# Challenges of a Sustainable Energy Future:

## Energy- Environment- Economy

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EPI Population Health Risk Assessment II
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# Today's Goals

- Global  Energy Trends & Global Challenges
- What this may mean for us?
  - Offer fresh thinking
  - Identify key issues, risks and uncertainties
  - Provide a Canadian & Ontario Context
- @Waterloo: our contribution to solutions

# World at Night

# Lack of Affordable Energy: What does it mean?

**Energy's link to human development:**

- **Productivity**
- **National Income**
- **Health**
- **Education**
- **Social Development**

# World at Night

**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

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# Population Growth, Energy, Income

**Global population divided into income groups:**

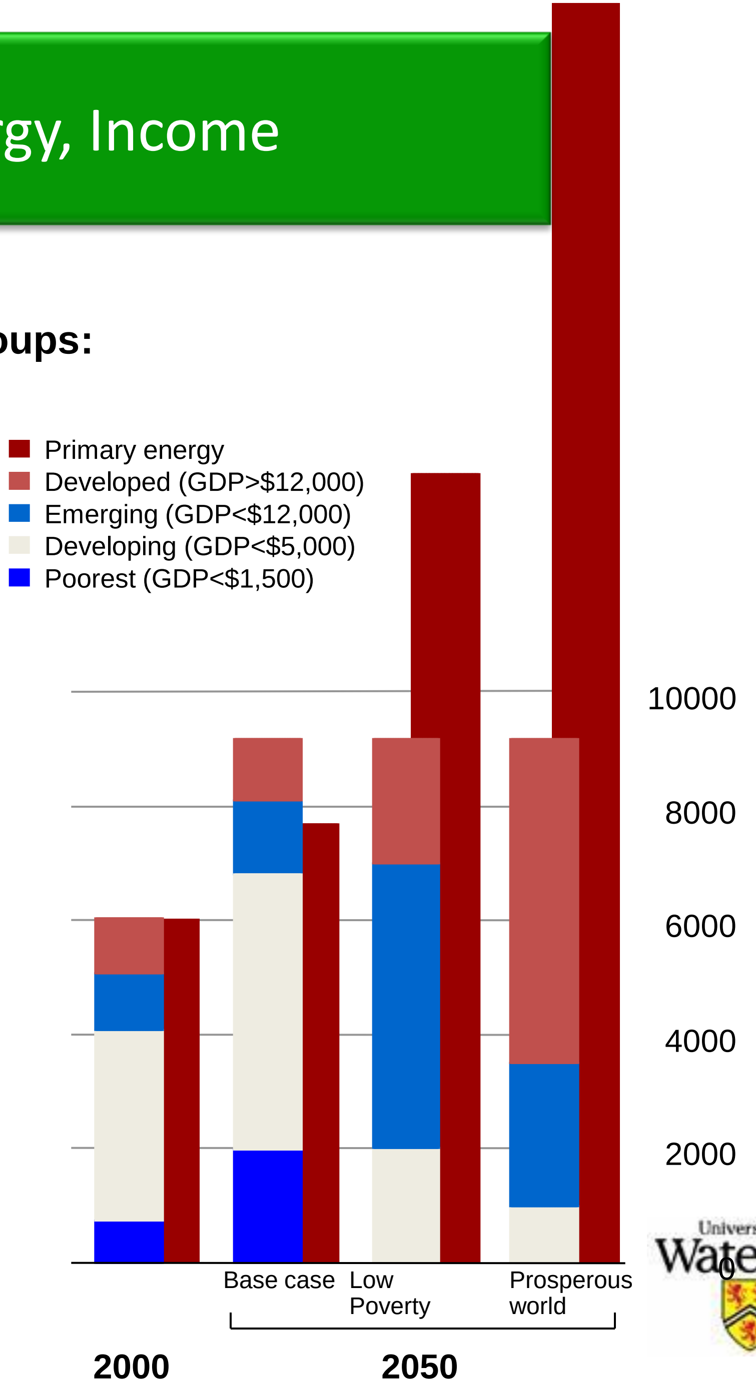
- **Poorest (GDP < $1,500)**
- **Developing (GDP < $5,000)**
- **Emerging (GDP < $12,000)**
- **Developed (GDP > $12,000)**

**Population expected to rise to 9 billion by 2050, mainly in poorest and developing countries.**

**Shifting the development profile to a "low poverty" world means energy needs double by 2050**

**Shifting the development profile further to a "developed" world means energy needs triple by 2050**

Source: WBCSD 2007




Source: WBCSD adaptation of IEA 2003

# The global challenge: how to de-carbonize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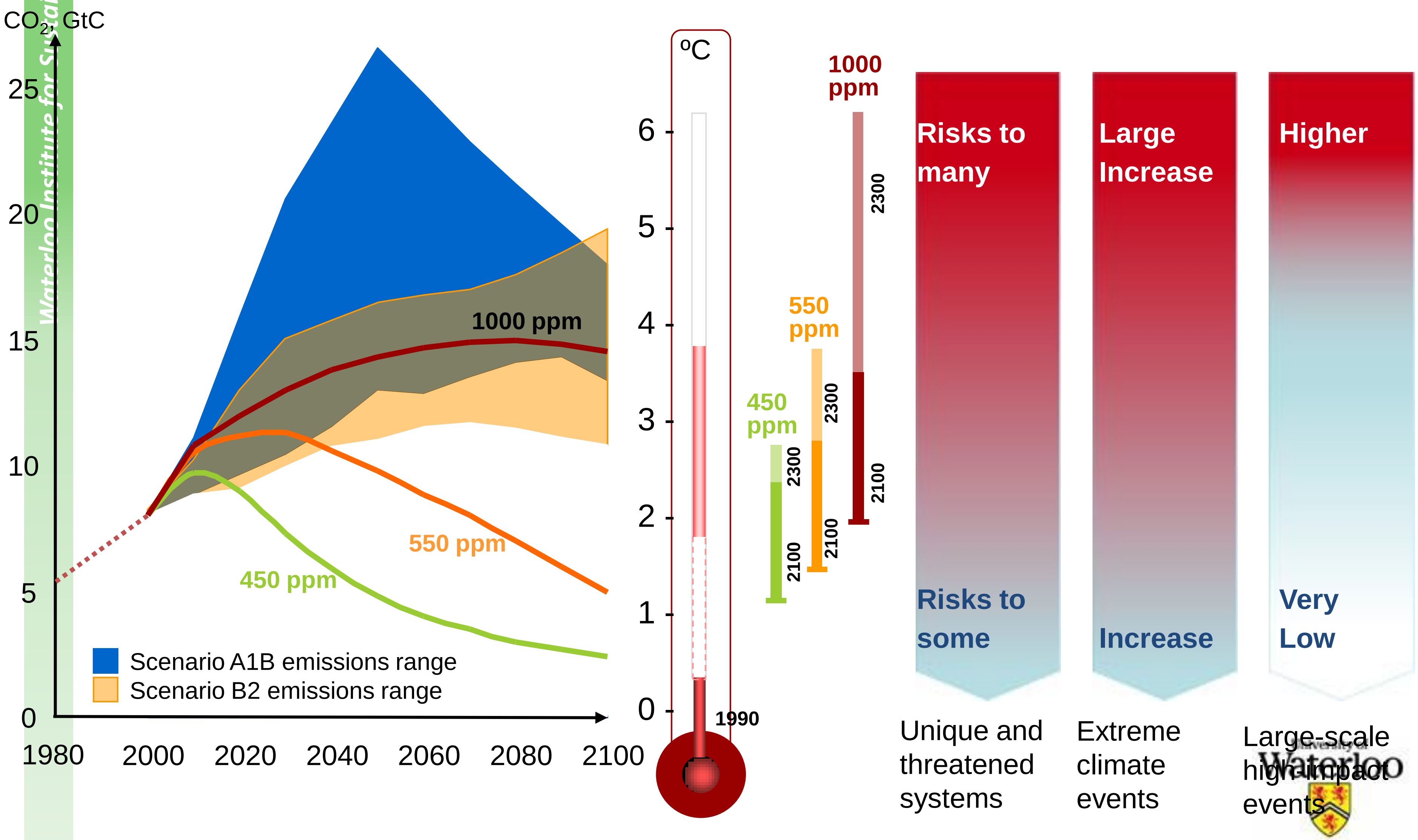
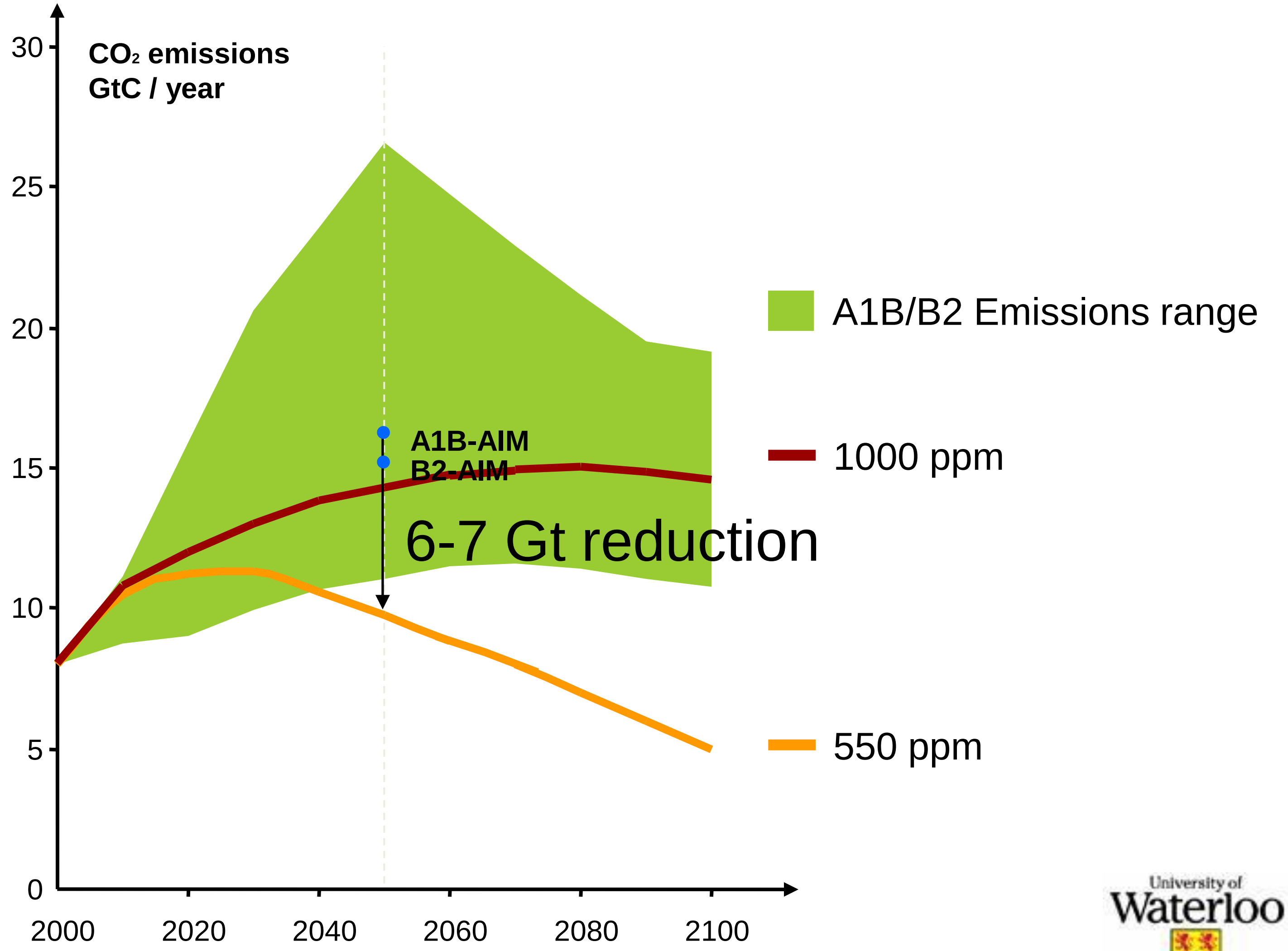
# Is there an acceptable limit for $CO_2$ emissions?




