging Station
Hybrid Charging Station

- EV
- ICV
- DV
- FCV
- Wireless
- Wired
- PV
- Controller
- AC/DC
- DC/AC
- Electrolyzer
- AC
- CHP
- Gas
- Heat
- WT
- WTE
- Waste
- Gas
- Grid
- TES
- H2
- H2 Station
- Hydrogen Tank
EV Charging Models

- AC Charging
  - Wireless Charging
  - Wired Charging

- DC Charging
  - Wireless Charging
  - Wired Charging

- Charging While Stop
- Charging While Moving
- Charging from Single EV
- Charging from Multi EVs
- Charge Single EV
- Charge Multi EVs

Fast Charging
Regular Charging
Charging of Toronto Bus Network
Electric Bus Charging On Route

EB Charging Options

Bus Stop  Bus Depot  EB  Flash Charger  Bus Terminal Charger  Battery Swap
## Optimization of Route Charging

<table>
<thead>
<tr>
<th></th>
<th>Route A</th>
<th>Route B</th>
<th>Route C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of Trips (per day)</strong></td>
<td>7</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td><strong>Number of Stops (per trip)</strong></td>
<td>70</td>
<td>80</td>
<td>75</td>
</tr>
<tr>
<td><strong>Total Number of Stops (per day)</strong></td>
<td>350</td>
<td>800</td>
<td>1200</td>
</tr>
<tr>
<td><strong>Trip Length (km)</strong></td>
<td>25</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td><strong>Bus Size (m)</strong></td>
<td>18</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td><strong>Average Consumption (kWh/km)</strong></td>
<td>1.8</td>
<td>2.2</td>
<td>2.2</td>
</tr>
</tbody>
</table>
CO2 Gas Emission by Different Types of Marine Ships in 2012

CO2 Emission by Different Marine Ships in 2012

CO2 Emission (million tonnes)

Vehicle
205, 26%

RO-RO
27, 3%

Refrigerated bulk
166, 21%

Other liquids tankers
124, 15%

Liquefied gas tanker
55, 7%

General Cargo
46, 6%

Ferry-ROPax
68, 9%

Ferry-pax only
35, 4%

Chemical tanker
18, 2%

Bulk Carrier
29, 4%

Oil Tankers
1, 0%

Container
1, 0%

Cruise
25, 3%
CO2 Emission by Marine Ships

- CO2 emission from shipping has been increased by 2.4% from 2013 to 2015
- CO2 emission was 910 million tons in 2013 but in 2015 it was 932 million tons

<table>
<thead>
<tr>
<th></th>
<th>Third IMO GHG Study (million tonnes)</th>
<th>ICCT (million tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global CO₂ Emissions</td>
<td>31,959</td>
<td>32,133</td>
</tr>
<tr>
<td>International Shipping</td>
<td>881</td>
<td>916</td>
</tr>
<tr>
<td>Domestic Shipping</td>
<td>133</td>
<td>139</td>
</tr>
<tr>
<td>Fishing</td>
<td>86</td>
<td>80</td>
</tr>
<tr>
<td>Total Shipping</td>
<td>1,100</td>
<td>1,135</td>
</tr>
<tr>
<td>% of global</td>
<td>3.5%</td>
<td>3.5%</td>
</tr>
</tbody>
</table>

CO₂ Emission from Marine Ship

BAU: Business As Usual
International Shipping and Environmental Impact

### Distribution of World Merchant Ships

- **General:** 32
- **Bulk Carrier:** 22
- **Crude Oil:** 14
- **Chemical:** 11
- **Container:** 10
- **Ro-Ro:** 9
- **Liquid:** 2

![Number of World Merchant Ships Graph](image)

### Percentage of CO₂ Emissions from Different Types of Ships

- **Container Ships:** 45%
- **Bulk Carriers:** 23%
- **Oil Tankers:** 19%
- **Other:** 13%

![CO₂ Emissions (%) Graph](image)
Projection of CO$_2$ Emissions from Marine Ships

- IMO predicts that tonne-miles of goods moved globally will increase 2% to 4% annually between now and 2050.

- In 2007, international shipping accounted for 870 million MT of CO$_2$ emissions and including domestic shipping it was around 1050 million MT.

- At current rates of increase, shipping sector CO$_2$ is expected to climb to between 2,500 million MT and 3,650 million MT by 2050.
Marine Ships Vs GHG Emissions

- If global shipping were a country, it would be considered as the sixth largest producer of GHG emission
- Ocean-going shipping is responsible for more than 3% of global GHG emission
- Emission from ocean-going ships is almost twice the emission from total registered cars in US
- 15 largest ships emit as much SOx as the world’s total 760 million cars.

