Waterloo Institute for Sustainable Energy

Energy and Innovation for Sustainability

Waterloo Institute for Sustainable Energy

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Executive Director, Waterloo Institute for Sustainable Energy

Presented at
IIT- Rajasthan (Jodhpur)
November 25th 2010

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WISE
Waterloo Institute for Sustainable Energy

The Waterloo Institute for Sustainable Energy (WISE)

- A top strategic priority of the University of Waterloo
- Full spectrum of energy R&D, education and training, partnerships and commercialization activities
- 80 + faculty members work as multi-disciplinary teams across faculties of Engineering, Science and Environment

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The Waterloo Institute for Sustainable Energy (WISE)

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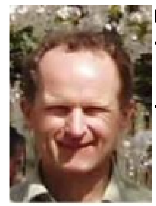

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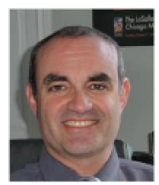

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Vision

To establish WISE as a recognized centre of expertise and excellence

for development of energy systems and policies sustainable over the long term

To promote innovation

to enhance national social, economic and environmental performance by creating options and alternatives to existing energy production and delivery systems

To conduct collaborative research in support of goals identified by utilities, business, government agencies and civil society groups

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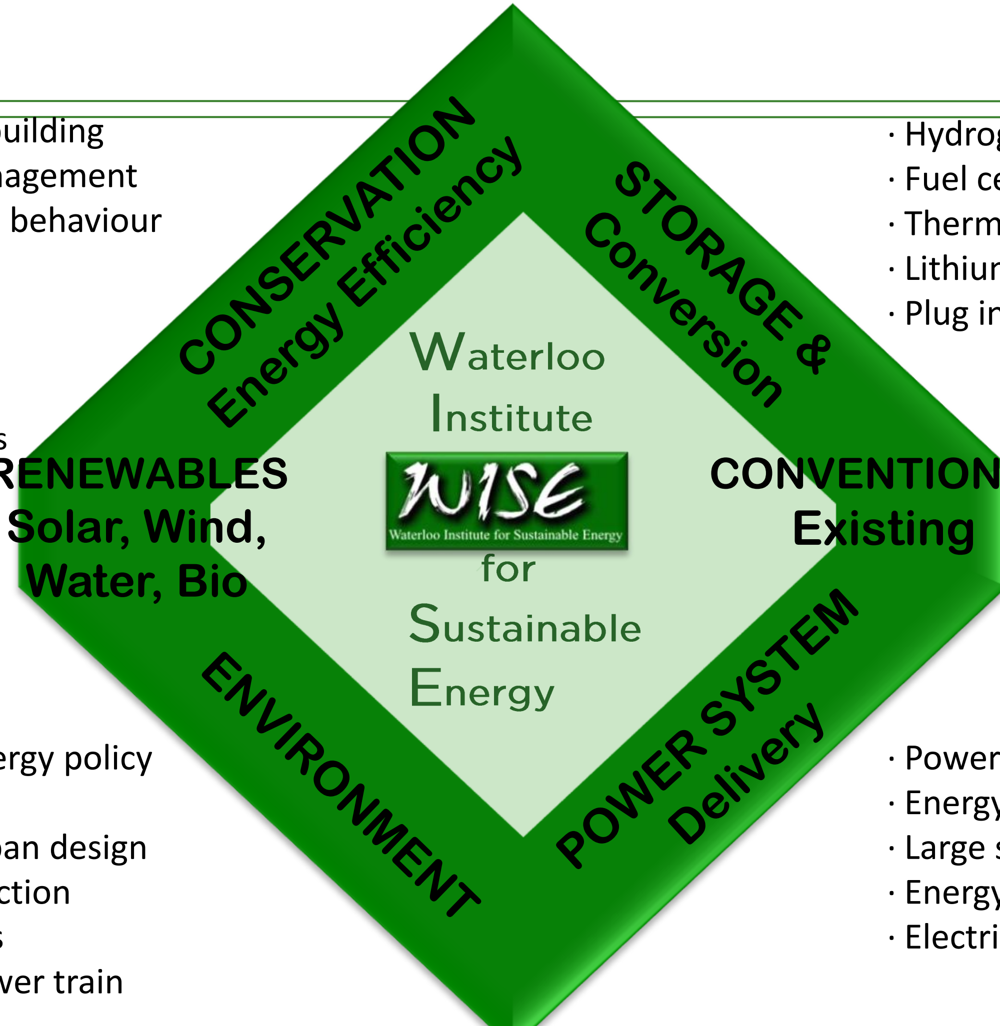
SUSTAINABLE ENERGY:
Policies, Programs, Directions

- Sustainable building
- Demand management
- Conservation behaviour

- Hydrogen production
- Fuel cells (solid oxide and PEM)
- Thermoelectric materials & devices
- Lithium ion batteries
- Plug in Vehicles

- Centre for Advanced Photovoltaics, Systems & Devices (CAPDS)
- Solar thermal applications
- Wind turbine design & performance
- Bioenergy
- Distributed generation



- CCS
- Clean diesel engines
- Clean coal technology
- Nuclear power plant reliability

- Sustainable energy policy & planning
- Sustainable urban design
- Emissions reduction
- Green batteries
- Green auto power train

- Power quality
- Energy systems reliability
- Large scale optimization
- Energy forecasting
- Electricity markets

Preserve & Create Energy Options
Multi-Disciplinary Research Teams
Economic Growth & Environmental Performance
Business, Government, Industry Engagement

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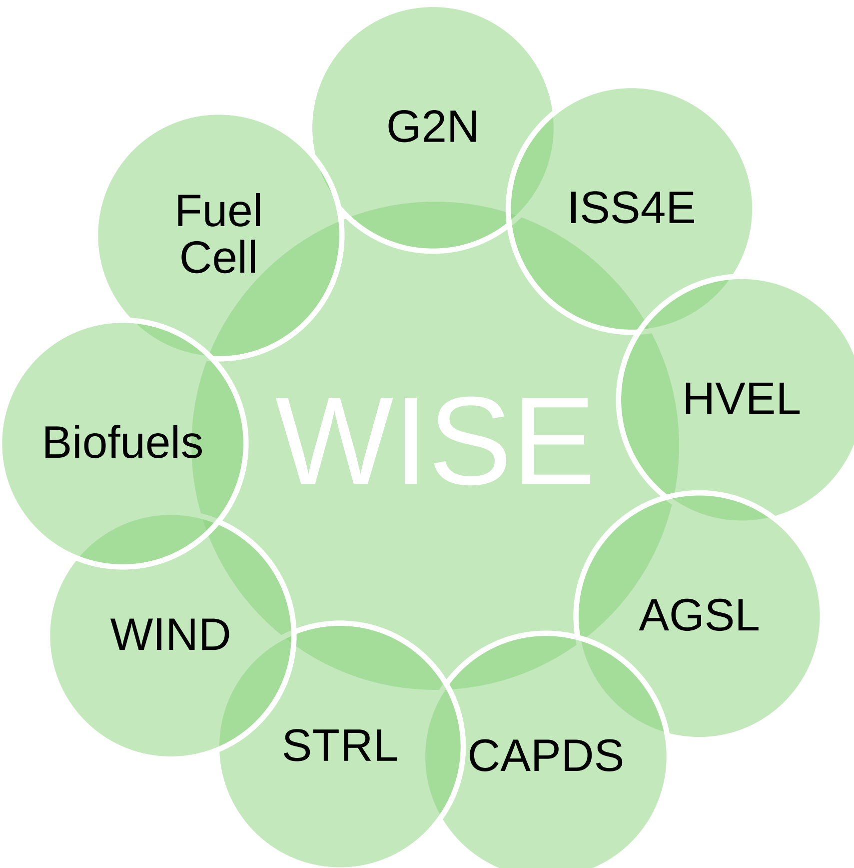
Some Research Labs



G2N Giga-to-Nano Lab
- Andrei Sazonov, Electrical & Computer Engineering

ISS4E Information Systems & Science for Energy
- S. Keshav, Computer Science

HVEL High Voltage Engineering Lab
- Shesha Jayaram, Electrical & Computer Engineering

AGSL Advanced Glazing System Lab
- John Wright, Mechanical & Mechatronics

CAPDS Centre for Advanced Photovoltaic Devices and Systems
- Siva Sivoththaman, Electrical & Computer Engineering

STRL Solar Thermal Research Lab
- Michael Collins, Mechanical & Mechatronics

WIND Labs
- David Johnson/Fue-Sang Lien, Mechanical & Mechatronics

Biofuel/Green Energy Lab
- Chao Tan, Mechanical & Mechatronics

Fuel Cell & Green Energy Lab
- Xianguo Li, Mechanical & Mechatronics

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Energy Research Centre (ERC)

Advanced Glazing System Laboratory

Glazing systems & shading devices

Solar Thermal Research Laboratory

Next generation solar thermal technologies

Centre for Advanced Photovoltaic Devices and Systems

Photovoltaic material synthesis, cell & module fabrication

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The world class UW Live Fire Research Facility, a large-scale indoor wind generation facility

Fuel Cell and Green Energy Research

Cost-effective & reliable fuel cell technology

Wind Turbine Acoustics

wind turbine noise

Wind Energy

Fan design & testing; incompressible flow; & measurement techniques

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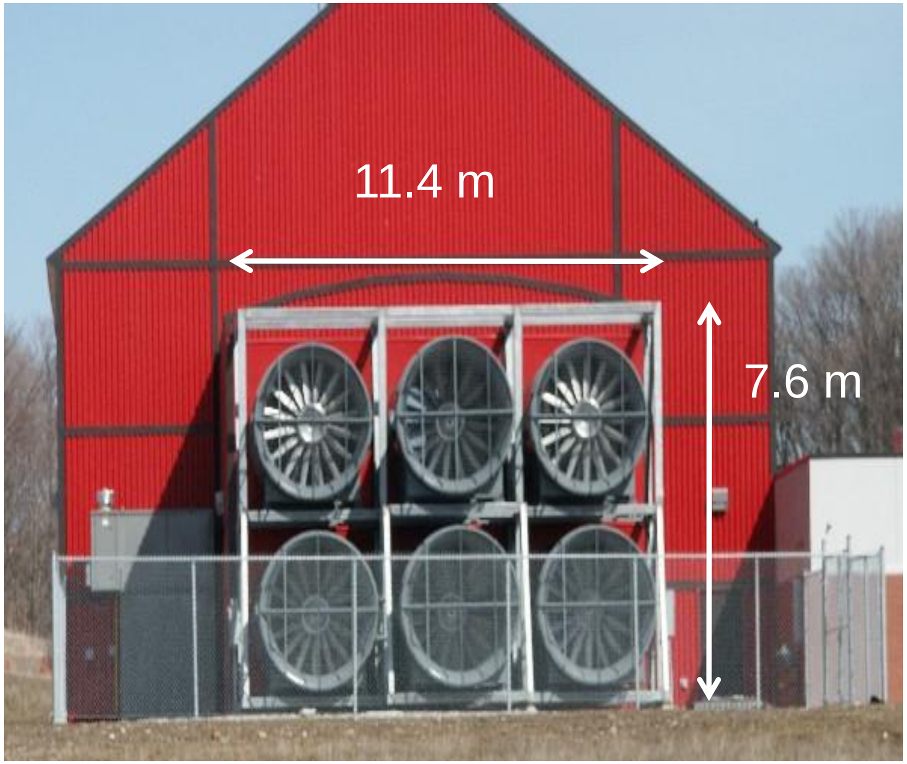
UW large-scale wind facility



UW Large-scale wind facility

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ISS4E

Information systems & science to increase efficiency & reduce the carbon footprint of energy systems

Giga-to-Nano Laboratory

Advanced flexible electronics fabrication & nanoelectric device integration

Laboratory for Research in Thermochemical Process and Green Energy

Thermochemical conversion of biomass to biofuels

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- High Voltage Engineering
  - Electrical insulation, applied electrostatics,
  - nanodielectrics, pulse power applications & power electronics

HVEL 800 kV 60 kJ Impulse Generator

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Giga-to-Nano (G2N) LaboratoryAdvanced flexible electronics fabrication and nanoelectricdevice integration

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Student Teams

AutoBIOmobile Team
Novel and sustainable materials for the automotive industry

Midnight Sun Team
Design & build solar powered cars

Formula SAE Team
Designs, analyzes & build open wheel race cars for the Society of Automotive Engineers (SAE)

RoboticsTeam
From simple autonomous robots to GPS-equipped &intelligent ground vehicles

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Student Teams

SAE Clean Snowmobile Team

Build & race environmentally friendly sleds

Alternate Fuels Team

US Dept of Transportation's EcoCAR Challenge: the team is converting a GM SUV into a fuel cell-battery hybrid electric vehicle.

SAE Off-road Mini Baja Team

Design & build a four-wheeled off-road vehicle each year, partipating in the Society of Automotive Engineers Mini-Baja competition.

The vehicle is evaluated for acceleration, top speed, skid pull, hill climb & maneuverability, & design to endure severe punishment on rough off-road terrain

Selected Highlights

Energy Hub Management System

- SW Ontario study of 65 microgrids: residential, industrial, commercial, institutional, and agricultural sectors
- Empower energy hubs to facilitate entities at different locations that require energy (e.g., manufacturing, farms, homes) to control, in real-time not, only demand but production, storage and ability to export and import energy

Off - grid hybrid power system for remote Communities

- Decrease or eliminate diesel dependency and provide a lower-cost, environmentally friendly solution for remote communities.

Connecting Solar Farms to the Grid

- Comprehensive solutions to help grid operators incorporate large-scale solar farms to their networks.