Source: IPCC 2001

# Achieving a lower $CO_2$ stabilization




Source: IPCC 2000

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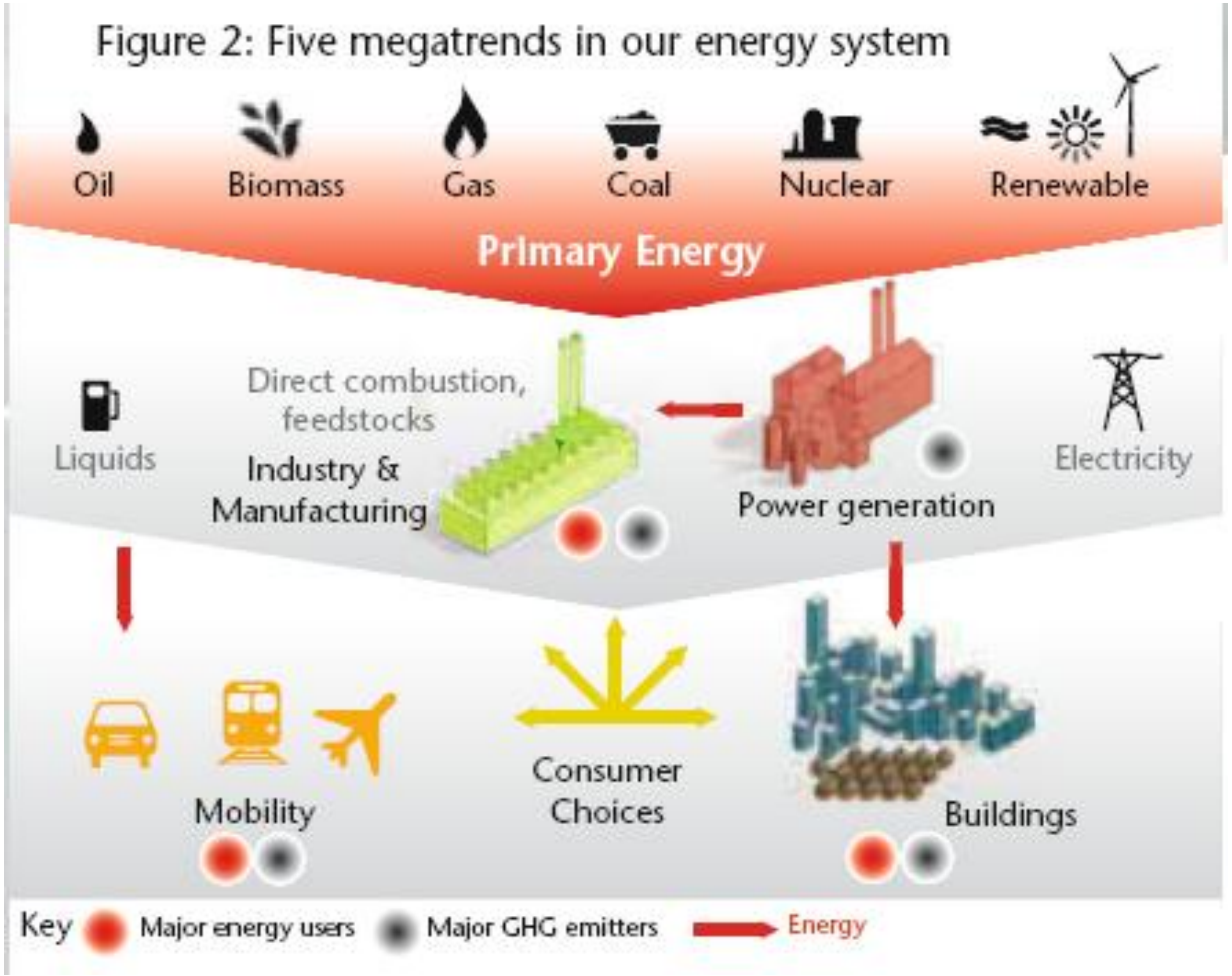
# Large changes in the energy system would be necessary over a 50 year horizon




Source: WBCSD Policy Directions to 2025, Nov 2007

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# Global Energy Mix: primary energy consumption and electricity

*Source:* IEA, 2006

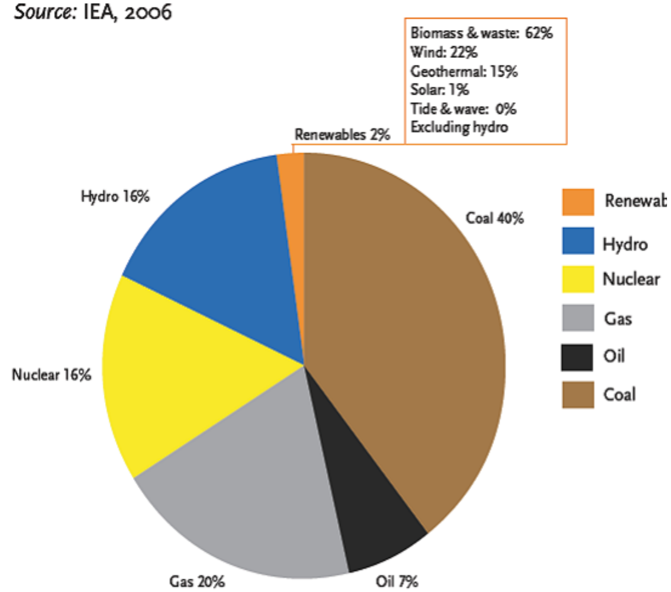



Figure 1.4 World electricity production by energy source, 2004

*Note:* Total world electricity production in 2004 was 17,408 terawatt-hou

*Source:* IEA, 2006.