<table>
<thead>
<tr>
<th>Year</th>
<th>Third IMO GHG Study (million tonnes)</th>
<th>ICCT (million tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global CO2 Emissions</td>
<td>32,133</td>
<td>31,822</td>
</tr>
<tr>
<td>CO2 Emissions from International Shipping</td>
<td>916</td>
<td>858</td>
</tr>
<tr>
<td>CO2 Emissions from Domestic Shipping</td>
<td>139</td>
<td>75</td>
</tr>
<tr>
<td>CO2 Emissions from Fishing</td>
<td>80</td>
<td>44</td>
</tr>
<tr>
<td>Total CO2 Emissions from Shipping</td>
<td>1,135</td>
<td>977</td>
</tr>
<tr>
<td>Total CO2 Emissions from Shipping (%)</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Percentage of International Shipping to Total Shipping Emissions</td>
<td>81</td>
<td>88</td>
</tr>
</tbody>
</table>

GHG emissions by marine ships
Fuel Efficiency and GHG Emissions with Marine

Marine ships are considered the 6\textsuperscript{th} largest contributor to GHG emissions due to the use of conventional fossil fuel as energy supply.

Distance in kilometres one metric ton of cargo travels on 1 litre of fuel.

Source: Research and Traffic Group analysis
## Power and Weight Capacity of Marine Units

<table>
<thead>
<tr>
<th>Marine unit</th>
<th>Size</th>
<th>Weight(kg)</th>
<th>Required power capacity (~hp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo ships</td>
<td>medium</td>
<td>25000</td>
<td>1378</td>
</tr>
<tr>
<td>Cruise</td>
<td>4000 passengers</td>
<td>20000</td>
<td>1102</td>
</tr>
<tr>
<td>Ferry</td>
<td>Medium</td>
<td>8000</td>
<td>441</td>
</tr>
<tr>
<td>Boat</td>
<td>6 persons</td>
<td>2100</td>
<td>115</td>
</tr>
</tbody>
</table>
# Ship Parameters and Voyage Route

## Table: Parameters of ‘Baltic Sunrise’

<table>
<thead>
<tr>
<th>SL. NO</th>
<th>SHIP DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ship's name (IMO number)</td>
</tr>
<tr>
<td></td>
<td>Baltic Sunrise (9307633)</td>
</tr>
<tr>
<td>2</td>
<td>Date delivered / Builder (where built)</td>
</tr>
<tr>
<td></td>
<td>Nov 08, 2005 / Hyundai Heavy Industries Co. Ltd., Ulsan Shipyard, Korea</td>
</tr>
<tr>
<td>3</td>
<td>Flag / Port of Registry</td>
</tr>
<tr>
<td></td>
<td>Marshall Islands / Majuro</td>
</tr>
<tr>
<td>4</td>
<td>Call sign</td>
</tr>
<tr>
<td></td>
<td>V7NP2 / 538006485</td>
</tr>
<tr>
<td>5</td>
<td>Type of ship</td>
</tr>
<tr>
<td></td>
<td>Oil Tanker</td>
</tr>
<tr>
<td>6</td>
<td>Length overall (LOA)</td>
</tr>
<tr>
<td></td>
<td>333.12 m</td>
</tr>
<tr>
<td>7</td>
<td>Length between perpendiculars (LBP)</td>
</tr>
<tr>
<td></td>
<td>324.00 m</td>
</tr>
<tr>
<td>8</td>
<td>Extreme breadth (Beam)</td>
</tr>
<tr>
<td></td>
<td>60.04 m</td>
</tr>
<tr>
<td>9</td>
<td>Deadweight</td>
</tr>
<tr>
<td></td>
<td>309373 MT</td>
</tr>
<tr>
<td>10</td>
<td>Displacement</td>
</tr>
<tr>
<td></td>
<td>352410 MT</td>
</tr>
</tbody>
</table>

## Fig: Route of ‘Baltic Sunrise’
Estimation of Ship Energy Demand

<table>
<thead>
<tr>
<th>SL. No</th>
<th>Parameter/ Assumption</th>
<th>Category</th>
<th>Notation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Beam of the ship</td>
<td>Parameter</td>
<td>$B$</td>
<td>60 m</td>
</tr>
<tr>
<td>2</td>
<td>Volume displacement of the ship</td>
<td>Parameter</td>
<td>$v$</td>
<td>344649.08 m³</td>
</tr>
<tr>
<td>3</td>
<td>Draught of the ship</td>
<td>Parameter</td>
<td>$D$</td>
<td>21.6 m</td>
</tr>
<tr>
<td>4</td>
<td>Extreme breadth (Beam)</td>
<td>Parameter</td>
<td>$\text{Bex}$</td>
<td>60.04 m</td>
</tr>
<tr>
<td>5</td>
<td>Average draught of the ship</td>
<td>Parameter</td>
<td>$D_{\text{avg}}$</td>
<td>16.15 m</td>
</tr>
<tr>
<td>6</td>
<td>Length between perpendiculaires</td>
<td>Parameter</td>
<td>$LBP$</td>
<td>324 m</td>
</tr>
<tr>
<td>7</td>
<td>Gravitational acceleration</td>
<td>Parameter</td>
<td>$g$</td>
<td>9.81 m/s²</td>
</tr>
<tr>
<td>8</td>
<td>Seawater density at 30°C temperature</td>
<td>Parameter</td>
<td>$\rho_w$</td>
<td>1021.7 kg/m³</td>
</tr>
<tr>
<td>9</td>
<td>Seawater viscosity at 30°C temperature</td>
<td>Parameter</td>
<td>$\gamma_w$</td>
<td>0.84931×10⁶ m³/s⁻¹</td>
</tr>
<tr>
<td>10</td>
<td>Average speed of the ship</td>
<td>Parameter</td>
<td>$V_{s\text{, avg}}$</td>
<td>11.94 kn or 6.1424 ms⁻¹</td>
</tr>
<tr>
<td>11</td>
<td>Incremental resistance coefficient due to surface roughness of ship</td>
<td>Assumption</td>
<td>$C_A$</td>
<td>0.0004</td>
</tr>
<tr>
<td>12</td>
<td>Maximum speed of the ship</td>
<td>Parameter</td>
<td>$V_{s\text{, max}}$</td>
<td>17.9 kn or 9.2185 ms⁻¹</td>
</tr>
</tbody>
</table>