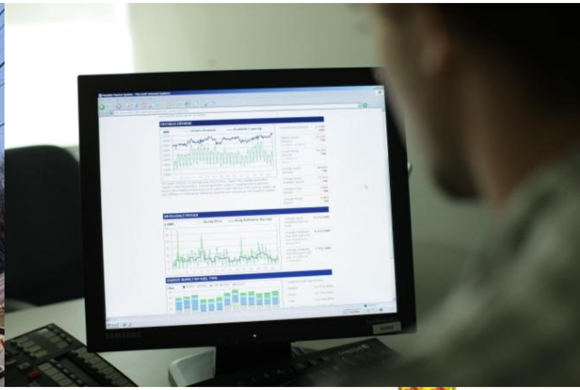
- Ontario Smart Grid Forum
- Plug-In Hybrid Electric Vehicles Ontario Action Plan
- "Affordable solar for the masses"- A major international initiative
- Integration of Distributed Generation into system
- Advanced batteries and storage technologies
- ISS4E

Enabling Tomorrow's Electricity System

Report of the Ontario Smart Grid Forum

Ontario Smart Grid Forum

- Industry leaders brought together to develop a smart grid vision for the province
- Vision designed to guide:
  - a co-ordinated approach across the sector
  - the mitigation of technology risks
  - the development of capital investment plans
  - a supportive regulatory framework



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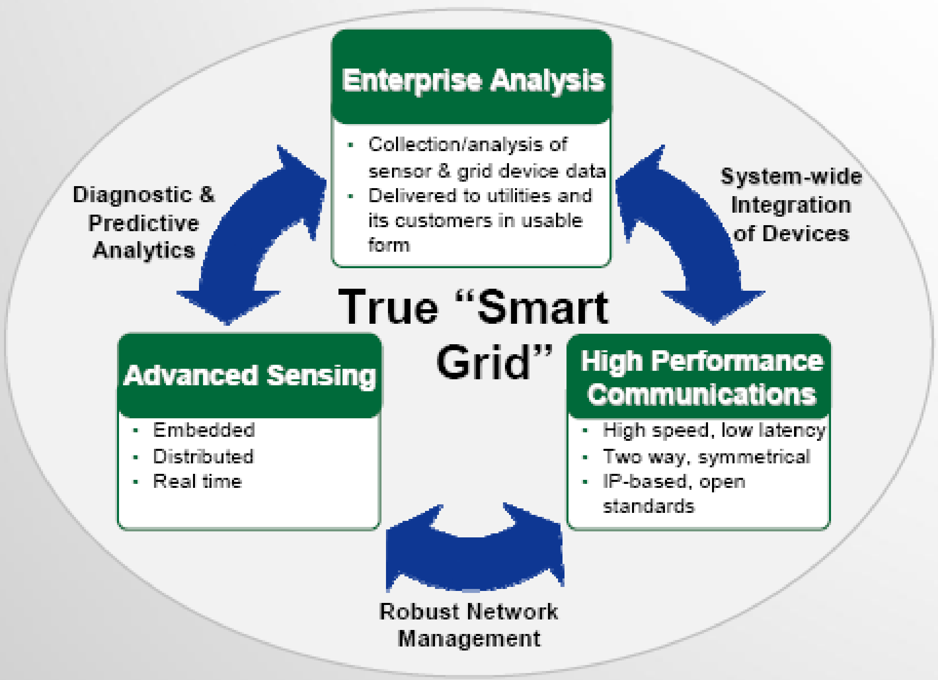
Why Smart Grids?

What is a Smart Grid?

- Smart grids comprise sensors, monitors and information technology – bringing together all elements of the electricity system
- Provide seamless integration of distributed energy, storage, allow electric vehicles charging and control and greater consumer choice with real time feedback

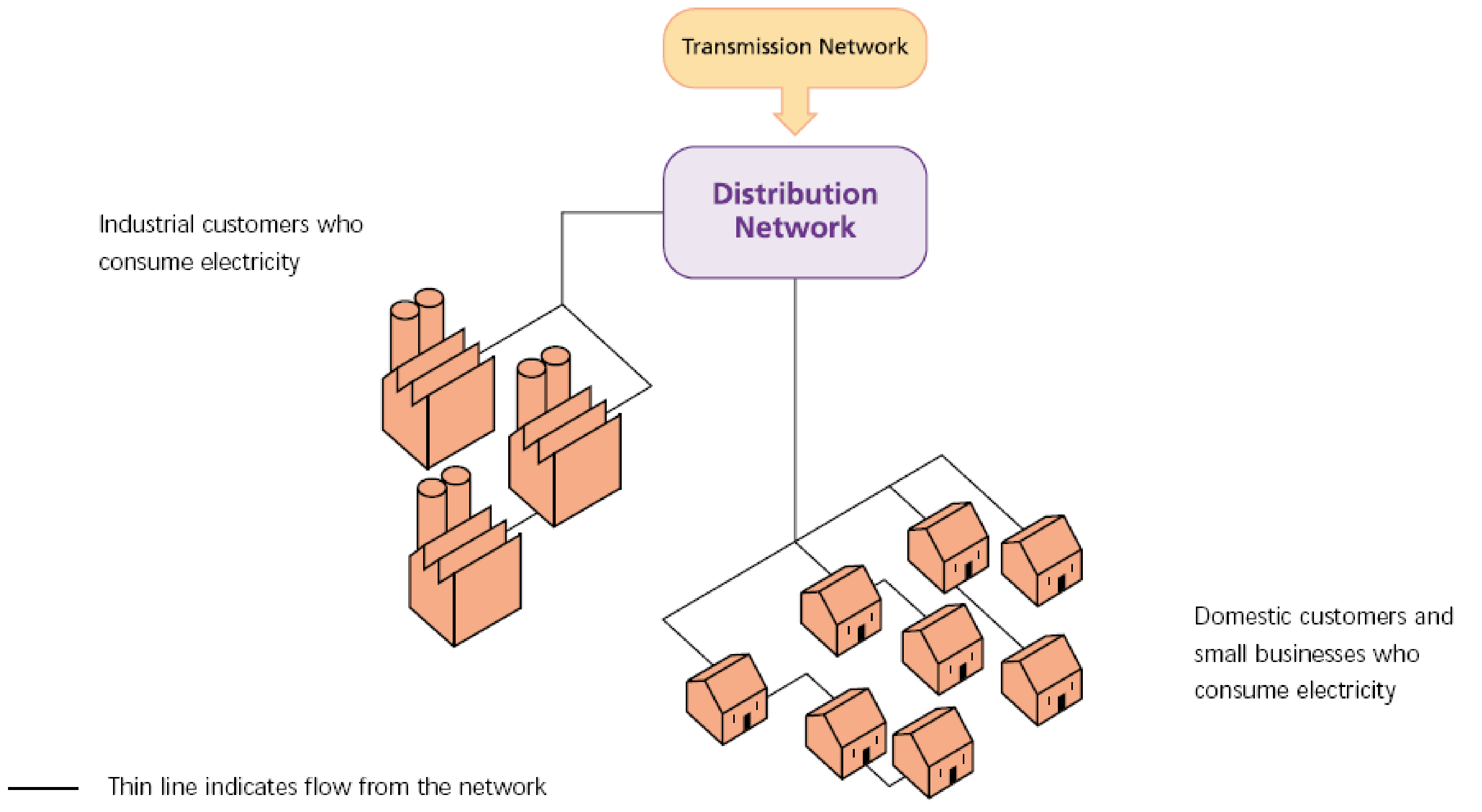
What is a Smart Grid?

"... a power system that can incorporate millions of <u>sensors</u> all connected through an <u>advanced communication</u> and data acquisition system. This system will provide <u>real-time analysis</u> by a distributed computing system that will enable <u>predictive</u> rather than reactive responses to blink-of-the-eye disruptions." (EPRI, emphasis added)

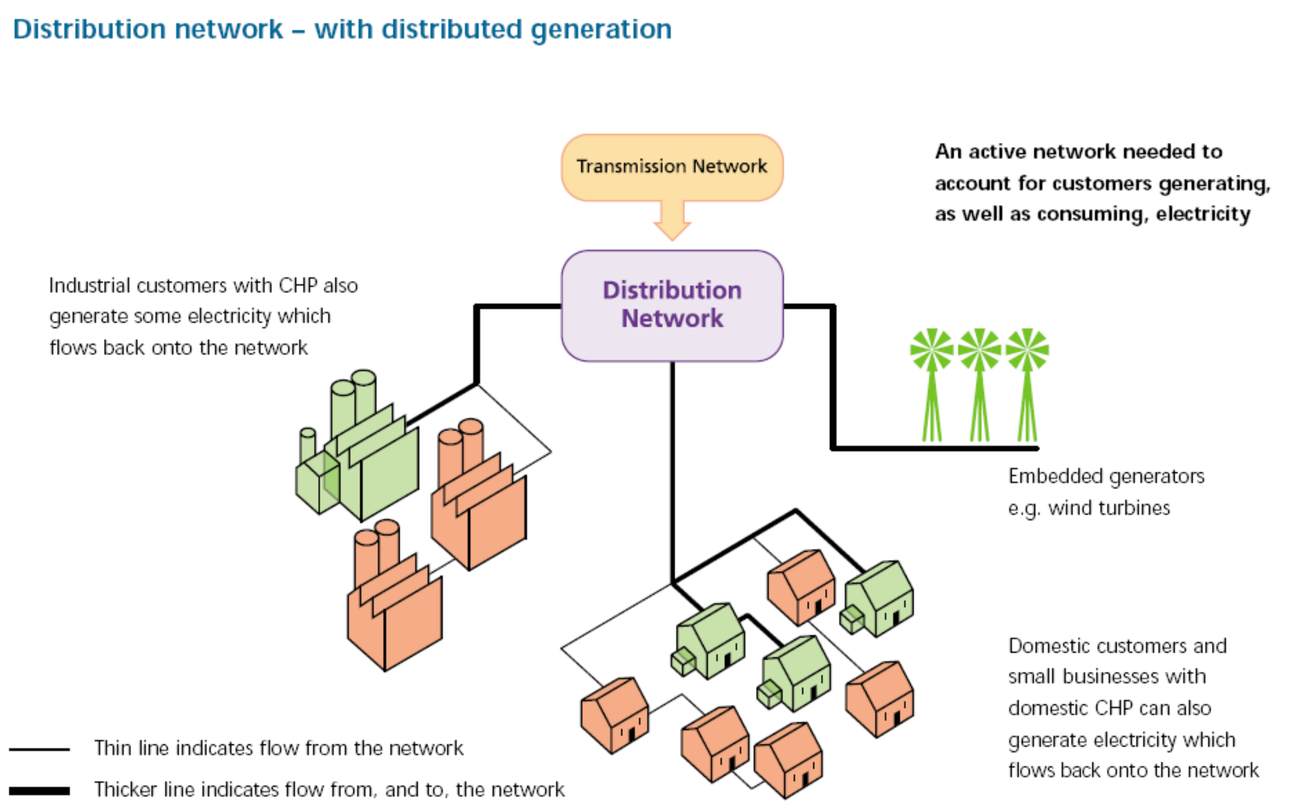


The Challenge is:
Power flows one way: network to the customer

Distribution network – conventional



Paradigm shift: Power flows both ways



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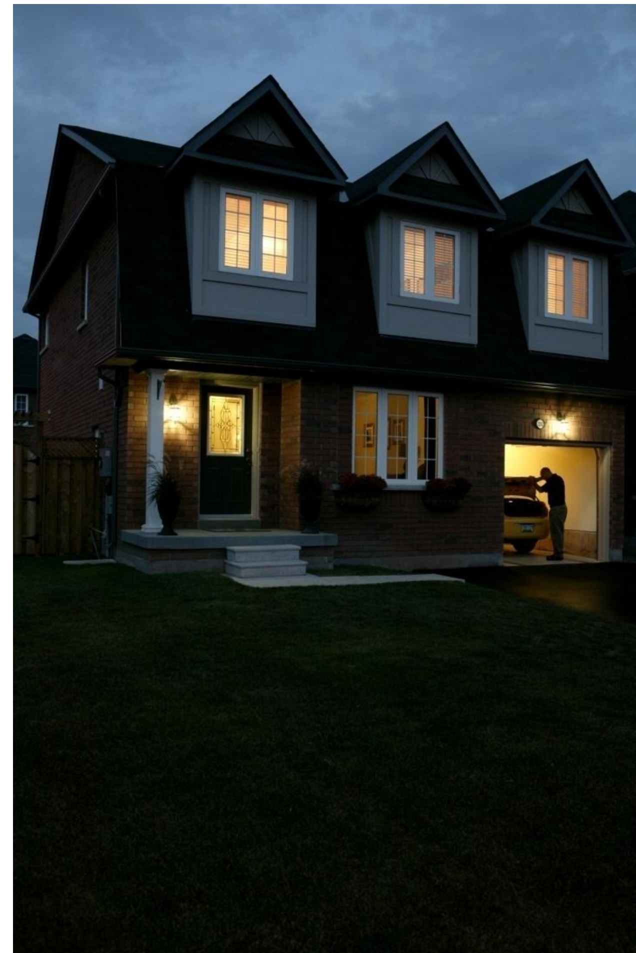
Smart Grid Benefits

- Modernizing the electricity system to serve the digital age:
  - Better integration of renewables and distribution generation
  - More efficient use of energy infrastructure and reduced energy losses
  - Empowered consumers with increased participation in conservation and demand response
  - More reliable distribution service with reduced outages and quicker response times



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Getting There: Innovation

- **New technologies need to be invented and brought to market**
  - opportunity to create green jobs
- **Sustained and significant investments are required**
  - All utilities required to develop Smart Grid plans for regulatory approval
  - Provincial government commitment to support R&D efforts
  - OEB proactive in facilitating these initiatives

The GEA Sets the Framework for a Smart Grid…

The GEA sets the objectives and framework for smart grid to "improve the flexibility, security, reliability, efficiency and safety" of the electricity grid.