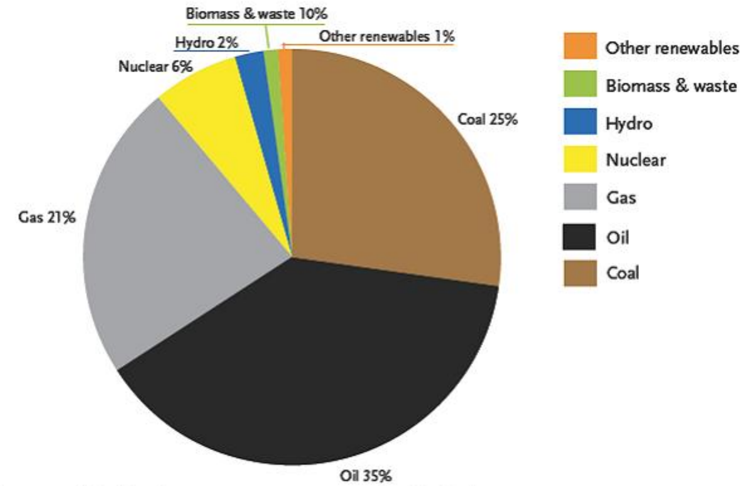



Figure 1.3 World primary energy consumption by fuel, 2004

*Note:* Total world primary energy consumption in 2004 was 11,204 megatons oil equivalent (or 448 exajoules).

# Near Term View: Today and 2030

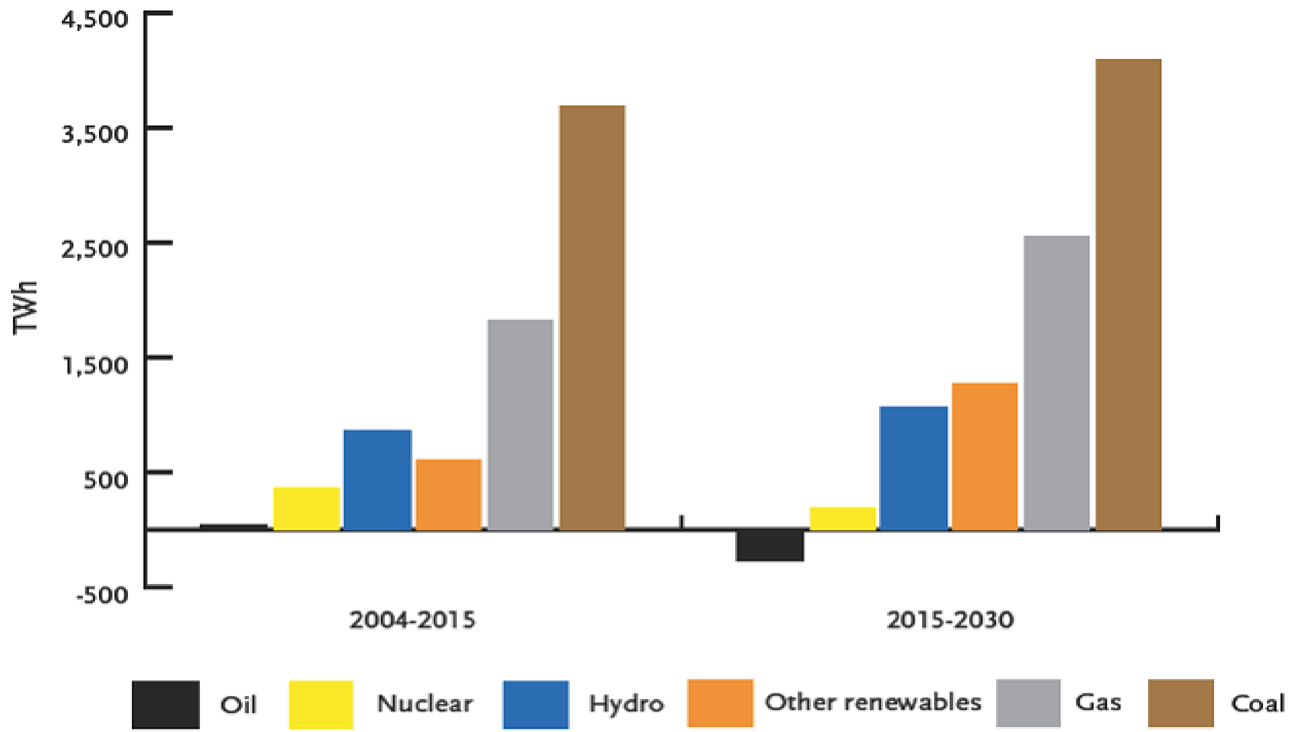
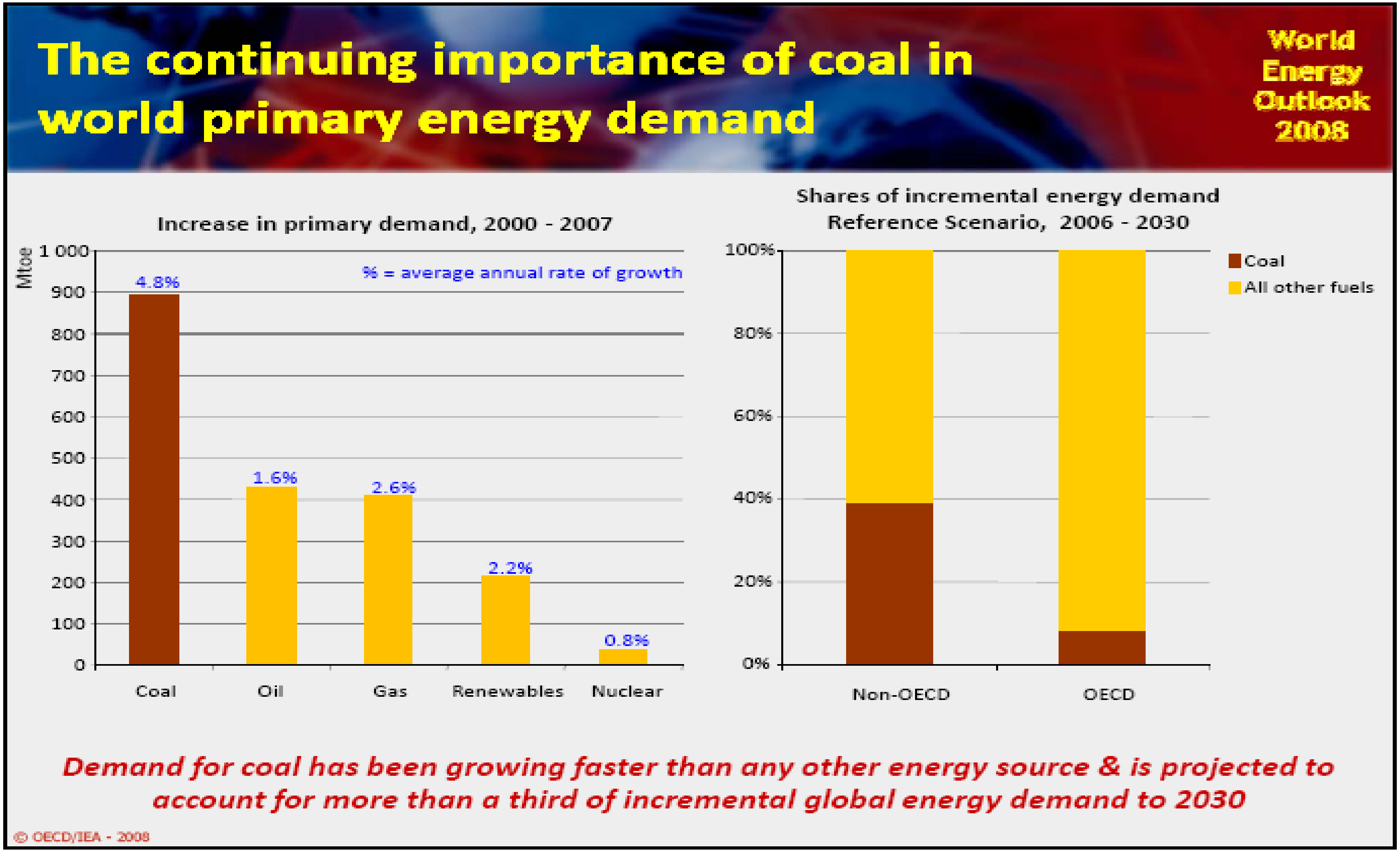



Figure 3.5 Projected world incremental electricity generation by fuel type

*Note*: 1 terawatt-hour (TWh) equals 3.6 petajoules.