Table: Parameters of ‘Baltic Sunrise’

\[
P_{\text{ship}}(x,y) = R_{\text{TBHS}} \cdot V_s(x,y)
\]

\[
R_{\text{TBHS}} = C_{\text{TBHS}} \cdot \frac{1}{2} \rho_w \cdot S_s \cdot V_{s\text{, avg}}^2
\]

\[
C_{\text{TBHS}} = C_{FS} + C_{RS} + C_A
\]

\[
L_{wl} = \frac{LBP}{0.97}
\]

\[
S_s = 1 \cdot 7L_{wl} \cdot B + \frac{v}{D}
\]

\[
R_{ns} = \frac{V_{s\text{, avg}} \times L_{wl}}{\gamma_w \left(\log R_{ns} - 2\right)^{\frac{1}{2}}}
\]

\[
C_{FS} = \frac{V_{s\text{, max}}}{\sqrt{g \times L_{wl}}}
\]

\[
F_{ns} = \sqrt{\frac{v}{l_{wl}^3}} \cdot \frac{B}{D}
\]

\[
A_m = B_{\text{ex}} \times D_{\text{avg}}
\]

\[
C_p = \frac{v}{A_m L_{wl}}
\]
Ship Speed Vs Propulsive Energy Demand

Fig: Speed of ‘Baltic Sunrise’

Fig: Effective power of ‘Baltic Sunrise’
SMR, vSMR, MR/MMR

- SMR is a fourth-generation nuclear reactor having power equivalent to 300 MWe or less.
- vSMR has power rating less than 15 Mwe.
- Microreactor (MR/MMR) is typically ranges from 1 MWe to 50 MWe.
### Nuclear Powered Ship

#### Nuclear Powered Ship (Non-Military)

<table>
<thead>
<tr>
<th>Ship Name</th>
<th>Country</th>
<th>Ship Type</th>
<th>Reactor Type</th>
<th>Power Output (MW)</th>
<th>Built Year</th>
<th>Status</th>
<th>Decommissioned Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savannah</td>
<td>USA</td>
<td>Container</td>
<td>PWR</td>
<td>80</td>
<td>1962</td>
<td>Not In Service</td>
<td>1977</td>
</tr>
<tr>
<td>Otto Hahn</td>
<td>Germany</td>
<td>Ore Carrier</td>
<td>FDR</td>
<td>38</td>
<td>1968</td>
<td>Not In Service</td>
<td>1982</td>
</tr>
<tr>
<td>Mutsu</td>
<td>Japan</td>
<td>Cargo</td>
<td>PWR</td>
<td>36</td>
<td>1972</td>
<td>Not In Service</td>
<td>1996</td>
</tr>
<tr>
<td>Gilgenh</td>
<td>Russia</td>
<td>Icebreaker</td>
<td>KLT-40M</td>
<td>171</td>
<td>1989</td>
<td>In Service</td>
<td></td>
</tr>
<tr>
<td>Akula</td>
<td>Russia</td>
<td>Icebreaker</td>
<td>PWR</td>
<td>342</td>
<td>1975</td>
<td>Not In Service</td>
<td>2008</td>
</tr>
<tr>
<td>Mowmow</td>
<td>Russia</td>
<td>Icebreaker</td>
<td>KLT-40M</td>
<td>135</td>
<td>1988</td>
<td>In Service</td>
<td></td>
</tr>
<tr>
<td>Taimyr</td>
<td>Russia</td>
<td>Icebreaker</td>
<td>KLT-40M</td>
<td>171</td>
<td>1989</td>
<td>In Service</td>
<td></td>
</tr>
<tr>
<td>Akademik</td>
<td>Russia</td>
<td>Icebreaker</td>
<td>OK-900A</td>
<td>342</td>
<td>1989</td>
<td>In Service</td>
<td></td>
</tr>
<tr>
<td>Lepida</td>
<td>Russia</td>
<td>Icebreaker</td>
<td>OK-900A</td>
<td>342</td>
<td>2007</td>
<td>In Service</td>
<td></td>
</tr>
<tr>
<td>Ivan</td>
<td>Russia</td>
<td>Icebreaker</td>
<td>PWR</td>
<td>318</td>
<td>1989</td>
<td>Not In Service</td>
<td>2008</td>
</tr>
</tbody>
</table>