GEA Smart Grid Objective	*Focus Area*	*Expected Outcomes*	
i. "expanding opportunities to provide demand response, price information and load control to electricity customers;"	**Customer Control**	• Smart meters • Time-of-use rates • In Home Displays • Load control	More Conservation
ii. "enabling the increased use of renewable energy sources and technology, including generation facilities connected to the distribution system;"	**Utility Flexibility**	• Customer based micro-generation • More distributed generation, used more efficiently (i.e. less transmission investment)	More Renewables
iii. "accommodating the use of emerging, innovative and energy-saving technologies and system control applications;"	**Adaptive Infrastructure**	• Mobile charging infrastructure to support EVs • Storage opportunities • Keeping room for innovative technologies	More Innovation

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The Future

2011

- Smart meters and time of use rates
- More in-home displays and LDC smart technologies
- Preparing the grid for plug-in electric vehicles

2015

- Substantial increase in smart appliances
- Renewables, demand response, storage projects and LDC automation technologies are widespread
- Electric car infrastructure in place

2020

- Coordination across the sector complete
- Smart appliances standard
- Micro-grids begin to emerge

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Smart Energy: Economic Development: Life Quality

Enhanced Well Being
Life Expectancy: 80 yrs

10^4

IMPROVED LIFE QUALITY
Life Expectancy: 60 yrs

10^3

BASIC QUALITY OF LIFE
Life Expectancy: 60 yrs

10^2

SURVIVAL
Life Expectancy: 40 yrs

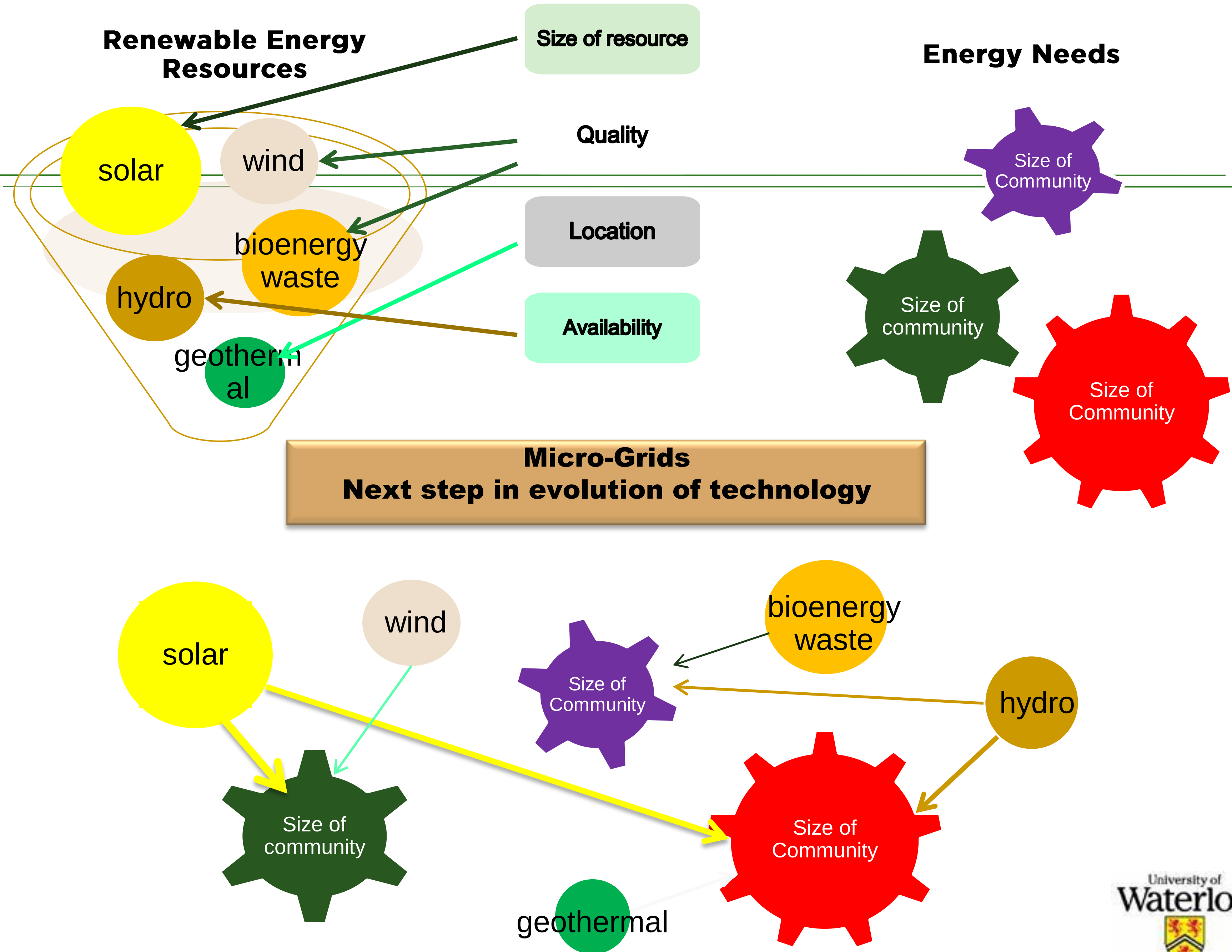
Annual
$GDP/Capita

Annual
kWh/capita

Microgrids for Rural and Remote Needs

Vision: an integrated model of electrification to meet basic human needs at 1000kWh/person

- Abundant, clean, secure, reliable and a flexible energy source.
- Resource endowment, knowledge, economic base varies with each community
- Focus on renewable resources (solar, wind, water, bio)
- Community size can vary from 500- 50,000
- Modular system design from 500kW- 10MW
- Rapid installation; tailored to community needs
- Social & economic development capacity build-up to own, operate, maintain infrastructure



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A Microgrid: what is it?

- An aggregate of small loads and distributed generation resources
- Operates as a single system that provides both power and heat..
- An integrated system that must be able to provide sufficient and continuous energy to a significant portion of the demand internal to the microgird
- A microgrid's distributed energy resources can include
  - High-frequency AC (microturbines)
  - DC systems (e.g., solar, fuel cells)

Microgrid Benefits

Choice: Extend Dx and Tx infrastructure (at a high cost) or provide local service through a microgrid

- **Reduced cost**—reducing the cost of energy service for affordability
- **Reliability**— attain level of reliability comparable to grid system
- **Green power**—manage the variable nature of renewables and promote deployment and integration of energy-efficient and environmentally friendly technologies
- **Service differentiation**—tailor to specific needs of a wide range of communities; provide levels and quality of service at different price points

When operating in grid parallel mode :

- **Power system**—assisting in optimizing the power delivery system, including the provision of Services
- **Security**—increasing the power delivery system's resiliency and security by promoting the dispersal of power resources

Microgrids - technical and functional requirements

- Greatest challenges are associated with protection, monitoring and control
- Three levels of control
  - Internal
  - External
  - Individual asset

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Micro Grids: if and when operated in "grid-parallel" mode

- Distributed energy resources must operate as a single aggregated system
  - Present itself to the bulk power system as one "control area" that meets the local needs for reliability and security.
- Must possess independent controls that can island and reconnect with the electric power grid with minimal service disruption.
- Grid parallel mode provides flexibility in configuring and operating the power delivery system and the ability to optimize a large network of loads, distributed energy resources and the power system.

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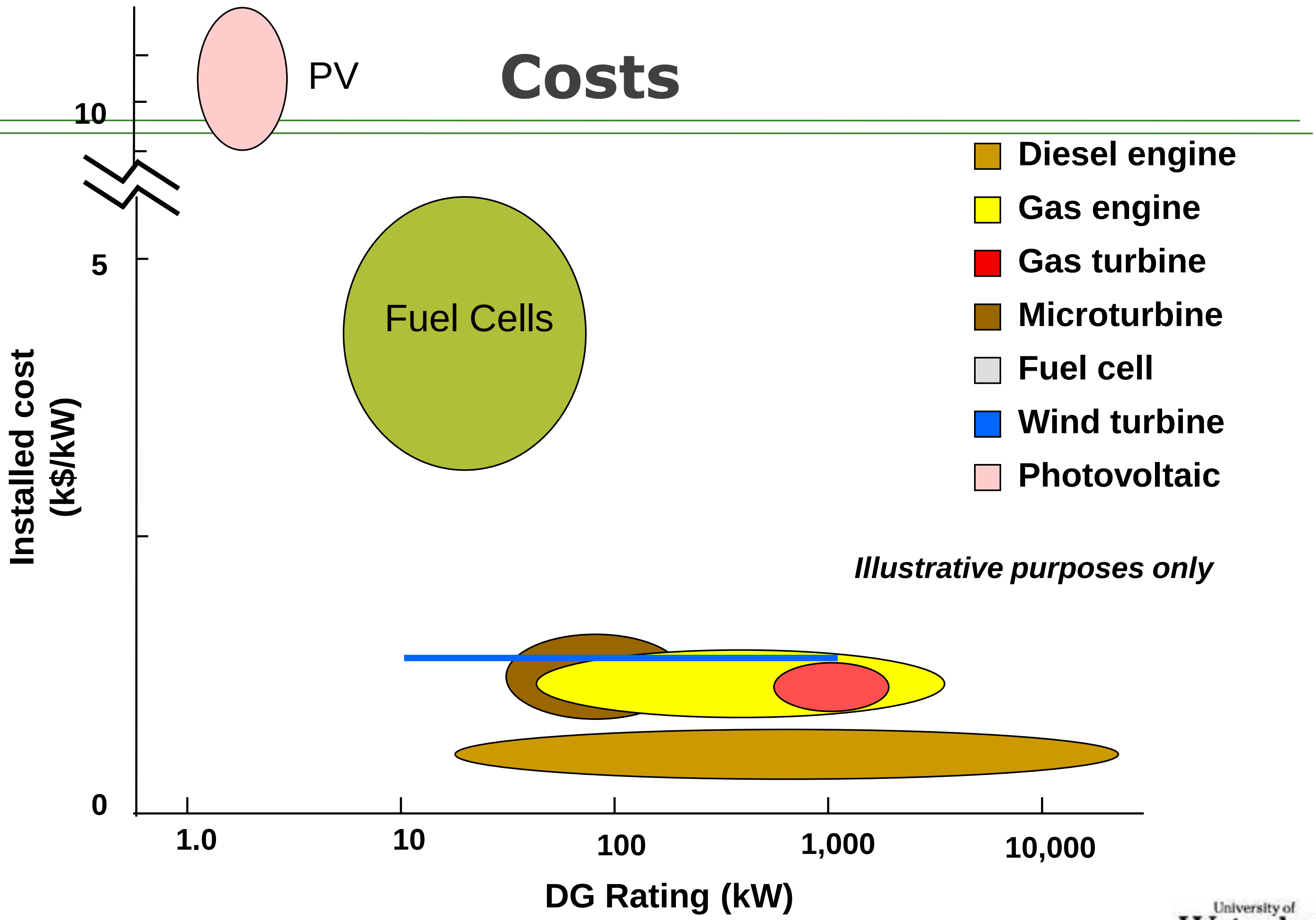
DG Resources and Characteristics

- Wind power (small projects with outputs from 50kW to 10MW)
- Biogas and biomass (landfill sites, agricultural and livestock operations, wood forest residues, wastewater treatment facilities:1-10MW)
- Combined Heat and Power (CHP) schemes including micro-CHP (residential 1kW-25 kW) and Stirling engines (1kW to 55kW)
- Solar photo-voltaic (PV) cells (50kW- 1MW)
- Fuel cells (1kW to 1MW)
- Microturbines (20-100kW)
- Natural Gas reciprocating engines (30kW- 3MW) and dual fuel reciprocating engines (90kW- 2MW)
- Gas and diesel fired combustion turbines (>1MW)
- Large DG applications & mobile systems for standby generation
  - (0.5 to 2MW),
  - peaking (1-5MW)
  - T&D support (0.5-10MW modules) and crisis operations