*Source*: IEA, 2006

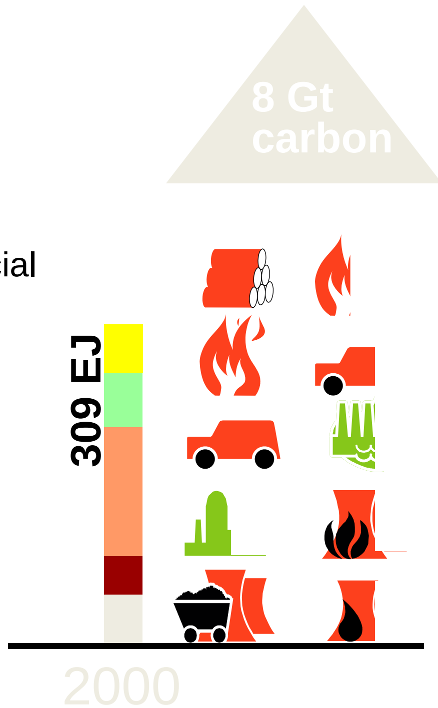
# Coal in the global energy system



# Today’s energy infrastructure

## Final Energy

- Electricity
- Gas
- Liquids
- Solids
- Non-commercial




| | |
|---|---|
| Direct burning of fuel | 3-4 Gt |
| 800 million vehicles | 1+ Gt |
| 700+ coal power stations | 1.5 Gt |
| Non-commercial biomass | 1 Gt |
| 800 gas or oil power stations | 0.7 Gt |
| Non emmitting technologies | 0 Gt |
| | **8.0 Gt** |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 25EJ per year solar | 500,000 5MW wind turbines | 1000 1GW coal power stations | 1000 1GW coal stations with sequestration | 1000 1GW oil power stations | 1000 1GW gas power stations | 1000 1GW nuclear plants | 1000 1GW hydro/ tidal /geothermal | 500 million vehicles (Biofuels) | 500 million low $CO_2$ (Biofuels) | 50EJ non-commercial fuel | 100 EJ direct fuel use (Biofuels) |

Source: WBCSD 2007

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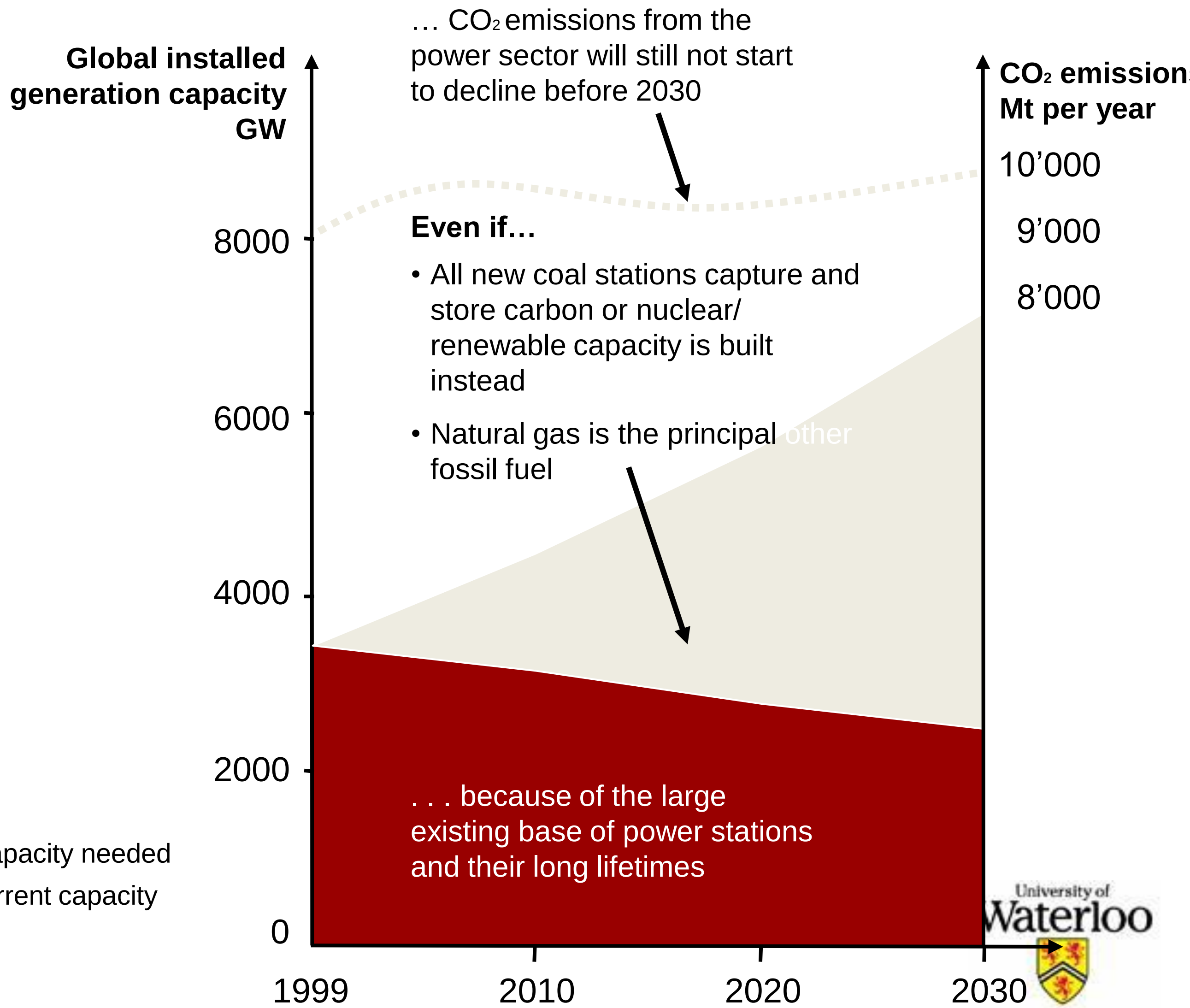
# Alternate power generation technologies: Impact on emissions

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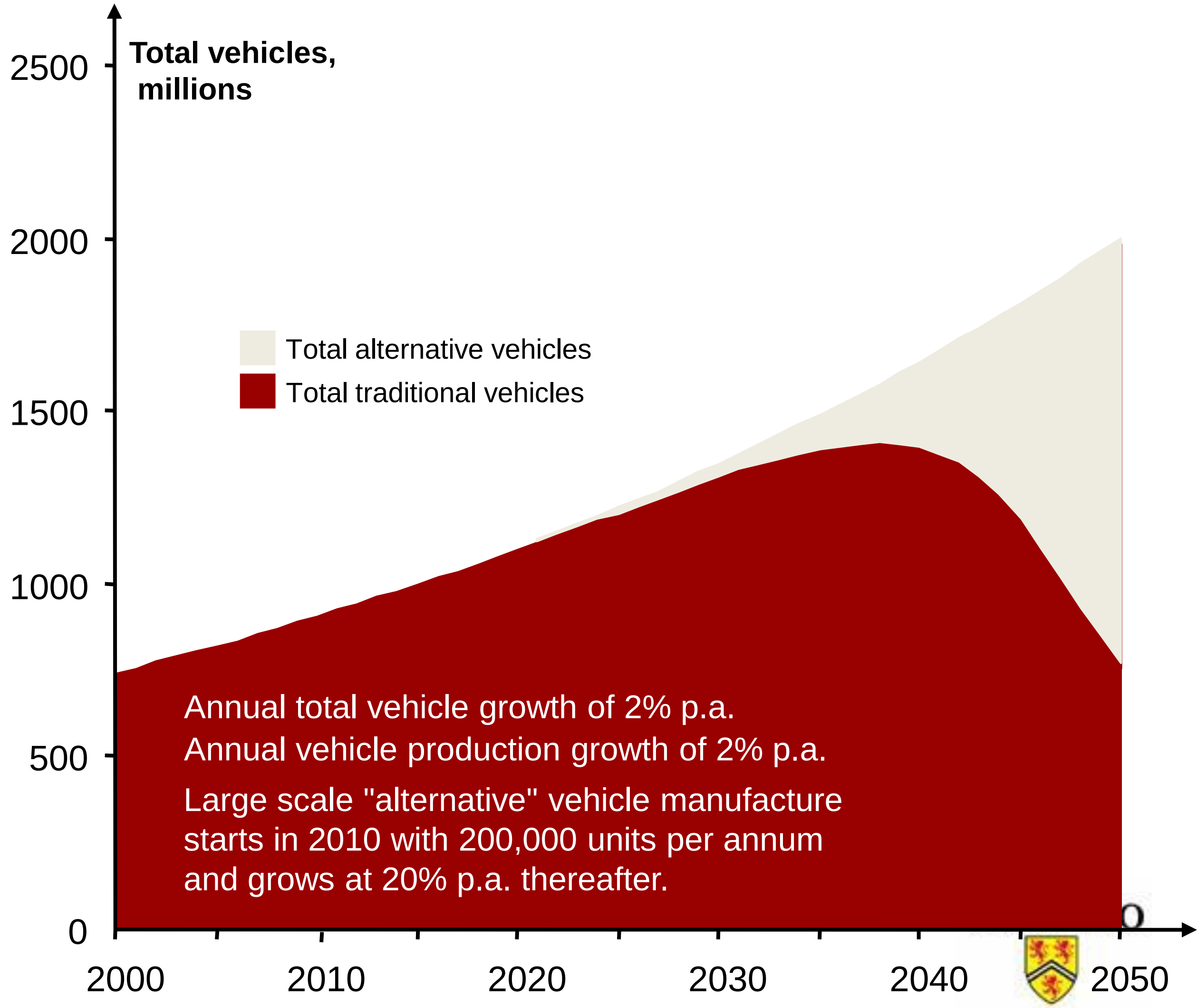
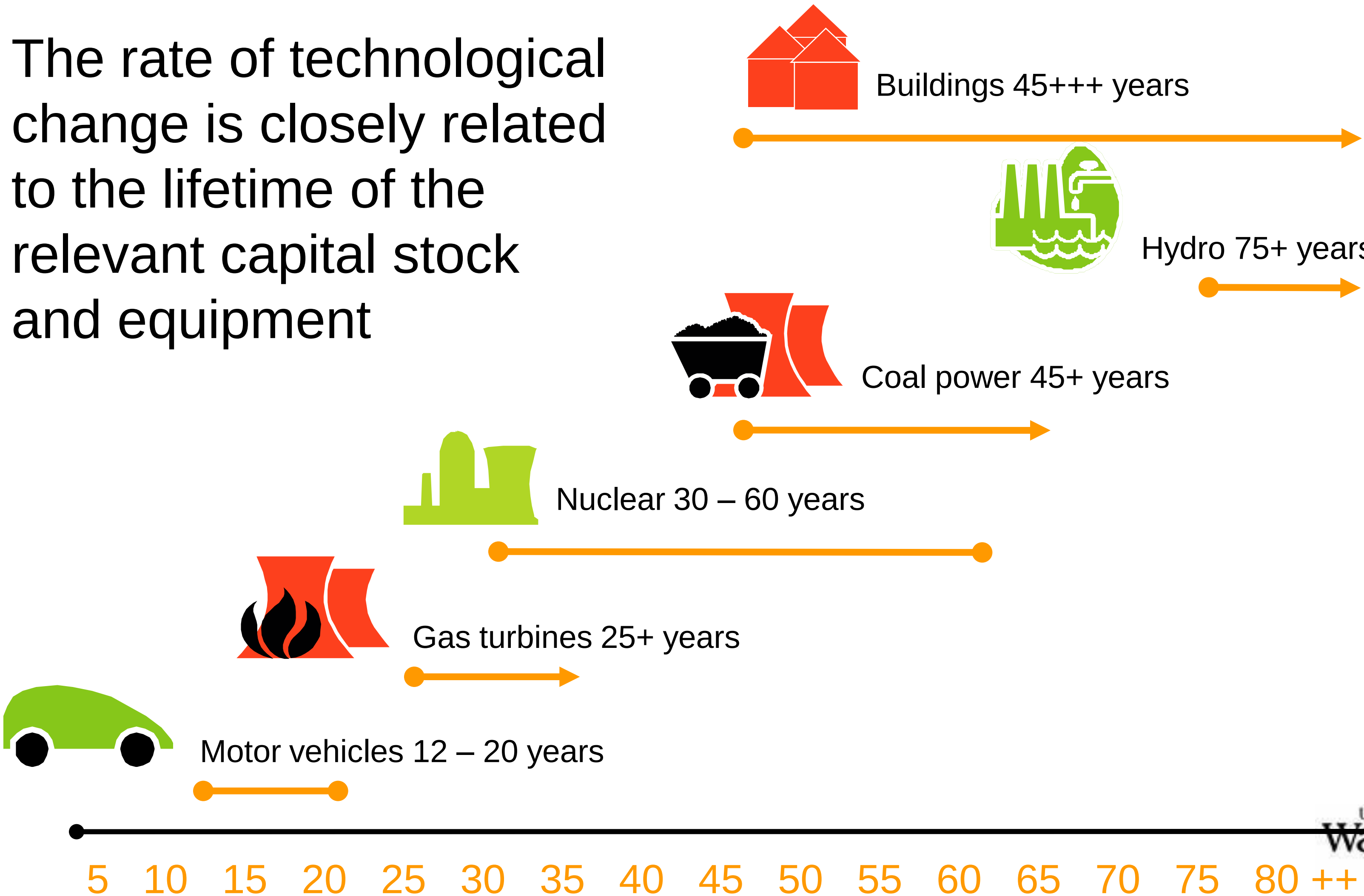
# Transport and Mobility