#### Commercial Nuclear-Powered Ship

- **Count**: 7
- **Distribution of Nuclear Powered Ships**

---

700 naval nuclear reactors and 200 of them are still in operation for military use.
# Estimation of Ship Energy Demand

<table>
<thead>
<tr>
<th>SL. No</th>
<th>Parameter/ Assumption</th>
<th>Category</th>
<th>Notation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Beam of the ship</td>
<td>Parameter</td>
<td>B</td>
<td>60 m</td>
</tr>
<tr>
<td>2</td>
<td>Volume displacement of the ship</td>
<td>Parameter</td>
<td>V</td>
<td>344649.08 m³</td>
</tr>
<tr>
<td>3</td>
<td>Draught of the ship</td>
<td>Parameter</td>
<td>D</td>
<td>21.6 m</td>
</tr>
<tr>
<td>4</td>
<td>Extreme breadth (Beam)</td>
<td>Parameter</td>
<td>Bex</td>
<td>60.04 m</td>
</tr>
<tr>
<td>5</td>
<td>Average draught of the ship</td>
<td>Parameter</td>
<td>D_avg</td>
<td>16.15 m</td>
</tr>
<tr>
<td>6</td>
<td>Length between perpendiculars</td>
<td>Parameter</td>
<td>LBP</td>
<td>324 m</td>
</tr>
<tr>
<td>7</td>
<td>Gravitational acceleration</td>
<td>Parameter</td>
<td>g</td>
<td>9.81 m/s²</td>
</tr>
<tr>
<td>8</td>
<td>Seawater density at 30°C temperature</td>
<td>Parameter</td>
<td>ρ_w</td>
<td>1021.7 kg/m³</td>
</tr>
<tr>
<td>9</td>
<td>Seawater viscosity at 30°C temperature</td>
<td>Parameter</td>
<td>γ_w</td>
<td>0.84931× 10⁻⁶ m³⁻¹</td>
</tr>
<tr>
<td>10</td>
<td>Average speed of the ship</td>
<td>Parameter</td>
<td>V_s_avg</td>
<td>11.94 kn or 6.1424 ms⁻¹</td>
</tr>
<tr>
<td>11</td>
<td>Incremental resistance coefficient due to surface roughness of ship</td>
<td>Assumption</td>
<td>C_a</td>
<td>0.0004</td>
</tr>
<tr>
<td>12</td>
<td>Maximum speed of the ship</td>
<td>Parameter</td>
<td>V_s_max</td>
<td>17.9 kn or 9.2185 ms⁻¹</td>
</tr>
</tbody>
</table>

Parameters of ‘Baltic Sunrise’

\[
P_{ship} (x,y) = R_{TBHS} \cdot V_s(x,y)
\]
\[
R_{TBHS} = C_{TBHS} \cdot \frac{1}{2} \rho_w \cdot S_s \cdot V_{s,avg}^2
\]
\[
C_{TBHS} = C_F + C_{RS} + C_A
\]
\[
L_{wl} = \frac{LBP}{0.97}
\]
\[
S_s = 1 \cdot 7L_{wl} \cdot B + \frac{V}{D}
\]
\[
R_{ns} = \frac{V_{s,avg} \times L_{wl}}{\gamma_w}
\]
\[
C_F = \frac{0.075}{(\log R_{ns} - 2)^2}
\]
\[
F_{ns} = \frac{V_s_{max}}{\sqrt{g \times L_{wl} \cdot \frac{B}{D} \cdot \frac{B}{D}^{3/2} \cdot \frac{A_m}{D_{avg}}}}
\]
\[
A_m = B_{ex} \times D_{avg}
\]
\[
C_p = \frac{v}{A_m L_{wl}}
\]
Estimation of Energy Demand of Marine Ship for a Given Route

- Estimation of Ship Power

\[ R_{TBHS} = C_{TBHS} \cdot \frac{1}{2} \rho_w \cdot s_s \cdot v^2 \]

- \( R_{TBHS} \) = Total bare hull resistance of ship
- \( C_{TBHS} \) = Total hull resistance of ship coefficient
- \( s_s \) = Ship surface wetted
- \( v \) = Speed of the ship
Applications on Marine Ships with SMR

Cargo Module

Propulsion Module
NR-HES Scenarios

Cost of Energy [$/kWh]

Share of Energy Sources

Option 1
Option 2
Option 3
Option 4
Option 5
Option 6

Solar PV
Wind
Nuclear Reactor
Cost/LCOE ($/kWh)
Implementation in Marine Ships

EV Fast Charging Station Design

Diagram of EV Fast Charging Station Design with components and connections labeled:

- PV (Solar Panels)
- WT (Wind Turbine)
- Grid
- NR (Navigation System)
- UC (User Interface)
- BT (Backup Power Source)
- FW (FCS User Interface)

Converter Stations:
- DC/DC Converter-1
- AC/DC Converter-2
- AC/DC Converter-3
- AC/DC Converter-4
- MI DC/DC Converter-5
- AC/DC Converter-6

Control Lines:
- RTCoS (Real-Time Control System)
- FCSEMS (Fast Charging Station Equipment Management System)
- TEMS-S (Tennants Equipment Management System)
- BEMS-S (Building Equipment Management System)
- VEMS-S (Vehicle Equipment Management System)

Power Lines:
- DC Line
- Wireless Data Line

Connecting Devices:
- FCS-C1
- FCS-C2
- FCS-C3
- TEMS-T
- BEMS-B
- VEMS-V

Load Following System

Additional labels include:
- EV Fast Charging Station
- Station Design
The proposed FCS load profile includes 35% Level 1, 35% Level 2, and 30% DC fast charging vehicles and the station can handle 1000 vehicles per day. 
Source: https://afdc.energy.gov/stations/#/find/nearest
Framework to Calculate Total Daily Load at Hybrid Charging Station (HCS)

SS: Station location index
IF: Industrial facility location index
EB: Electric bus
EM: Electric marine
ET: Electric truck

Calculate Daily Load at $HCS_i$

Calculate Daily Load at $HCS_i$ for Charging EVs

Calculate Daily Load at $HCS_i$ for Charging EBs

Calculate Daily Load at $HCS_i$ for Charging ETs

Calculate Daily Load at $HCS_i$ for Charging IF$_j$

Calculate Daily Load at $HCS_i$ for Charging SS$_k$

Total Daily Load to Charge Swapped Batteries at $HCS_i$

Daily Load at $HCS_i$ = Total Daily Load for EVs + Total Daily Load for EBs + Total Daily Load for ETs + Total Daily Load for IF$_j$ + Total Daily Load for SS$_k$ + Total Daily Load to Charge Swapped Batteries

Daily EVs Charging Load at $HCS_i$ = Daily Number of EVs Charged * Energy Charged per EV Trip

Daily EBs Charging Load at $HCS_i$ = Daily Number of EBs Charged * Energy Charged per EB Trip

Daily ETs Charging Load at $HCS_i$ = Daily Number of ETs Charged * Energy Charged per ET Trip

Daily IF$_j$ Load at $HCS_i$ = Number of Charging IF loads * Energy Charged per Time

Daily SS$_j$ Load at $HCS_i$ = Number of Charging SS loads * Energy Charged per Time

Daily Load of Charging Swapped Batteries at $HCS_i$ = Total Daily Load of Swapped Batteries for EVs + Total Daily Load of Swapped Batteries for EBs + Total Daily Load of Swapped Batteries for ETs + Total Daily Load of Swapped Batteries from other HCSs
Scenarios

• **Scenario-1: Single on-route terminal charging station**

  Terminal-1  ➔  Terminal-2

• **Scenario-2: Two on-route terminal charging stations**

  Terminal-1  ➔  Terminal-2
Tracking Performance and Stability

(a) Tracking performance, (b) step response, and (c) bode plot of MRAC system
MRAC with Mixed-Integer Linear Programming

Step 1: Optimization Problem Formulation

The entire optimization issue may be stated as follows, taking into account the constraints and objective function established in the preceding sections:

minimize \( R \)

subject to binary variables

storage model

storage constraints

power balance

Illustration of MRAC system with optimization strategy
MRAC with Mixed-Integer Linear Programming

Step 2: Optimization Problem Solution

The optimum input sequence for the prediction horizon $N_p$ is found by solving the MILP problem:

$$u_{opt}(k) = [(u_{opt}(0))^T (u_{opt}(1))^T \ldots (u_{opt}(N_p - 1))^T]$$

Step 3: Control Set-Points Execution

Although a whole series of $N_p$ future control signals is calculated, only $u_{opt}(0)$ is applied to the system, and the other optimum values in $u_{opt}(k)$ are omitted.

Step 4: Shift the Prediction Horizon

The prediction horizon is shifted, and steps 1 – 3 are repeated to generate a new optimum sequence, $u_{opt}(k)$. All this is done by re-evaluating the system’s current state, re-calculating power electronic efficiencies, and then resolving a new optimization issue.
Simulation of EMS with Optimization

(a) Simulink model of the proposed EMS (b) MATLAB function block for EMS
Performance Analysis

Performance of the system with (a) conventional EMS (b) Proposed EMS (c) Power saving by the proposed EMS
The proposed system improves the utilization of the ESS and reduces the COE.