Distributed Generation Resources: Reality Confronts Vision

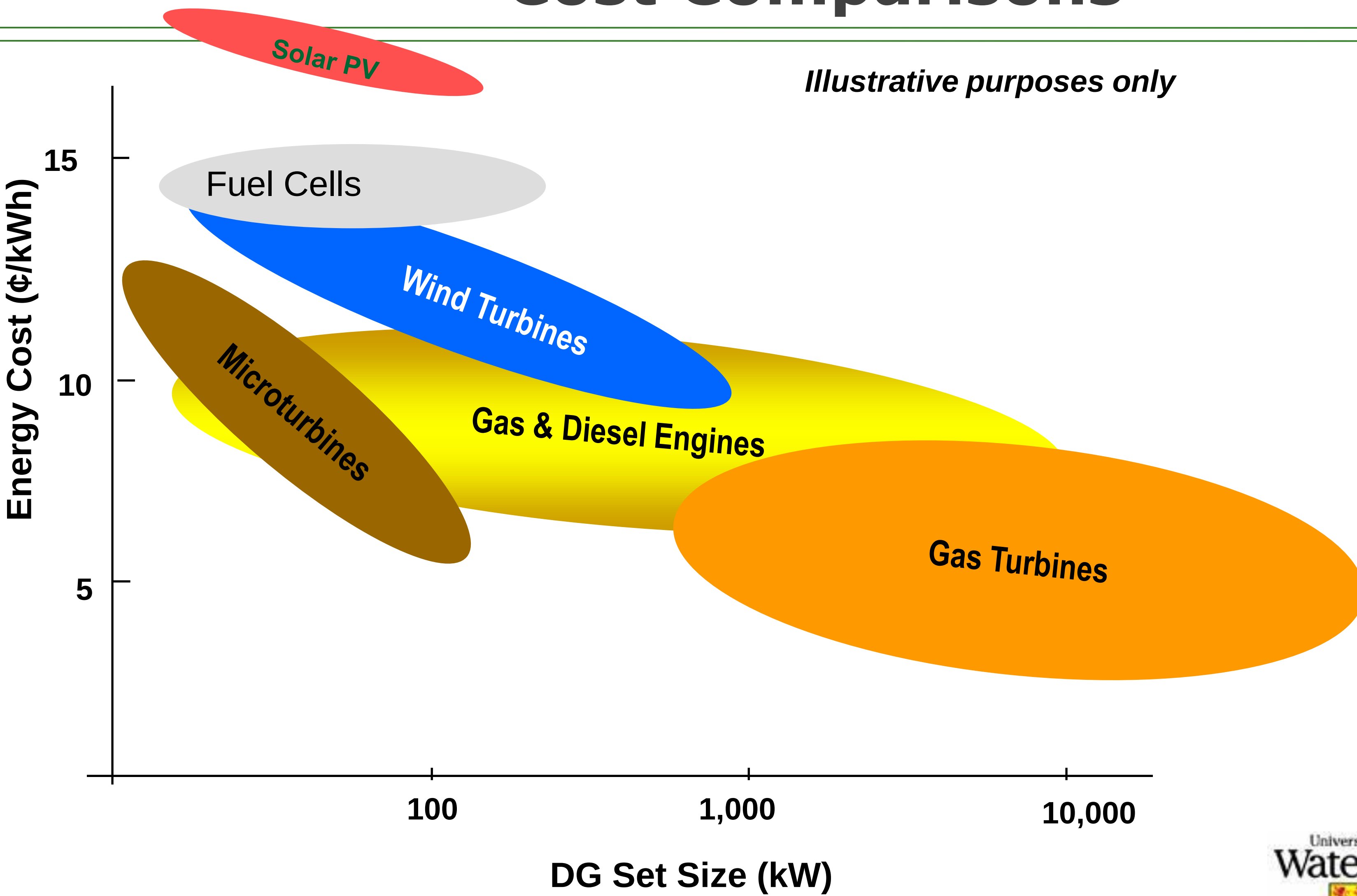
- Performance has not equaled promise
- Fuel cells, microturbines, photovoltaics - still too expensive
- Need to look closely at the multiplicity of DG solutions
  - renewables based DG combined with storage
  - evolve technolgy solutions to “plug-and –play” or “delivered on a crate” status
  - “Eberry” equivalent to the “Blackberry”- a device that has mass market appeal.

Costs



Source: OPA: IPSP DP#4, 2007

Cost Comparisons



Source: OPA: IPSP DP#4, 2007

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Summary- Vision is an integrated model of electrification to meet basic human needs at 1000kWh/person

- Can we engineer this vision?
- Is a "smart micro-grid" capable of meeting specific needs of rural and remote communities primarily through use of renewable resources?
- Given multiplicity of size, resource endowment and economic capacity, how many projects would be required to establish feasibility of delivering tailored solutions?
- Reducing costs ("technology + transactional") is the key determinant; ease of installation is another.

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Energy Hub Management System (EHMS)

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hydro one

energent

MILTON HYDRO

Ontario Centres of Excellence

Where Next Happens

OPA

Ontario Power Authority

Context

- ‘Transformative Energy Innovation’ competition launched by Ontario Centres for Excellence (Centre for Energy) in August 2007
- 100+ applicants, 16 invited to submit full application, 6 selected in February 2008

Ontario Centres o
Excellence

For Immedia

Centre for Energy

Ontario Centres of Excellence Injects $28 Million Into Breakthrough Clean Energy Technologies

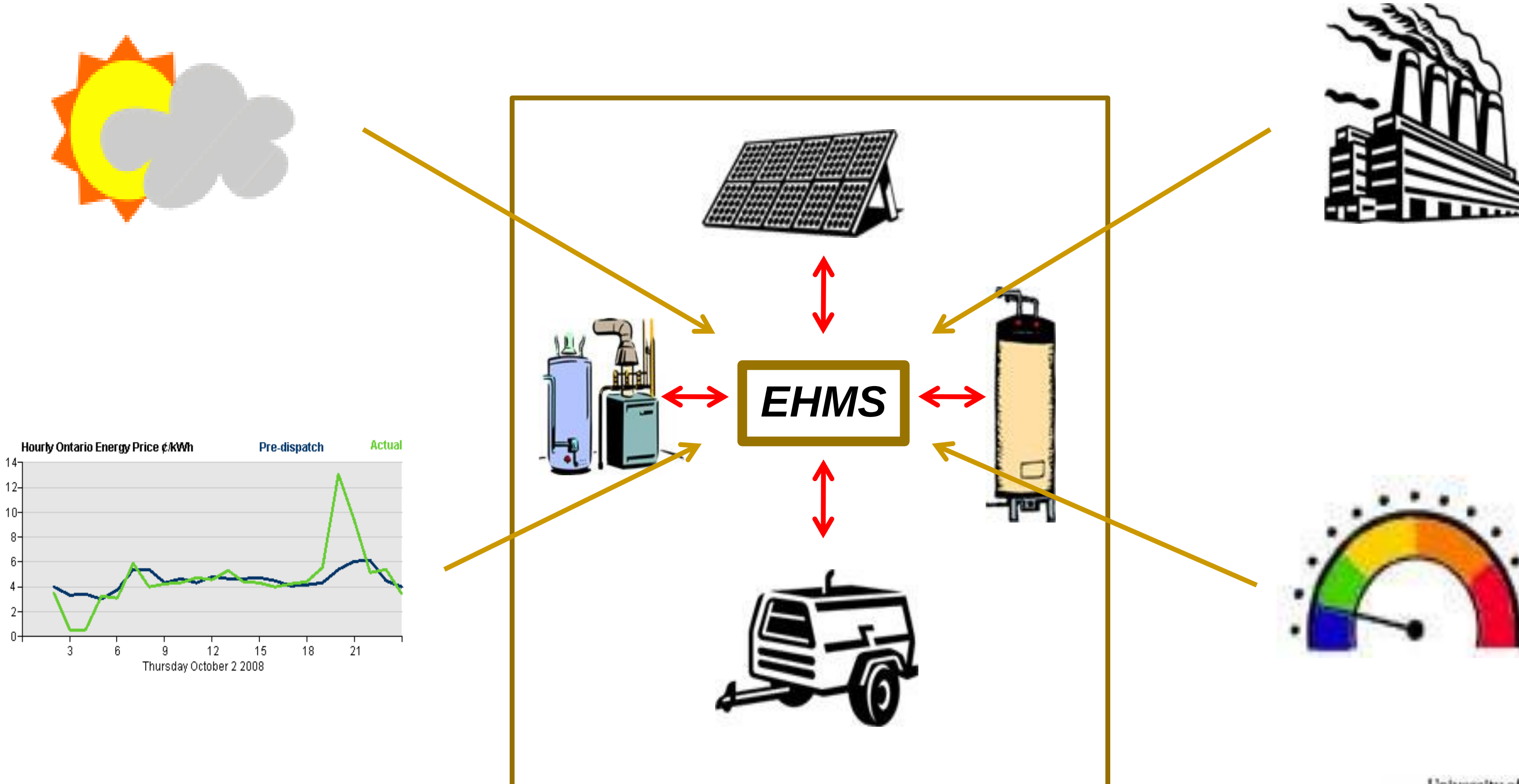
Major investment in groundbreaking clean energy technologies promises to reshape the way Ontarians use and think about energy

www.oce-ontario.org/Pages/COEEnergy.aspx?COE=EN

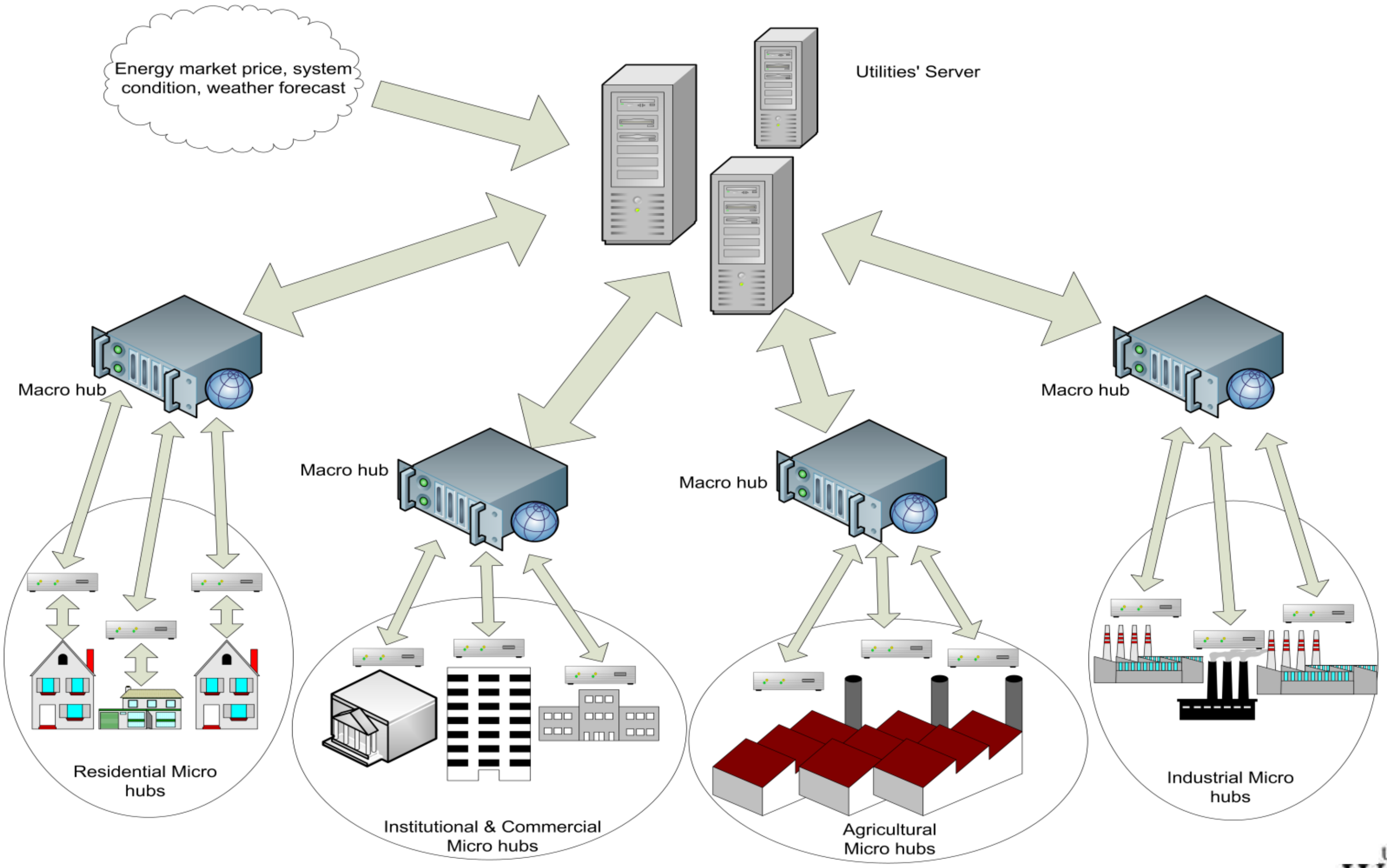
EHMS

- ‘Energy Hub Management System: Enabling and Empowering Energy Managers Through Increased Information and Control’
  - will allow static energy users to manage effectively their energy requirements.
  - will empower energy hubs – that is, individual locations that require energy (e.g., manufacturing facilities, farms, retail stores, detached houses) – so that they can contribute to the development of a sustainable society through the real-time management of their energy demand, production, storage and resulting import or export of energy.

EHMS

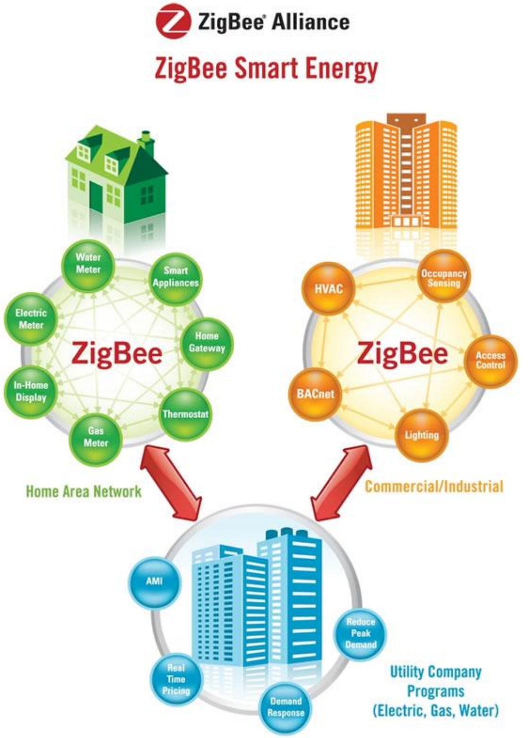

EHMS
Hourly Ontario Energy Price ¢/kWh
Pre-dispatch
Actual
14
12
10
8
6
4
2
0
3
6
9
12
15
18
21
Thursday October 2 2008

EHMS


Energy market price, system condition, weather forecast
Utilities' Server
Macro hub
Macro hub
Macro hub
Macro hub
Residential Micro hubs
Institutional & Commercial Micro hubs
Agricultural Micro hubs
Industrial Micro hubs

Software

- communication infrastructure development
- scanner development for communication between hub and devices
- modelling engine
- external data collector



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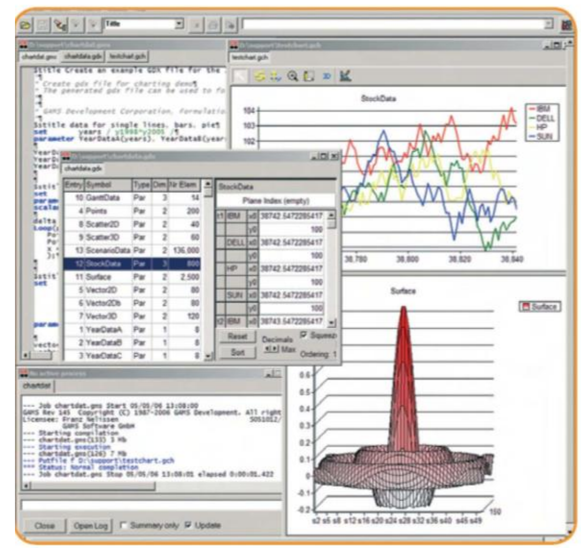
Modeling

- develop optimization models

General Algebraic Modeling System (GAMS)

The General Algebraic Modeling System (GAMS) is a high-level algebraic modeling system for large scale optimization.