# The lifetime of energy infrastructure

The rate of technological change is closely related to the lifetime of the relevant capital stock and equipment




Source: WBCSD 2007

# Canadian and Ontario context in light of global trends

Global Trends

1. Five major trends in the energy system relate to
   - power production, transport (mobility), manufacturing and industry, buildings and consumer choices
2. Doubling or tripling of global energy demand
3. Climate change and a carbon constrained world
4. Efficiency in energy conversion from primary fuel to end use
5. Close coupling of electricity with wealth creation as opportunity

# Electricity as a vector of change:

# A look at the contrast between energy and electricity



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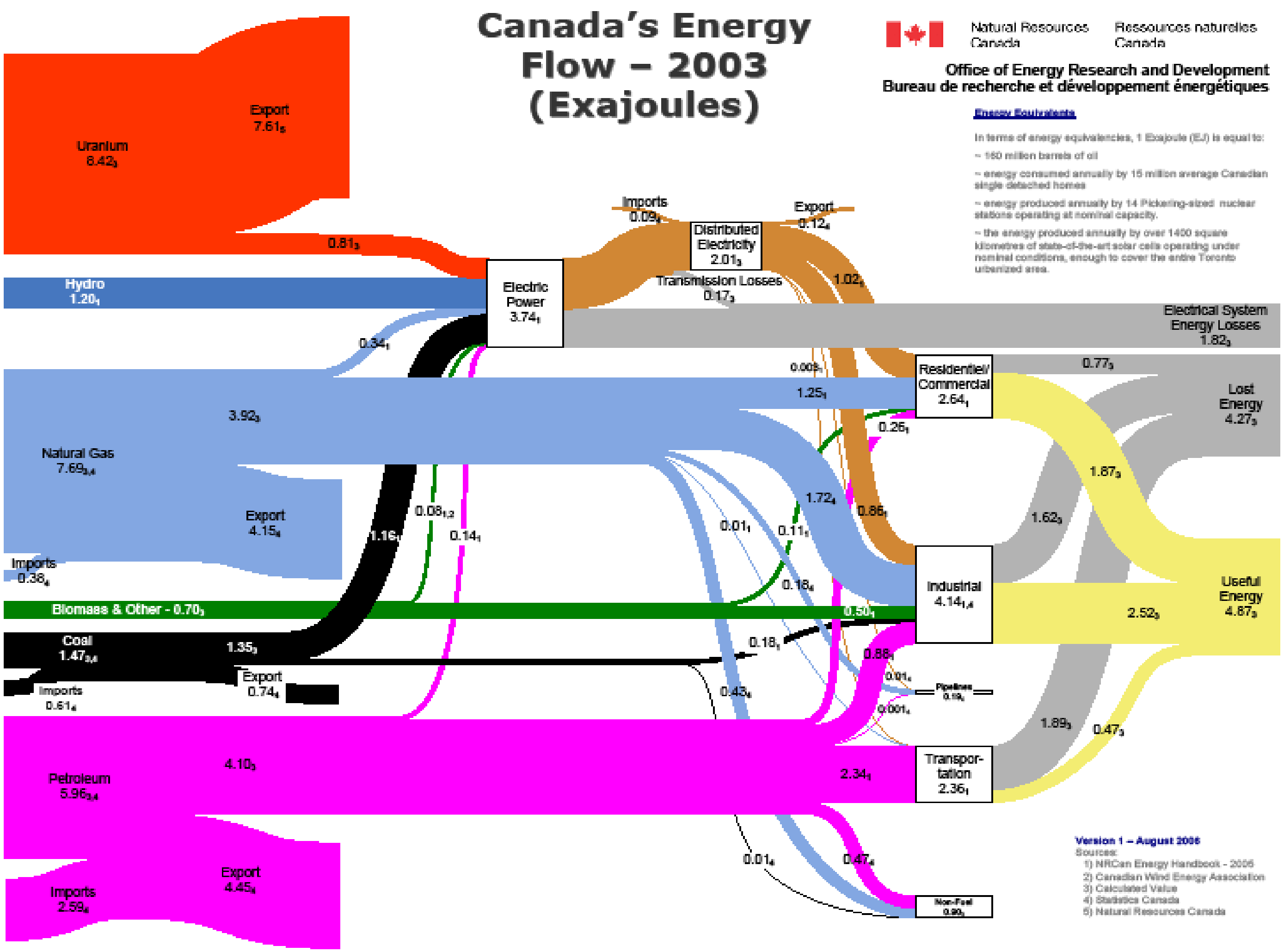
# It takes a lot of energy to get to useful energy