(a) Energy storage system SoC profile (b) cost of energy of the system
Performance Analysis

12 minutes to reach from 20% to 80% of SoC

17 minutes to reach from 20% to 80% of SoC

(a) Charging profile of (a) electric vehicle (b) electric bus from the proposed fast charging station

(b)
Sensitivity Analysis - Electrical Power Requirement

Rate of Change in NPC with Electrical Power (Case-01)

Rate of Change in NPC with Electrical Power (Case-02)

Rate of Change in NPC with Electrical Power (Case-03)

Rate of Change in NPC with Electrical Power (Case-04)
Emergency Analysis for Fast Charging Infrastructure

Emergency Level:
- World
- Country
- State
- City
- Area
- Vehicle
- Human

Emergency Nature:
- Wind Storm
- Snow Storm
- Sand Storm
- Rain Storm
- Radiation
- Pandemic
- Infrastructure Destruction
- Very High Temperature
- Very Low Temperature
- Cyber Security
- Terror
- Flood
- Water
- Food
- Road
- Traffic
- Trip
- Charging Station
- Vehicle
- Human
- Service Provider

Emergency Coupling with Transportation:
- Coupling with Energy
EV Charging Models

- **AC Charging**
  - Wireless Charging
  - Wired Charging
- **DC Charging**
  - Wireless Charging
  - Wired Charging

**Charging Models**

- **While Stop**
  - Charging from Single EV
  - Charge Single EV
  - Charging from Multi EVs
  - Charge Multi EVs

- **While Moving**
  - Fast Charging
  - Regular Charging
Layers of Resiliency Analysis (LORA) of FCS

- **WICR**: Wireless Charging
- **WDCR**: Wired Charging
- **SBTR**: Swap BT
- **CBTR**: Charge BT

**Charging Load**
- RD11
- RD12
- RD13
- RD14

**Charging Unit**
- RD21
- RD22
- RD23
- RD24

**Power System**
- RD31
- RD32
- RD33
- RD34

**Energy Systems**
- RD41
- RD42
- RD43
- RD44

**Resiliency Demand**: RD
**Resiliency Likelihood**: RL
Layers of Resiliency Analysis (LORA) of FCS

Frequency of occurrence of "RD*"

RD1* 0.05  RL1* 0.97  Mitigated Resiliency Performance after layer-1

0.07  RD2*  RL2* 0.82  Mitigated Resiliency Performance after layer-2

0.02  RD3  RL3* 0.96  Mitigated Resiliency Performance after layer-3

0.06  RD4*  RL4* 0.87  Mitigated Resiliency Performance after layer-4

0.18  TR*  Mitigated Resiliency Performance after layer-4

RD: Resiliency Demand, RL: Resiliency Likelihood
Emergency Index Analysis for Charging Station

EL: Emergency Index
Performance Index Analysis for Charging Station

PI: Performance Index
Vehicle Energy Management for Charging in Emergencies
Vehicle Energy Management for Charging in Emergencies
Transactive Energy for FCS

DC Line

Charging Station (CU1)
Charging Station (CU2)
Charging Station (CU3)

PV-C
PV-C
PV-C
PV-C

DC/DC Converter-1
DC/DC Converter-2
AC/DC Converter-3
AC/DC Converter-4
AC/DC Converter-5
AC/DC Converter-6
AC/DC Converter-7

WT-C
GR-C
NR-C
ES-C
FW-C

PV
WT
Grid
NR
UC
BT
FW

FC
PV
WT
Grid
NR
UC
BT
FW

FCS-C1
FCS-C2
FCS-C3

Transactive Energy
Transactive Mobility

FCS User Interface
FCSEMS
TEMS-S
BEMS-S
VEMS-S

RTCoS
Distributed Optimization Model

- **EV Optimizer**
- **ICV Optimizer**
- **DV Optimizer**
- **FCV Optimizer**
- **EV Charging Optimizer**
- **ICV Fueling Optimizer**
- **DV Fueling Optimizer**
- **H2 Supply Optimizer**
- **HCS Optimizer**
- **TES Optimizer**
- **Grid Optimizer**
- **Gas/Diesel Supply Optimizer**
- **Waste Supply Optimizer**

Symbols:
- $P_{cws}$
- $P_{cwd}$
- $P_{ses}$
- $T_{uss}$
- $G_{us}$
- $T_{ge}$
- $G_{sus}$
- $G_{gm}$
- $H_{ge}$
- $D_{us}$
- $D_{sus}$
- $P_{cws}$
- $P_{cwd}$
- $P_{shs}$
- $H_{us}$
- $H_{su}$
- $G_{su}$
- $D_{su}$
- $W_{su}$
- $P_{sgm}$
- $P_{rmg}$
- $T_{st}$
# Energy-Water Coupling