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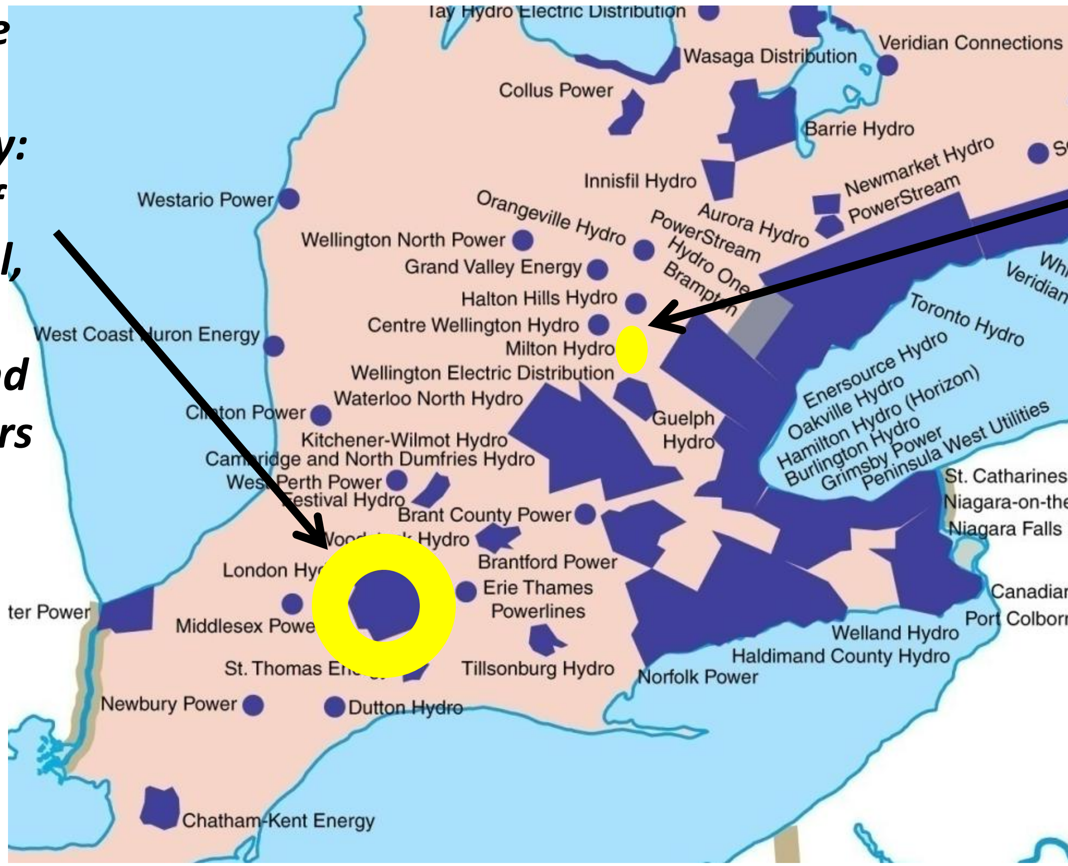
EHMS

15 pilots in the Hydro One service territory: five in each of the agricultural, commercial/ institutional and industrial sectors



50 residential pilots in the Milton Hydro service territory

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Community

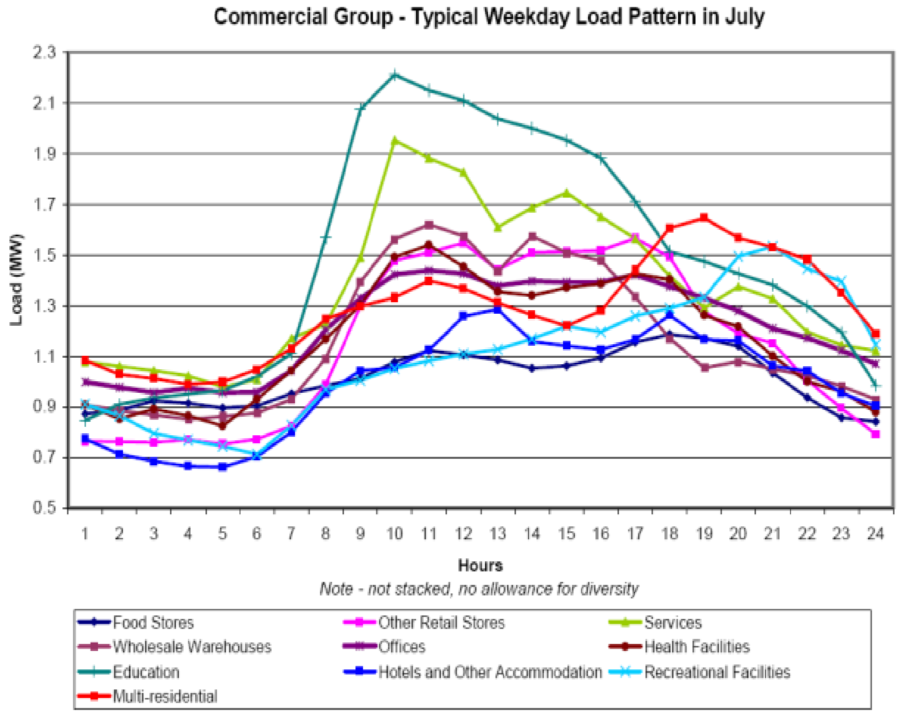
- customer priorities on energy issues
- behavioural aspects – energy management
- technology in its social setting

EHMS output/results

- Create functioning micro-hubs within different customer segments
- Evaluate customer response
- Examine intelligence and optimisation in the micro-hub
- Develop 'first ideas' about how optimisation and centralized intelligence across micro-hubs would occur at the level of a few micro-hubs

Achievements to date

- developing optimization models



http://www.conservationbureau.on.ca/Storage/14/1959_OPA_Report_FactorAnalysis_Final.pdf

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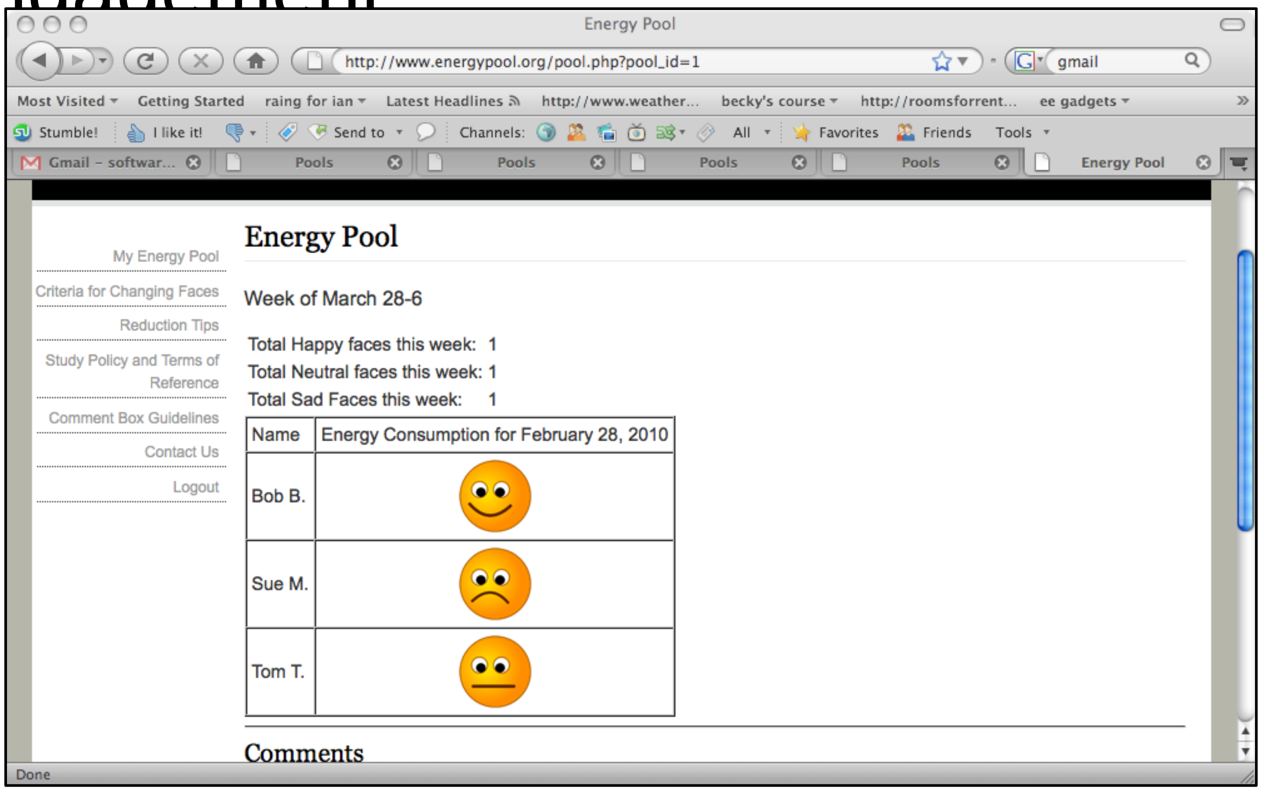
Achievements to date

- understanding keys to consumer engagement



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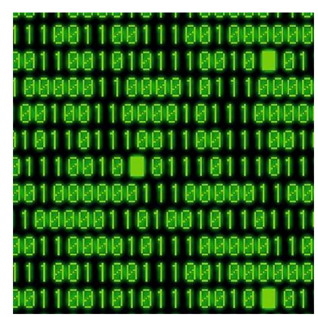
Achievements to date

- creating an integrative system



www.simplehomenet.com; www.versalogic.com; www.aartech.ca; www.stdcarriers.com

Partnership

Ontario Centres of Excellence
Where Next Happens

OPA
Ontario Power Authority

MILTON HYDRO

energent

WATERLOO | ENVIRONMENT

hydroOne

WATERLOO | ENGINEERING

Energy for Remote & Rural Communities

- Many communities in Canada and remote communities in the rest of the world are not connected to ‘the Grid’ and are dependant on other means to supply electrical energy to their community
- Remote Communities in Northern Canada have no road access
- The dominant source of electrical energy for these communities is through diesel fuel burning ‘gen sets’
- Diesel fuel must be supplied to these communities
- All of the community supply comes from brief winter road access or by air
- Energy costs in remote Canadian communities can be many times greater than a grid connected community

Energy services for Remote Communities

- Need for clean, reliable renewable electricity in remote communities of Canada and the world
- Reduce energy costs and cost uncertainty – fuel and transportation
- Energy costs in remote Canadian communities can be many times greater than a grid connected community
- Reduce potential damage to environment from fuel transportation and emissions (gases and particulates)

“Off grid –Microgrid” for Kasabonica Lake F.N.

Kasabonika Lake

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Current Approach

- Existent system: Three Diesel Generators 1000, 600, 400 kW
  - Diesels work well – well-known technology for many years
  - Many are familiar and comfortable with operation
  - Require regular attention (maintenance, service, replacement)

One diesel gen set

Diesel tank farm

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Self Sustaining Renewables-Based Microgridds for Remote Communities

- Develop local renewable energy sources (wind, hydro, biomass, geothermal, solar)
- Develop wind turbines specifically for installation and operation in the climatic conditions of the remote community
- Develop energy storage media to supply low wind periods
  - currently planning hydrogen generation, storage and fuel cells
  - many other possibilities
- Develop micro grid controller to integrate and control multiple energy sources
- Engage community in entire process