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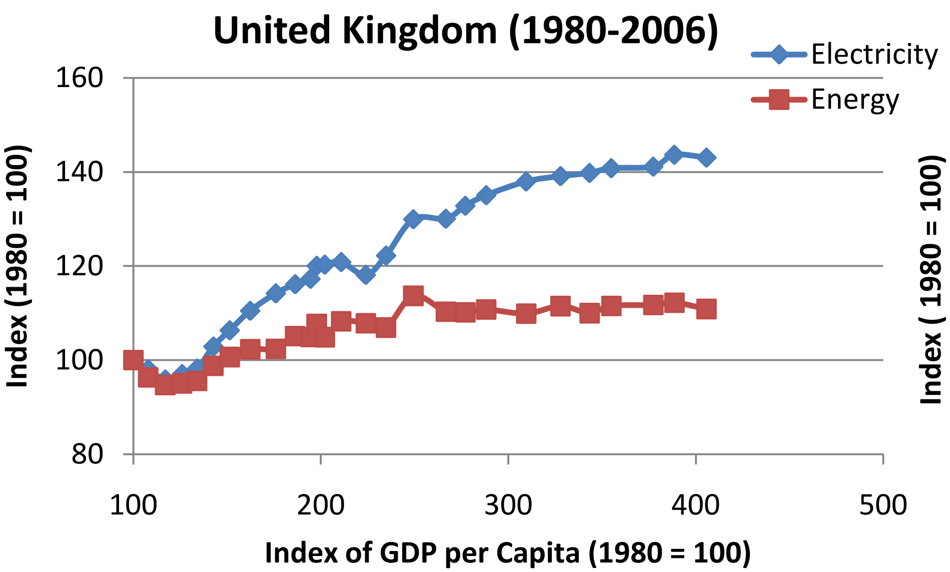
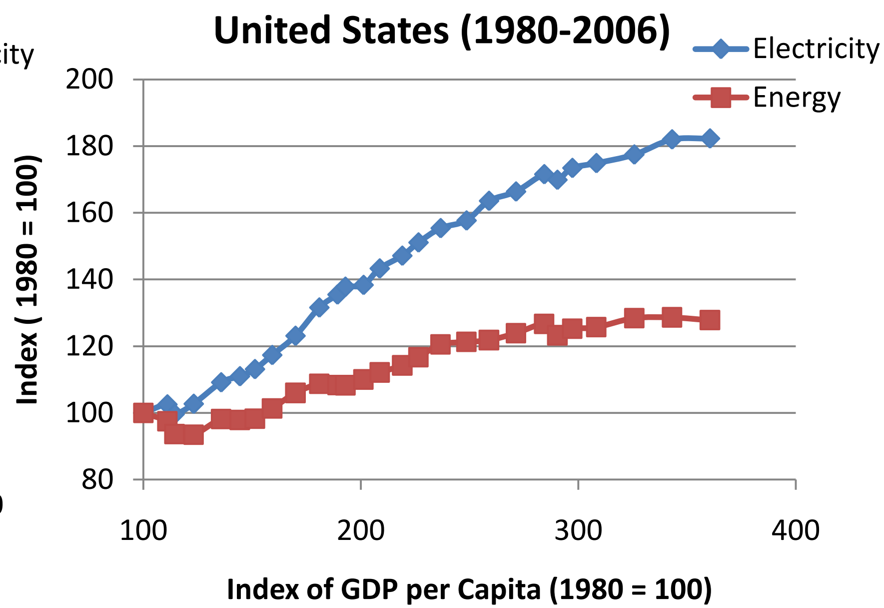
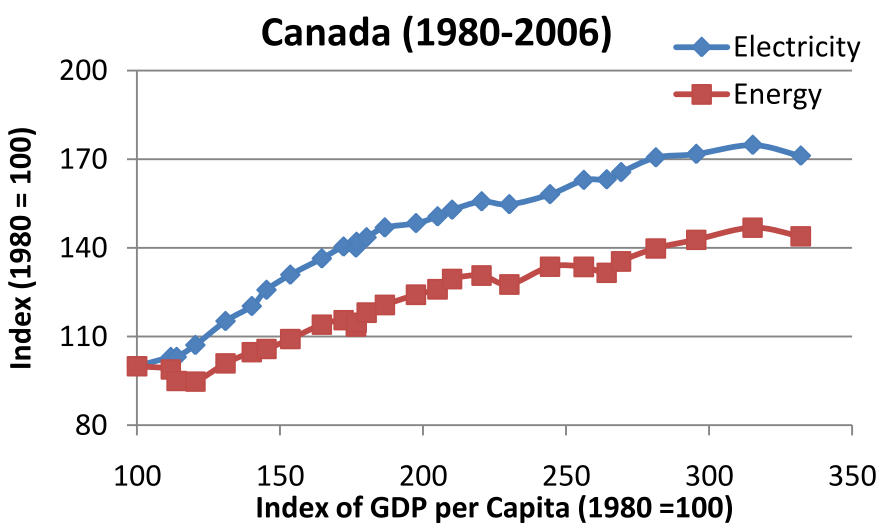
# Electricity and Energy Contrast

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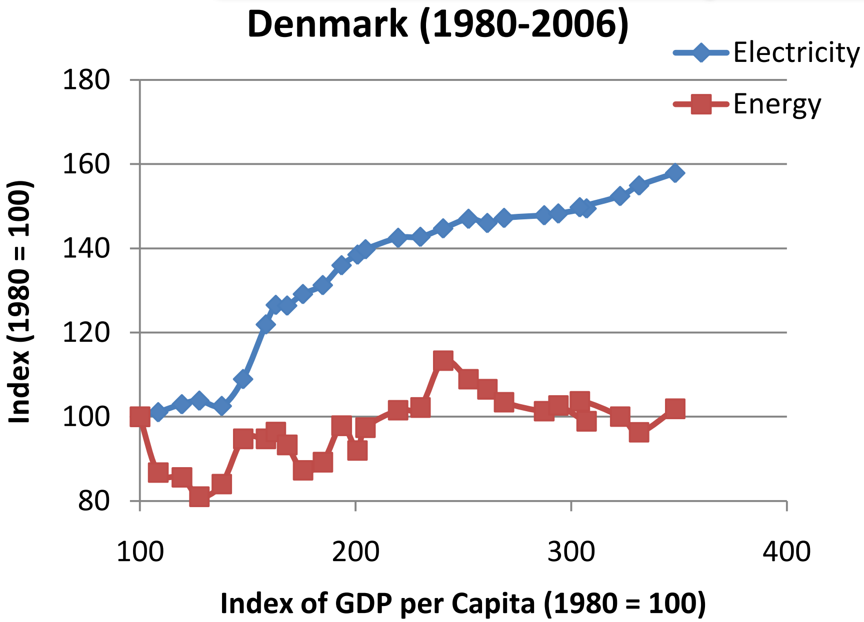
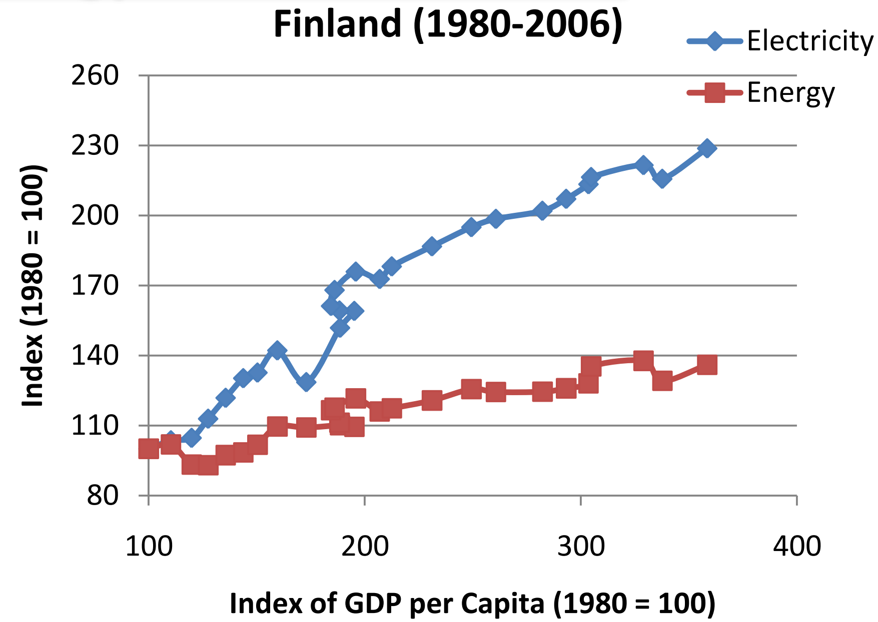
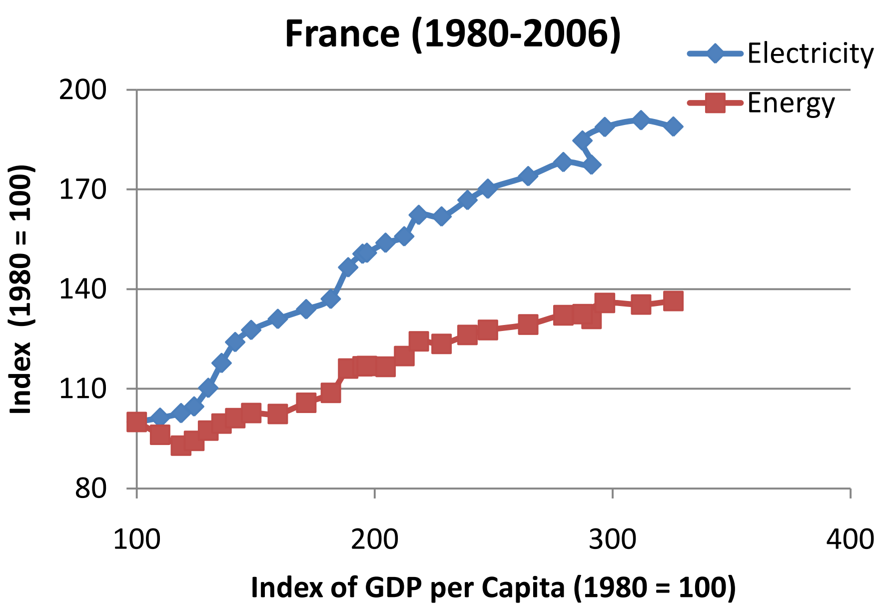
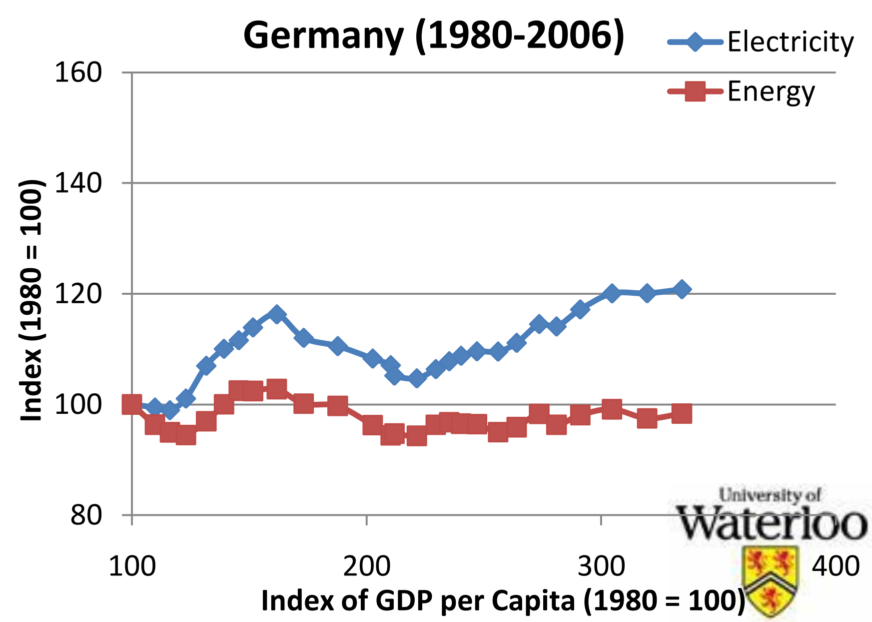
# Electricity and Energy Contrast