<table>
<thead>
<tr>
<th>Energy-Water Coupling</th>
<th>Supply Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy inputs into Water Grids</td>
<td>Energy supply to water sources</td>
</tr>
<tr>
<td></td>
<td>Energy supply to water treatment</td>
</tr>
<tr>
<td></td>
<td>Energy supply to water storage</td>
</tr>
<tr>
<td></td>
<td>Energy supply to water transfer</td>
</tr>
<tr>
<td></td>
<td>Energy supply to water loads</td>
</tr>
<tr>
<td>Water inputs into Energy Grids</td>
<td>Water supply to energy sources</td>
</tr>
<tr>
<td></td>
<td>Water supply to energy conversion</td>
</tr>
<tr>
<td></td>
<td>Water supply to energy storage</td>
</tr>
<tr>
<td></td>
<td>Water supply to energy transfer</td>
</tr>
<tr>
<td></td>
<td>Water supply to energy loads</td>
</tr>
</tbody>
</table>
Water-Energy Analysis Levels (Food-Health)

City-level
- Water and energy flows
- Climate changes and pollutions
- Urban nexus conceptual framework

Regional-level
- Water, energy and environment connections
- Policy decisions regarding
- Systematic model framework

National-level
- Water scarcity, climate change and environmental capacity
- Policy intervention
- Institutional arrangement
- Integrated implementation framework

Transboundary-level
- Trade-offs of shared resources
- Institution coordination
- Benefits share frameworks
Energy-Water in Farms
Energy-Water Optimization

- **Objective function** = \( \min (f_1 + f_2 + f_3) \)

- where \( f_1 \) is the cost of electric energy consumption, \( f_2 \) is the cost of pump maintenance and \( f_3 \) is the cost of demand charges.

\[
\begin{align*}
  f_1 &= \sum_{i=1}^{np} \sum_{j=1}^{24} P_{ij} \times c_{ej} \\
  f_2 &= c_d \times P_{\text{max}} \\
  f_3 &= \sum_{i=1}^{np} c_m \times Sw_{\text{max}_i}
\end{align*}
\]
Ontario Daily Energy Tariff
# Optimization Results

<table>
<thead>
<tr>
<th>Pump</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
<th>#5</th>
<th>#6</th>
<th>#7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power (kW)</td>
<td>595</td>
<td>445</td>
<td>260</td>
<td>260</td>
<td>595</td>
<td>740</td>
<td>330</td>
</tr>
<tr>
<td>Water Flow (m³/hr)</td>
<td>1800</td>
<td>1440</td>
<td>828</td>
<td>828</td>
<td>1800</td>
<td>2240</td>
<td>1000</td>
</tr>
</tbody>
</table>

- **Tank 1:**
  - Lower limit (m): 6.5
  - Upper limit (m): 9

- **Tank 2:**
  - Lower limit (m): 6.5
  - Upper limit (m): 8.5

- **Tank 3:**
  - Lower limit (m): 6
  - Upper limit (m): 9
Daily Power Consumption of Toronto Water Pump Stations

Hourly power consumption of Toronto WDN

- Unoptimized
- Optimized
Integrated Collaborative Simulation for Regional Planning and Optimization of Hydrogen Deployments Strategies

User Interface

- Manage H2 Strategy
- Manage H2 Scenario
- Manage H2 Technology
- Manage Infrastructure
- Manage Transactive Energy
- Manage KPI

Collaborative Simulation

- Control
- Optimization

ChatGPT

ESN
CSDB

Tools:
- TRANSYS
- HOMER
- Matlab
- SWITCH
- NR-HESS
- EXCEL
Case study 2: Starting to include fuel cell vehicles
## Main KPIs

### Region KPIs
- CO2 emissions (tons/year)
- Operating costs ($/year)
- Power demand (MWh/year)
- Water demand (ML/year)

### Zone KPIs
- CO2 emissions (tons/year)
- Operating costs ($/year)
- Power demand (MWh/year)
- Water demand (ML/year)

### Power plants KPIs
- CO2 emissions (tons/year)
- Operating costs ($/year)
- Generated power (MWh/year)
- Capital costs ($)

### Hydrogen plant/s KPIs
- Generated hydrogen (kg/year)
- Operating costs ($/year)
- Capital costs ($)

### Water plants KPIs
- Operating costs ($/year)
- Processed water (ML/year)
System architecture

Two Installation options

**Google collab:**
- Easy start, installation of 2-3 minutes
- Installation required on every use
- Information should be saved constantly in case collab limit is exceeded

**Local:**
- Initial installation is complex
- Installation required one time (except when there are code updates)
- Information storage is flexible

Must be updated every time new modules are developed/changed

Source code
Location: Github

https://github.com/ElenaVH/switch_E

Interpreting output data

Manually

From user interface (currently not implemented)

Modifying input data

Manually

From user interface (currently not implemented)

Data files:
- carbon_penalties.csv
- financials.csv
- fuel_cost.csv
- htr.csv
- gen_build_costs.csv
- gen_build_deterministic.csv
- gen_info.csv
- load_zone.csv
- loads.csv
- modules.csv
- non_fuel_energy_sources.csv
- pe.csv
- switch_input_version.txt
- timepoints.csv
- timeseries.csv
- water_demand.csv
- water_plants_info.csv

Code is private: only accessible to our team

Must be updated every time new modules are developed/changed

https://github.com/ElenaVH/switch_E
Data preprocessing: Power

Power separation proportional to population density

Population in Toronto, East and Essa areas vs population in Durham region: Select applicable FSAs,
Digital Architecture for Transactive Mobility