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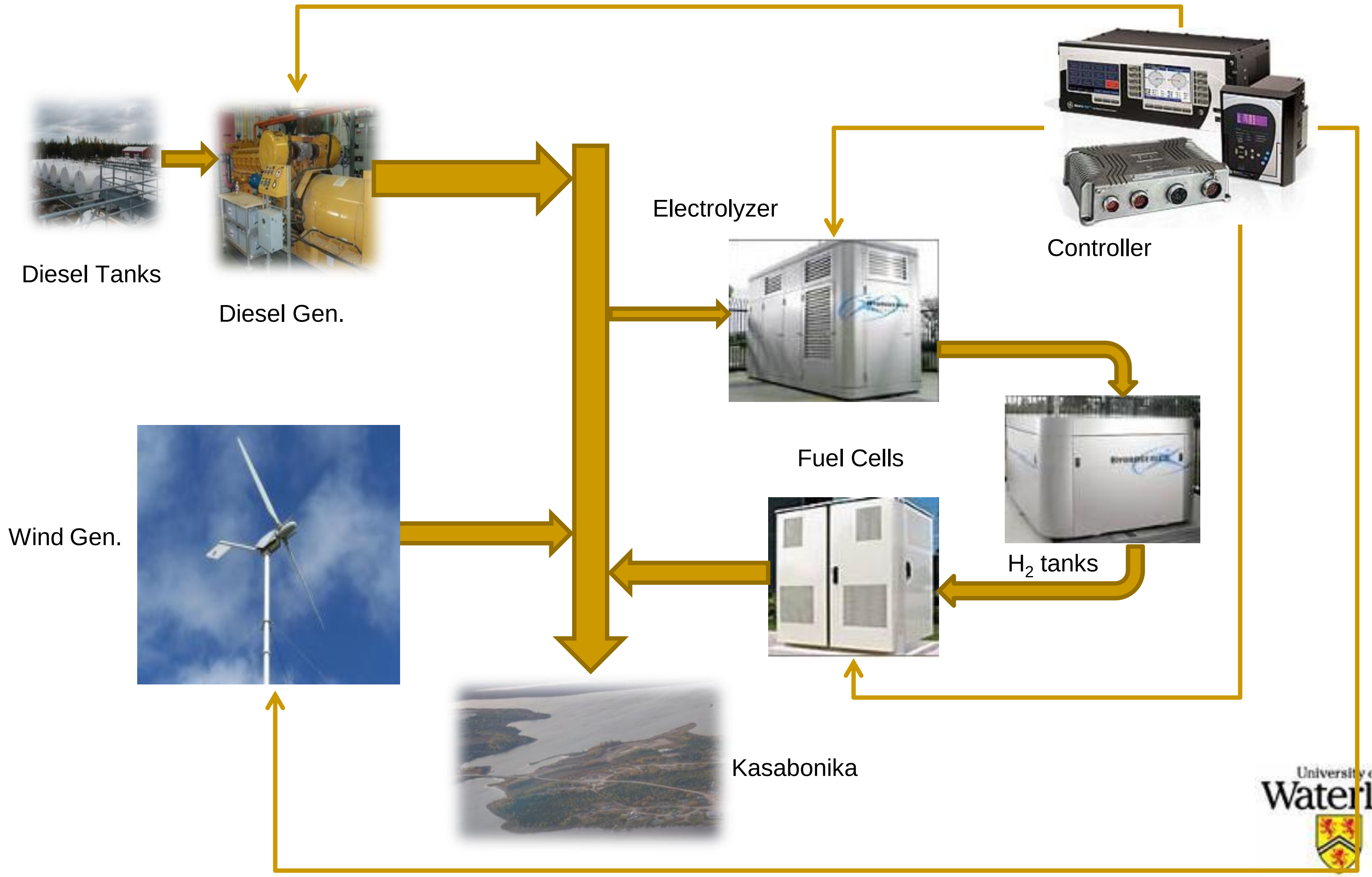
Microgrid for Remote Communities



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Specific Research Goals

Three Technology Research Streams

1. Wind Energy Technologies
2. Energy Storage (hydrogen generation storage @utilization)
3. Power Integration and Control

Plus

1. Social Innovation

- Full Community Engagement at Step 1 and through all phases
- Ultimately robust capacity building for communities

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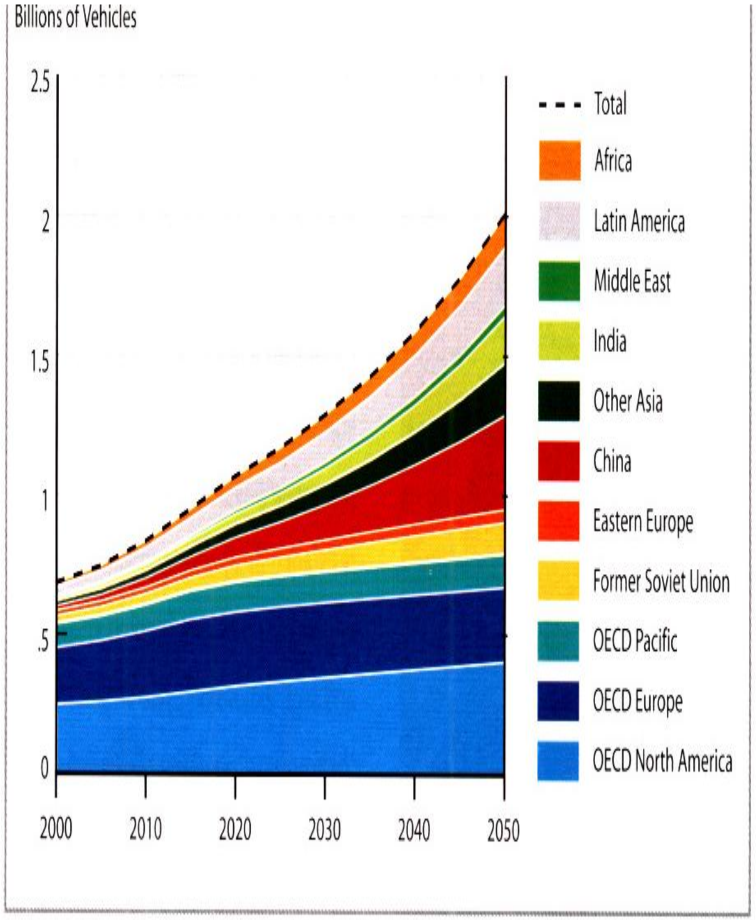
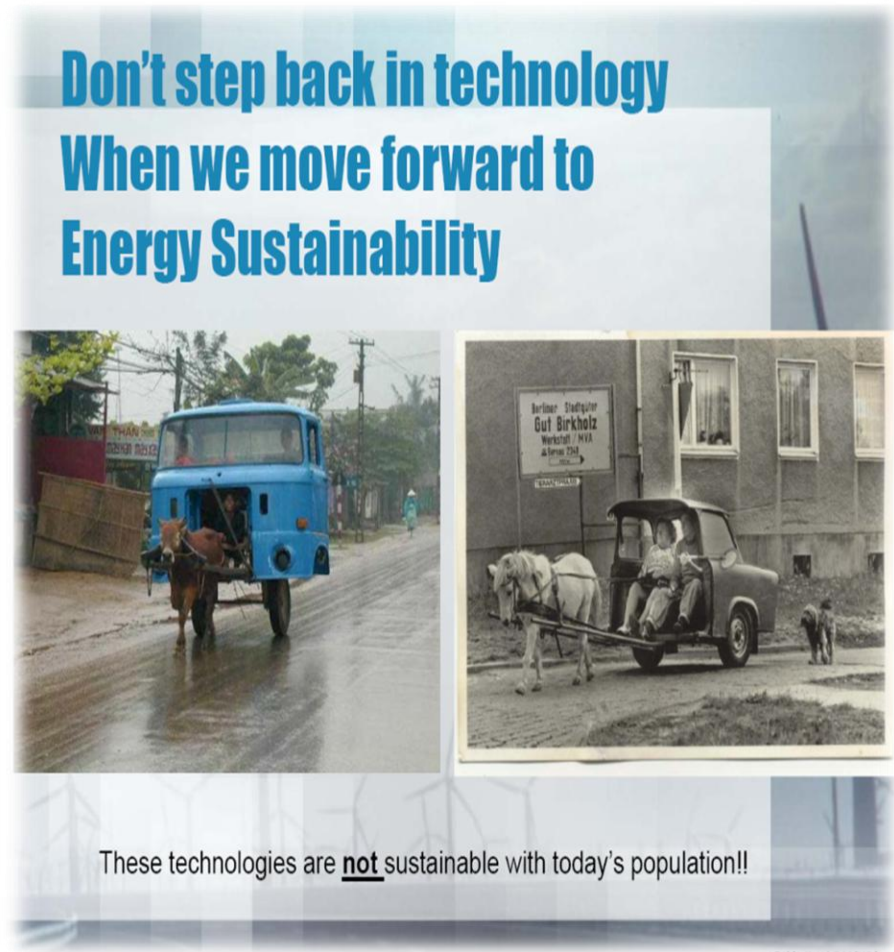
Microgrid for Remote Communities

- Multi phase project:
  - Research on components and integration at Waterloo
  - Demonstration site at Hydro One (Owen Sound)
  - Demonstration site at Kasabonika Lake FN
- Research projects in:
  - wind energy
  - hydrogen generation/storage/utilization
  - power electronics/microgrid
  - Community engagement
- Significant Ontario industry partners
- University of Waterloo multidisciplinary research team

Sustainable mobility



Source: Sustainable Mobility Project calculations.



- Powered by lithium-ion battery
- Charges in under 1 minute.
- Range: 15 km at 40 km/h.
- Cold weather testing in Sapporo next month.
- Uses 10% less energy than existing streetcars.

New UCDavis PHEV that will run on Sunshine *40mi/day* and a little Ethanol

Can be **ZERO** gasoline or diesel Now for the avg. driver!!!

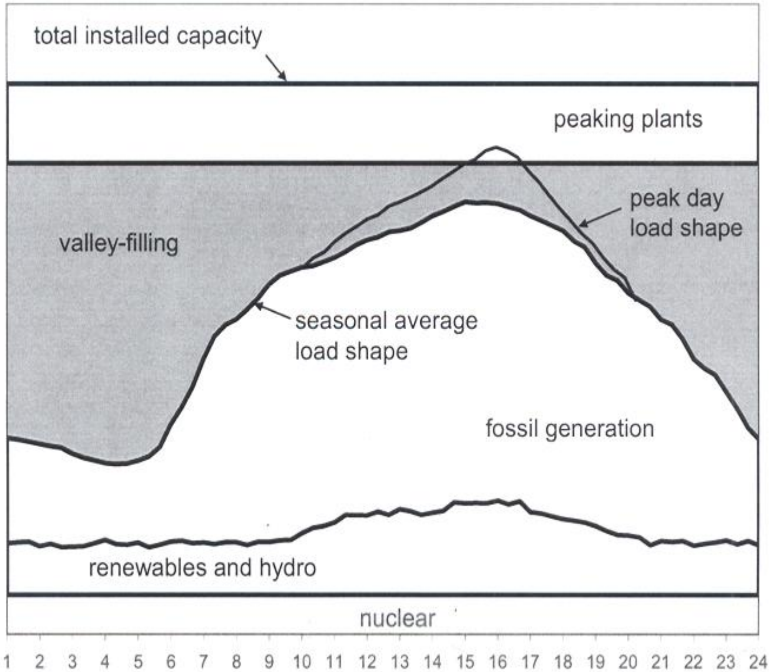
Electricity & Sustainable Mobility: A Plan for Ontario

- PEV Report May 2010:
  - Auto Sector Developments and Needs
  - Electricity Sector Development and Needs
  - Consumers, Communities and Markets
  - Plan for Ontario
  - Conclusions and Recommendations

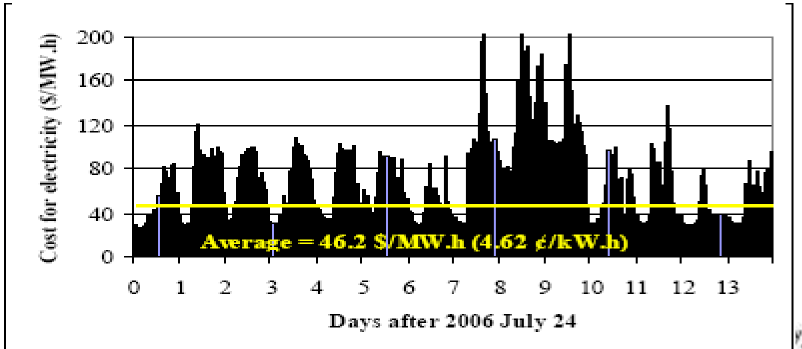
PEV Report

- Primary goal wasto identify the key Ontario specific technical issues associated with meeting the electricity demands of PEVs in the Ontario market, while maintaining system reliability and price stability.
- Identify important technical matters that need to be understood and addressed from a planning and regulatory perspective associated with the integration of PEVs into the existing Ontario power system.
- Focus on identifying the “technological gaps” the elimination of which would enable Ontario’s electricity grid to effectively, reliably, economically and cleanly meet the forecasted demand of PHEVs.

Low cost electricity to displace gasoline "green electrons as substitutes for carbon"



- Assume vehicles will recharge between midnight and 6 a.m.
- Select lowest-cost periods
  - Either 1 hour, 2 consecutive hours, or 3 consecutive hours
- Convert to annual demand
  - Typical Canadian light vehicle covers 20 000 km/a
    - 45% highway at 21.1 kW.h/100 km; 55% city at 16.8 kW.h/100 km
    - 3370 kW.h/a
- This will be new generation at off-peak periods with no obvious market
  - Could be used to recharge 2.72 million vehicles (one-third of the Ontario fleet) between midnight and 6 a.m.
- Estimated annual fuel cost
  - Around 100 $/a
  - Compared to gasoline at 720 $/a (before taxes)