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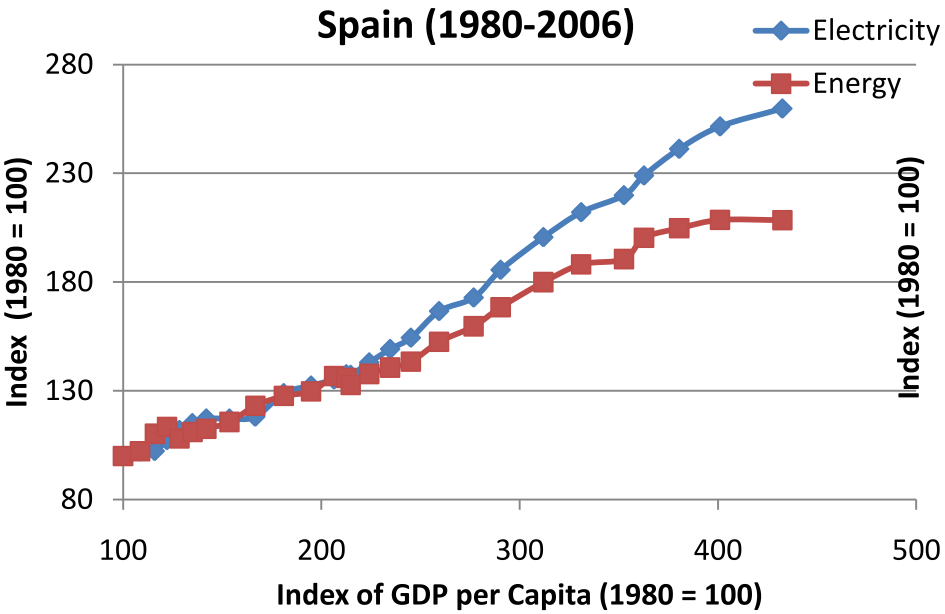
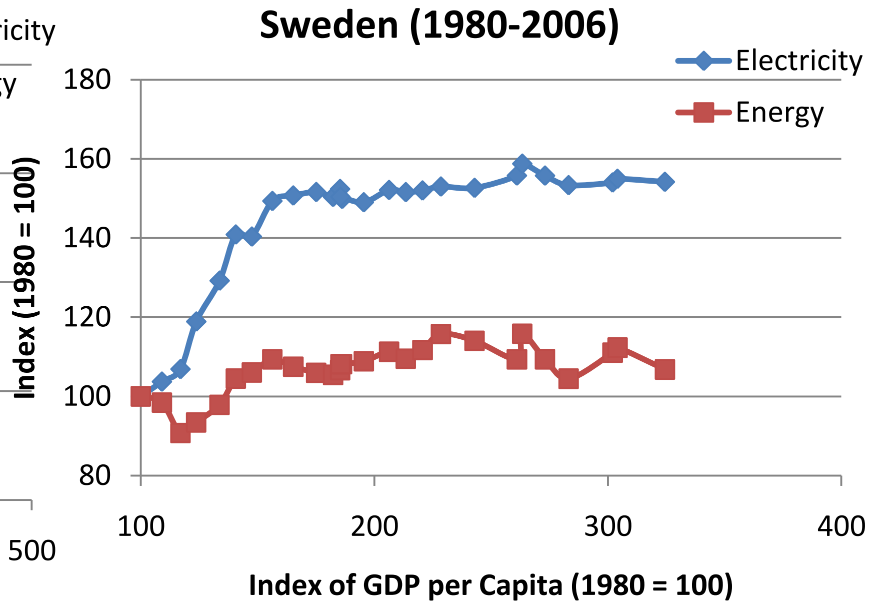
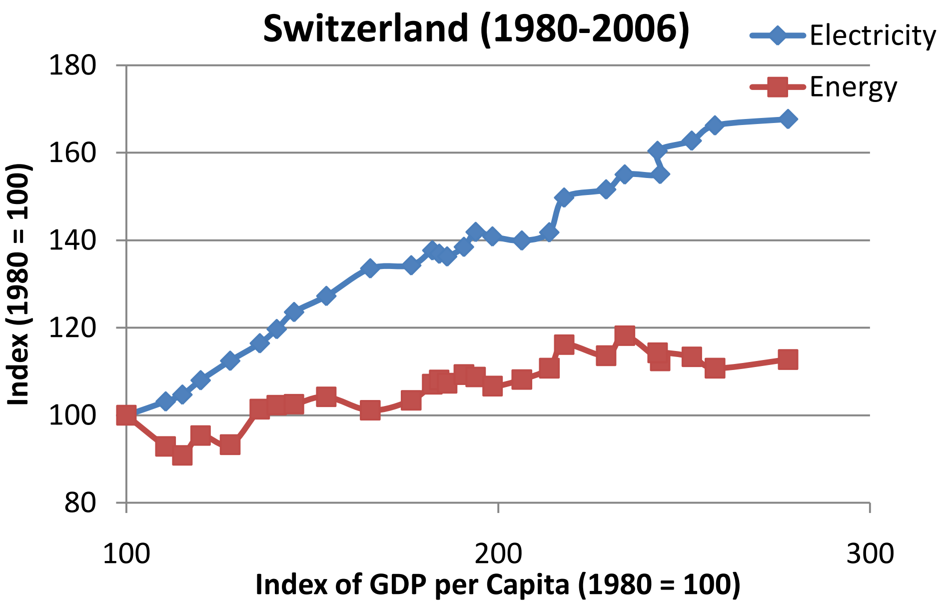
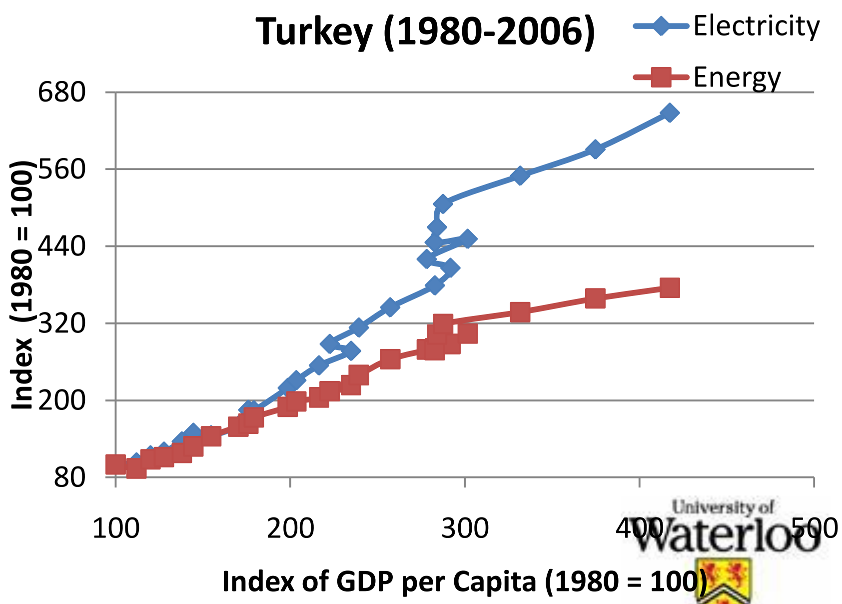
# Electricity and Energy Contrast