- **Cloud Server**
- **Edge Server**
- **Traffic Signal**
- **Surveillance Camera**
- **Charging Station**
- **EV1**
- **EV2**
- **DSRC**
- **4G/5G Network**
- **Cellular**
- **Pedestrian**

**Edge Entities:**
- CAVs, Traffic Signals, Surveillance Cameras, Mobile Devices of Pedestrians, etc.

**Charging Stations:**
- CS1
- CS2
- CS3
- CS4
- CS5
- CS6
- CS7
- CS8

**Connectivity:**
- Ethernet / Optical Fiber
- Cellular
- DSRC

**Networks:**
- Clouds
- Central Traffic Control Server
- Base Stations
- Roadside Units
Integrated Energy-Water-Food-Health-Transportation Data Center (Efficiency, Conservation, Safety, Reliability)
AI for Smart Energy-Water-Food-Health-Transportation Infrastructures

\[
C^i = \begin{bmatrix}
    c_{1,1}^i & \cdots & c_{1,l_1-1}^i \\
    \vdots & \ddots & \vdots \\
    c_{j,1}^i & \cdots & c_{j,l_j-1}^i
\end{bmatrix}_{j_i \times j_i}
\]
Integrated Modeling & Simulation for Smart Energy-Water-Food-Health-Transportation Grids Planning, Control, and Optimization

Ontario Ministry of Energy
- Utility Companies
- IESO / OPA / Licensing
- Energy Technology / Service Providers
- Consumers

Gas Network
Thermal Network
Electricity Network
Water Network
Transportation Network

Ontario Energy Model (SEN / ESN)

Application Layer
GIS Layer
Data Management
Communication / Control
Grid Physical System

Business Process Modeling
- Gas Supply Networks
- Gas-Power Technology Assessment
- Renewables Technology Assessment
- ESN KPI Modeling
- Geographical & Environmental Modeling
- MEG Topology Modeling
The Resilient Design of the Microgrid
Real-time Co-simulation for Microgrid Applications
Lab Demonstration of Microgrid with FCS
H2VPRO – Novel Hydrogen Generation Technology

H2VPRO Specification

- **Type**: Alkaline Electrolysis
- **Dimension**: 30 × 40 × 50 cm
- **Electrode**: Ni 99.9%
- **Electrical input**: Voltage 3.6 V, Current 10.8 A
- **H₂ Purity**: 99.5%
- **Temperature/Pressure**: Ambient (22oC)/Atmospheric
- **Efficiency**: 94.3%

H2VPRO Productivity

<table>
<thead>
<tr>
<th>Consumed Power W</th>
<th>H₂ mL/min</th>
<th>H₂ kg/hr.</th>
<th>H₂ kg/day</th>
<th>H₂ kg/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>39</td>
<td>71</td>
<td>0.0004</td>
<td>0.0085</td>
<td>3.1174</td>
</tr>
</tbody>
</table>
Key Features & Summary Description of SSWT

- This patent is concerned with the ability to install a vertical axis turbine as a hydrokinetic turbine on both the board of maritime transports and shoreline infrastructures. The patent is establishing a new Savonius turbine with a vertical axis concept S shape water turbine (SSWT), which consists of a simple design with higher efficiency at low wind and water speeds than other turbines. In addition, this design presents a compact size, self-starting, ease of installation and maintenance, and independence concerning water flow direction.
The Conventional OTEC System
The Proposed OTEC System

Warm sea water at Sea surface

Cold sea water at Sea Depth

Vertical Turbine (It is used as electric power source for pumps)

Electric Power Output

- Electrolyzer
- Grid/Load
- H2 Storage
- Fuel Cell
- ICV Fueling
- Load/EV Charging

Decide based on location and higher output power

- Wind
- Hydrokinetic

Analyze HES-OTEC Loads and Demands, and Optimize Performance

• Smart Energy Grid Engineering Book: http://store.elsevier.com/Smart-Energy-Grid-Engineering/Hossam-Gabbar/isbn-9780128053430/
Welcome Message

It is our great pleasure to invite you to join our International Conference on Smart Energy Grid Engineering (SEGE), which is sponsored by Toronto Section PES Chapter and hosted by Ontario Tech University. This event will provide a unique opportunity to have fruitful discussions about smart energy grid infrastructures, technologies, engineering design methods, and best practices that address industrial challenges. The event includes a large number of speakers and quality papers that cover energy generation, transmission, and distribution infrastructure, energy storage, electrification, information, and communications, and security. The 12th International Conference on Smart Energy Grid Engineering will be held during August 13-15 in 2023. We look forward to welcoming you at Ontario Tech University, Oshawa, Canada.

Dr. Hossam Gabbar
Founder and General Chair of IEEE SEGE
Ontario Tech University
Oshawa, Ontario, Canada

Hosted by

Ontario Tech University

Sponsored by

IEEE Conference on Smart Grid Engineering
Thank You