Solar Charging Stations for Electric Vehicles

2 kW EV Charging Station

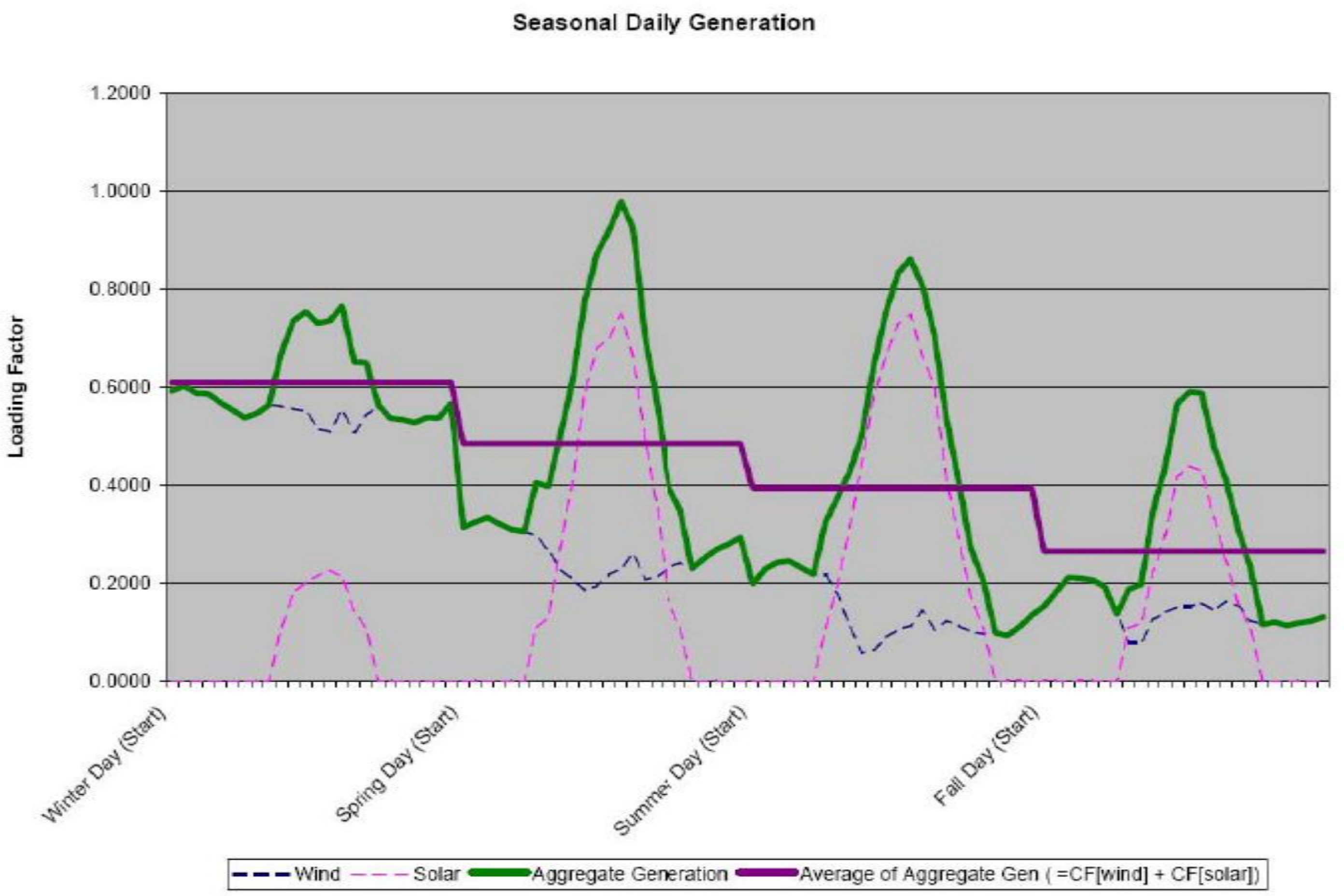
10 kW EV Charging Station

30 kW EV Charging Shade Structure

300 kW EV Charging

Source: steve@renewables.com

Benefits of Diversity and Distributed Resources



 Source: R. Seethapathy

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Solar tractors as a sustainable solution

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The Importance of Batteries

	Weight of 20 kWh Pack	Cost	Life (years)	Range*
Lead Acid	1200 lbs	$1,400-$6,000	3 – 6	40 miles
Nickel Metal Hydride	700 lbs	$15,000	7 – 20	150 miles
	No longer available in large format for EVs			
Lithium Ion	400- 500 lbs	$10,000-$40,000	7 - 15	250 miles

* For optimized EVs with 1/3 battery weight

DC vs. AC

	Weight	Cost	Life (years)
DC	300 lbs	$7-10,000	5 - 20
AC	200 lbs	$15- 40,000	10 - 50

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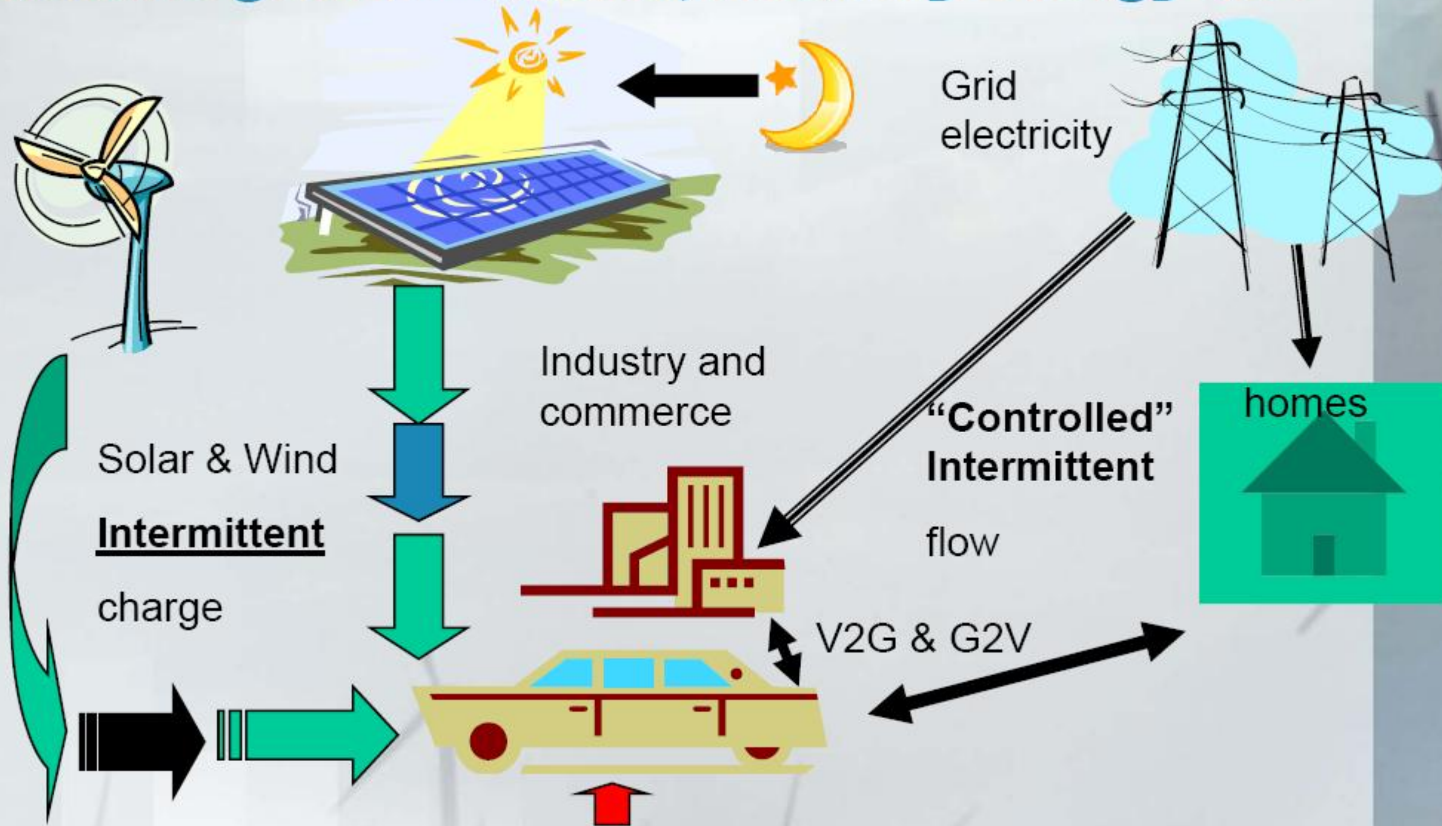
Solar and Wind *integrated* by the PHEV Electric grid with home, industry energy use

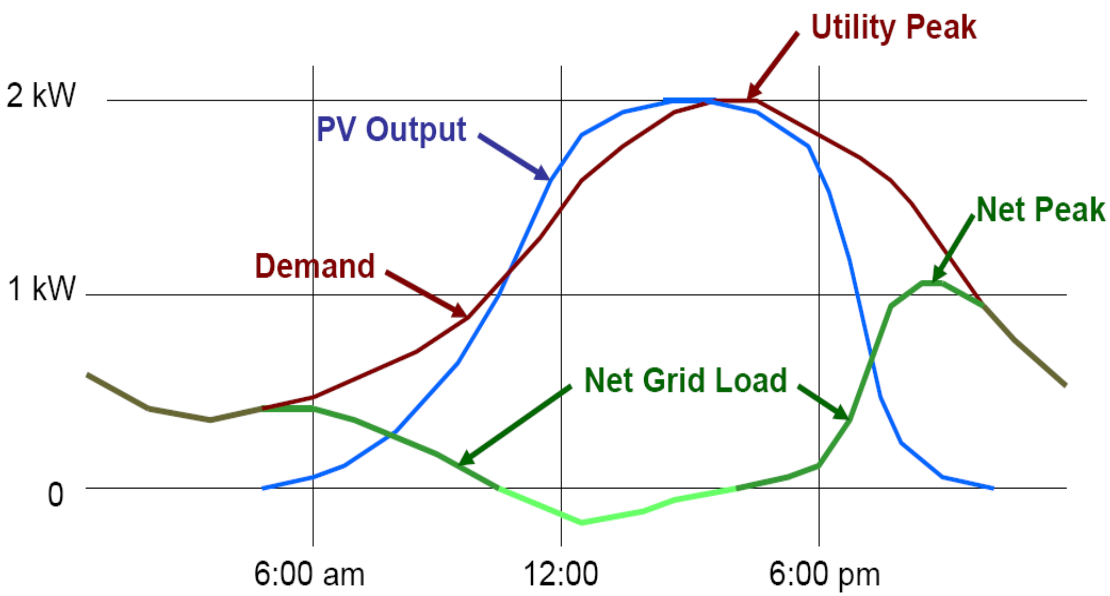


Energy stored in **PHEV** car **Batteries**

All over Society --5gigKwhrs of energy in US!!

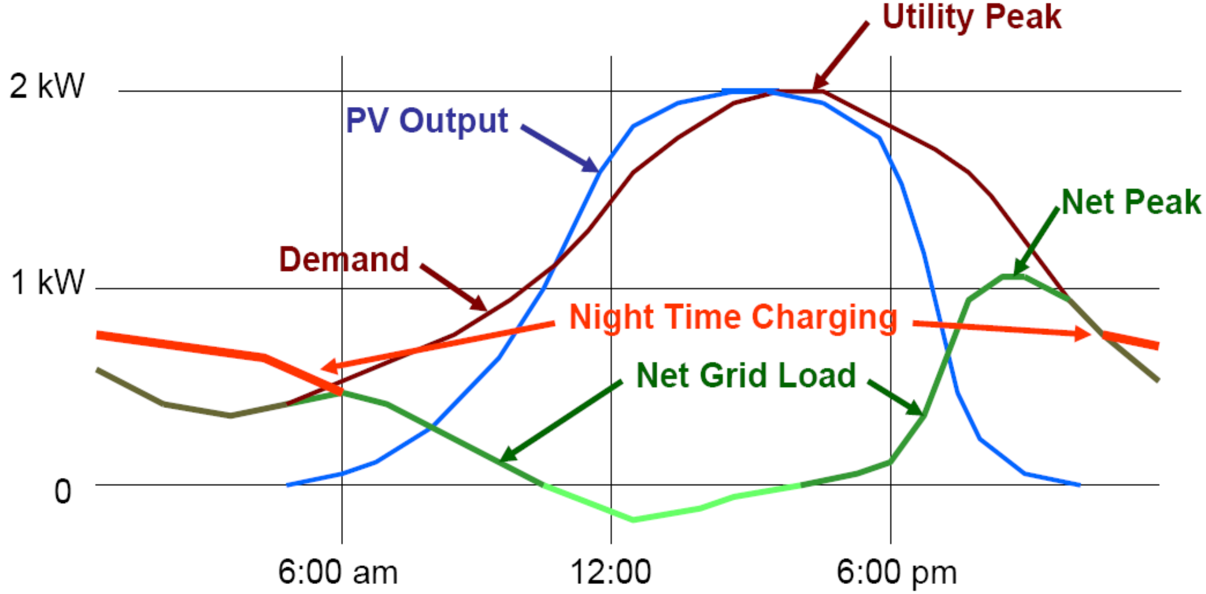
EDI/AAF

Graph of Net Grid Load on Home with 2 kW West Facing BIPV System and 2 kW Peak Summer Load



High peak air-conditioning loads coincided with the peak performance from PV installations.

Graph of Net Grid Load on Home with a 2 kW West Facing BIPV System, a 2 kW Peak Summer Load and an EV Charged at Night



Night Time Charging Levels Utility Loads by Using Wasted Spinning Reserve

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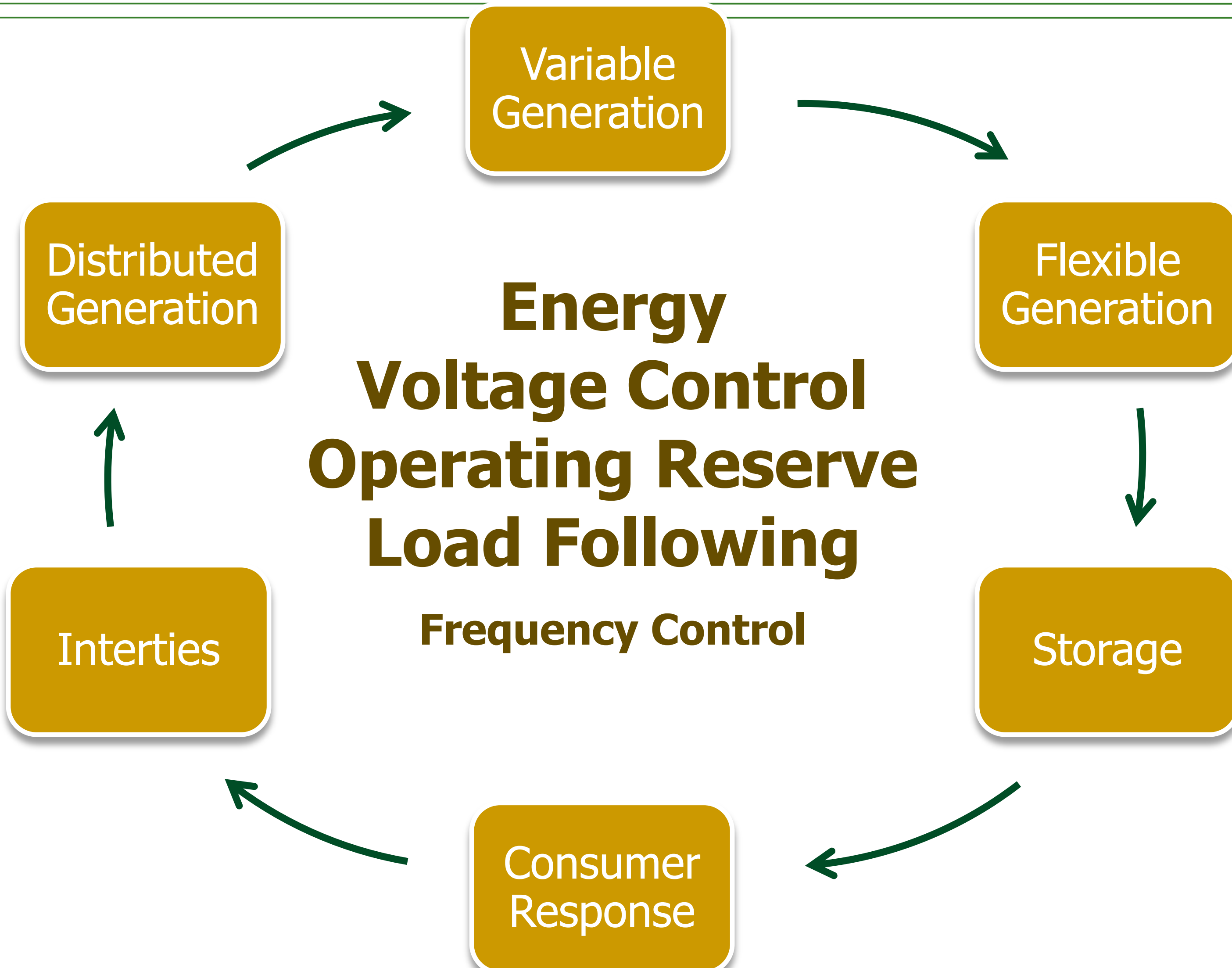
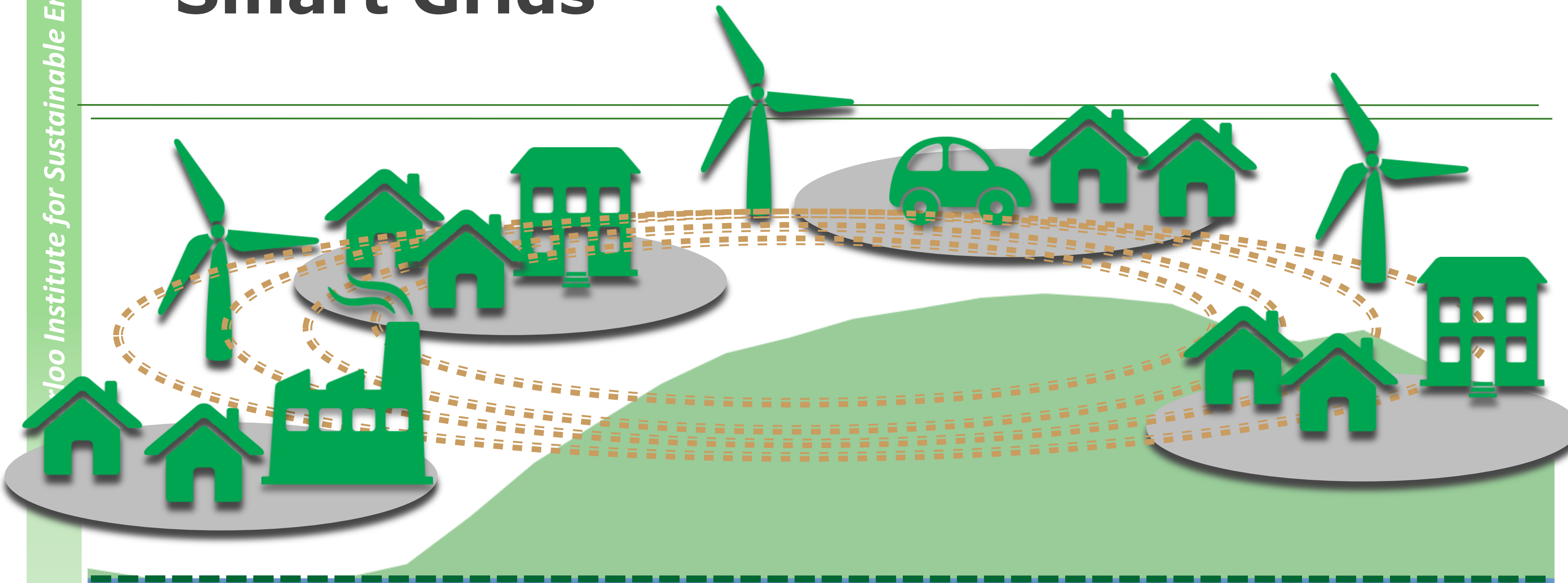
Flexibility from *all* resources

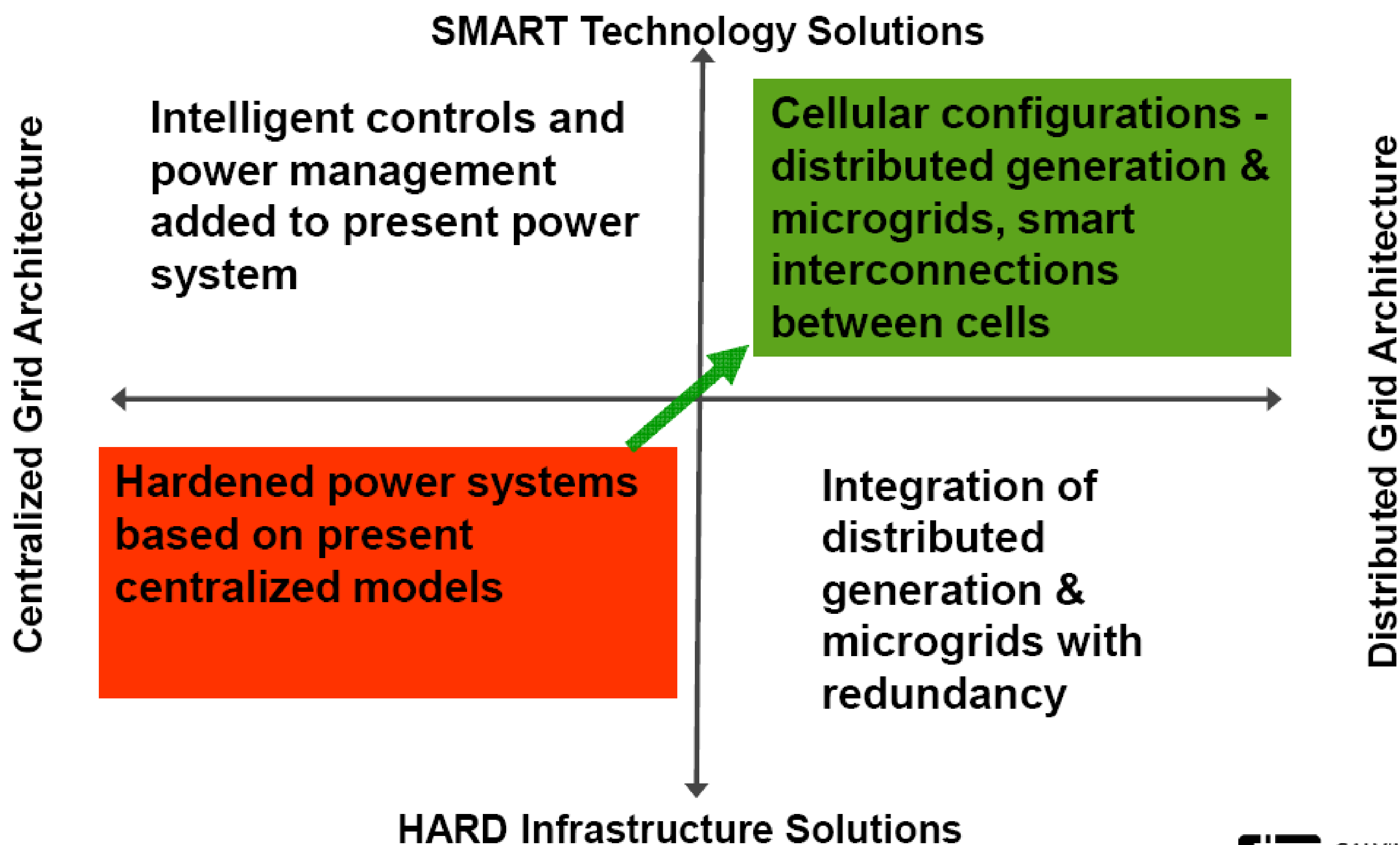


Smart Grids

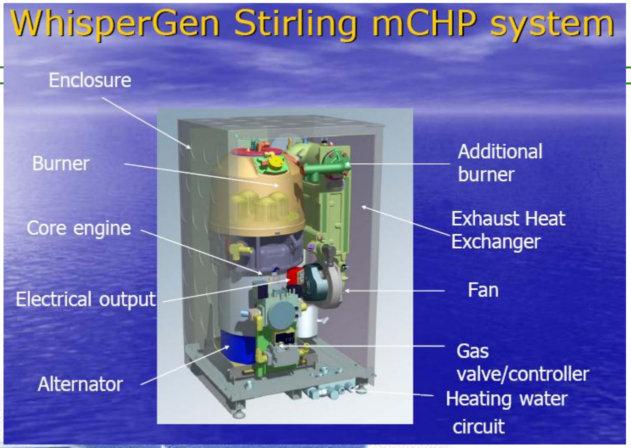


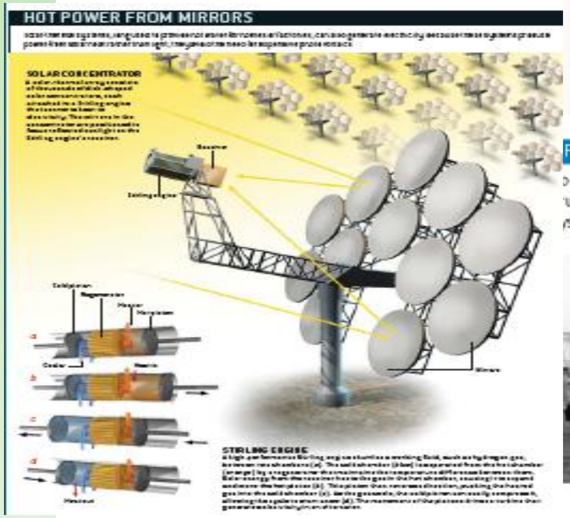
Customer Control
Utility Flexibility
Adaptive Infrastructure

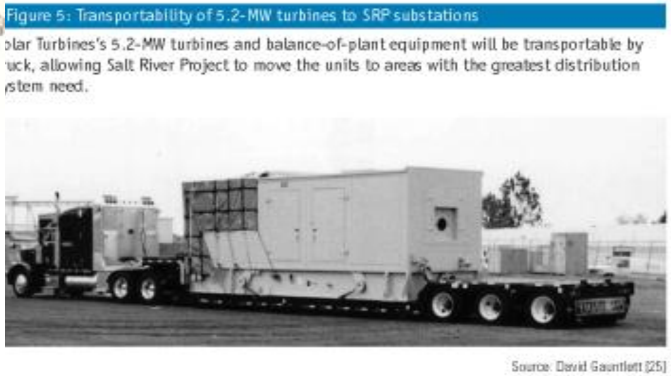
Conceptual Framework for Alternatives



Technology Innovations







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The Power System That Evolved in Late 19th Century to Provide Power to the Newly Invented Light Bulbs ....

1879 - Thomas Edison Developed a “Practical Light Bulb”

Line crew of Niagara Falls Power Co. in 1895

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…….. has Remained Essentially the Same as it Powers the Essential Services and the Digital Revolution in the 21st Century

August 29. 2005: Power poles are pushed over in a flooded street after Hurricane Katrina

- → Powers the critical pumps that takes water out from New Orleans and makes drinking water in a water treatment plant
- → Powers the communication towers and central telephone stations that are essential for the communication infrastructure
- → Powers the essential life saving services in a hospital
- → Powers the continuous process industries that are the life blood of an industrial society
- → Powers the computers, servers and routers that enable the digital revolution

Large Scale Solar Integration

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Western

hydro one

OPTISOLAR™

London Hydro

BLUEWATER POWER DISTRIBUTION CORPORATION

Ontario Centres of Excellence

Where Next Happens

OPA

Ontario Power Authority

Large Scale Solar Integration Project

- To provide world-class, pioneering, innovative and comprehensive technologies for integration of PV solar farms in T&D networks in Ontario

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Large Scale Solar Integration

Sarnia Solar Farm: 60 MW (40 MW 2009), i.e. ~0.2% of peak demand

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Large Scale Solar Integration

Theme	Research	Objectives
I	**Grid Interconnection of PV Solar Power System**	Increasing the penetration levels of solar power in distributed generation systems
II	**System Tools and Techniques for Network Management**	Increasing the dispatchability of solar power for electricity market in Ontario
III	**Power Electronic Interfaces for PV Solar Power System**	Enhancing the quality of power supplied by the PV solar power plants to the main grid
IV	**PV Device Technology**	Increasing the efficiency and consequent reduction in the cost of PV solar panels
V	**Snow and Wind Loading of Solar Arrays**	Determining the optimal design of solar panels
VI	**Land Use Policies for PV Solar Power System**	Defining the land use policies for the growth of solar power investment in Ontario

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Summary of Observations: Possible Next Steps?

- How can we bring innovation to deliver the energy solutions that are sustainable with low environmental impacts?
- Can we engineer this vision of an integrated model of electrification to meet basic human needs at 1000 kWh/person?
- Is a "smart micro-grid" capable of meeting specific needs of rural and remote communities primarily through use of renewable resources?
- Given multiplicity of size, resource endowment and economic capacity, how many projects would be required to establish feasibility of delivering tailored solutions?
- Reducing costs ("technology + transactional") is the key determinant; ease of installation is another.

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