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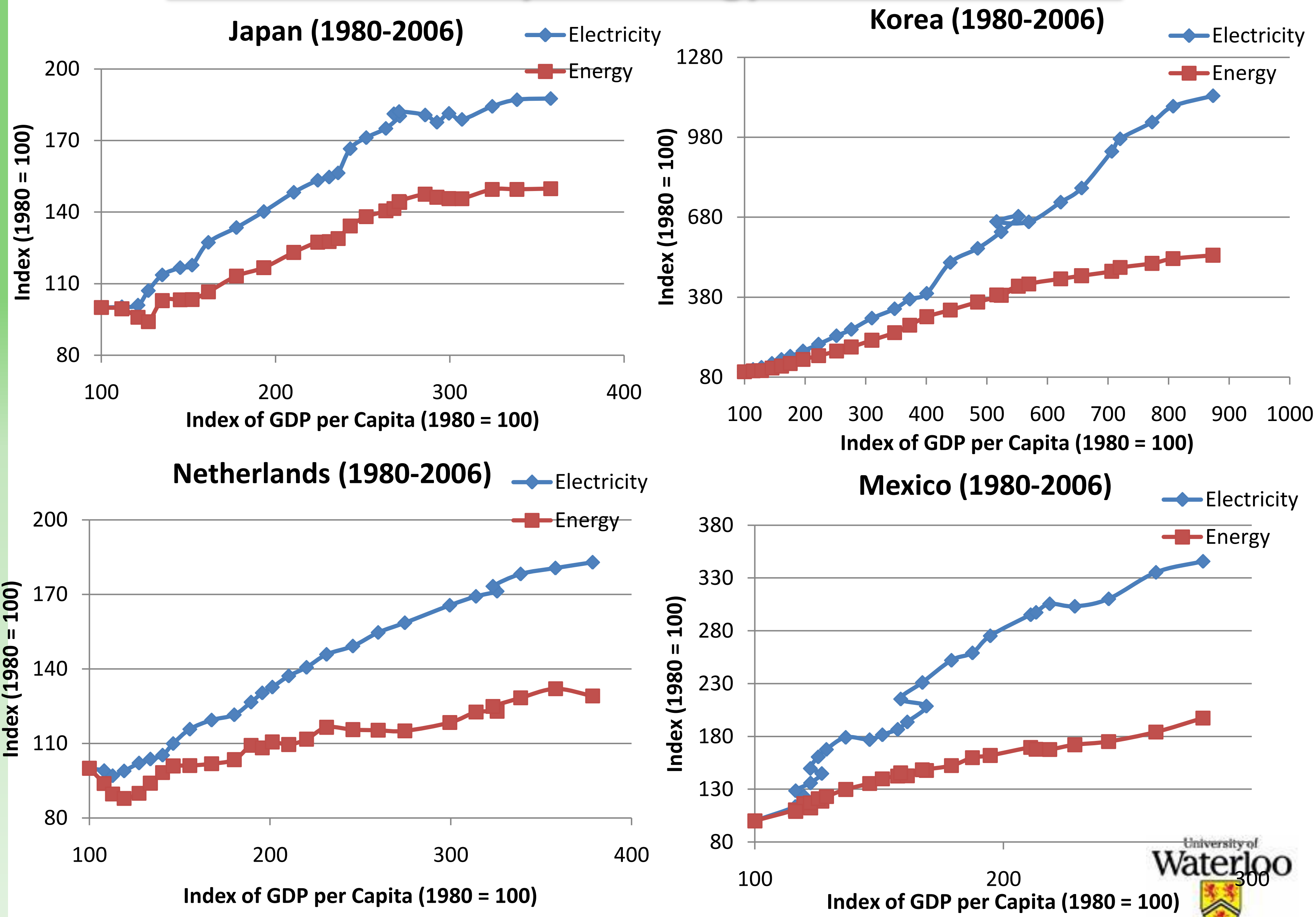


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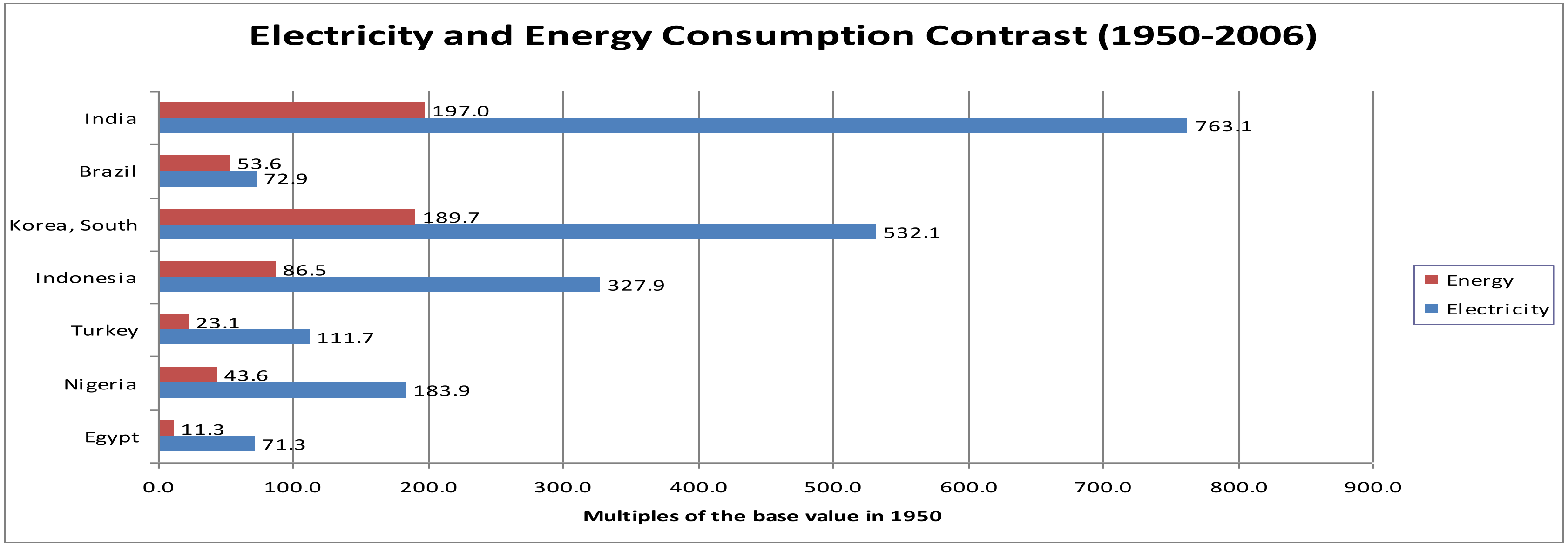


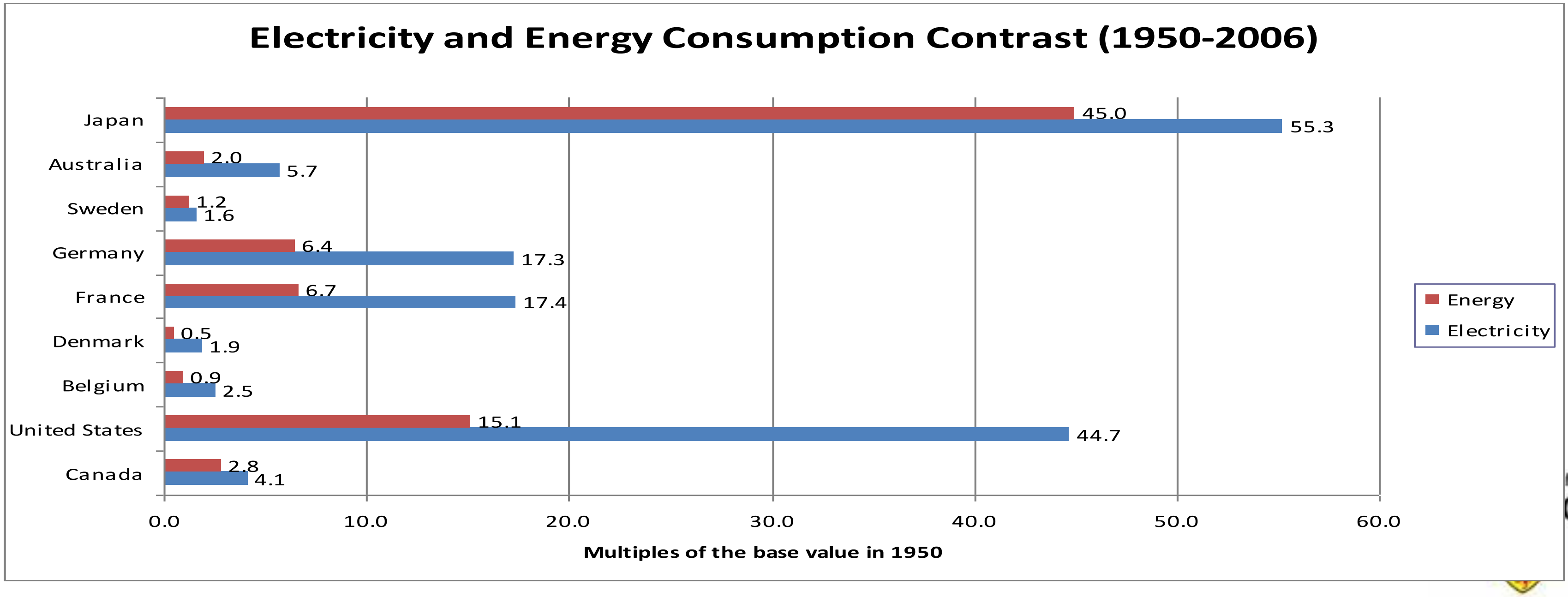

**Energy sector will be driven towards a quantifiable, long term pathway for reduced GHG emissions**

if so

- ? **How do we get there**
- ? **What role for innovation**
- ? **What capacity for change**
- ? **What is the status of the infrastructure**
- ? **What are the governance and policy issues**

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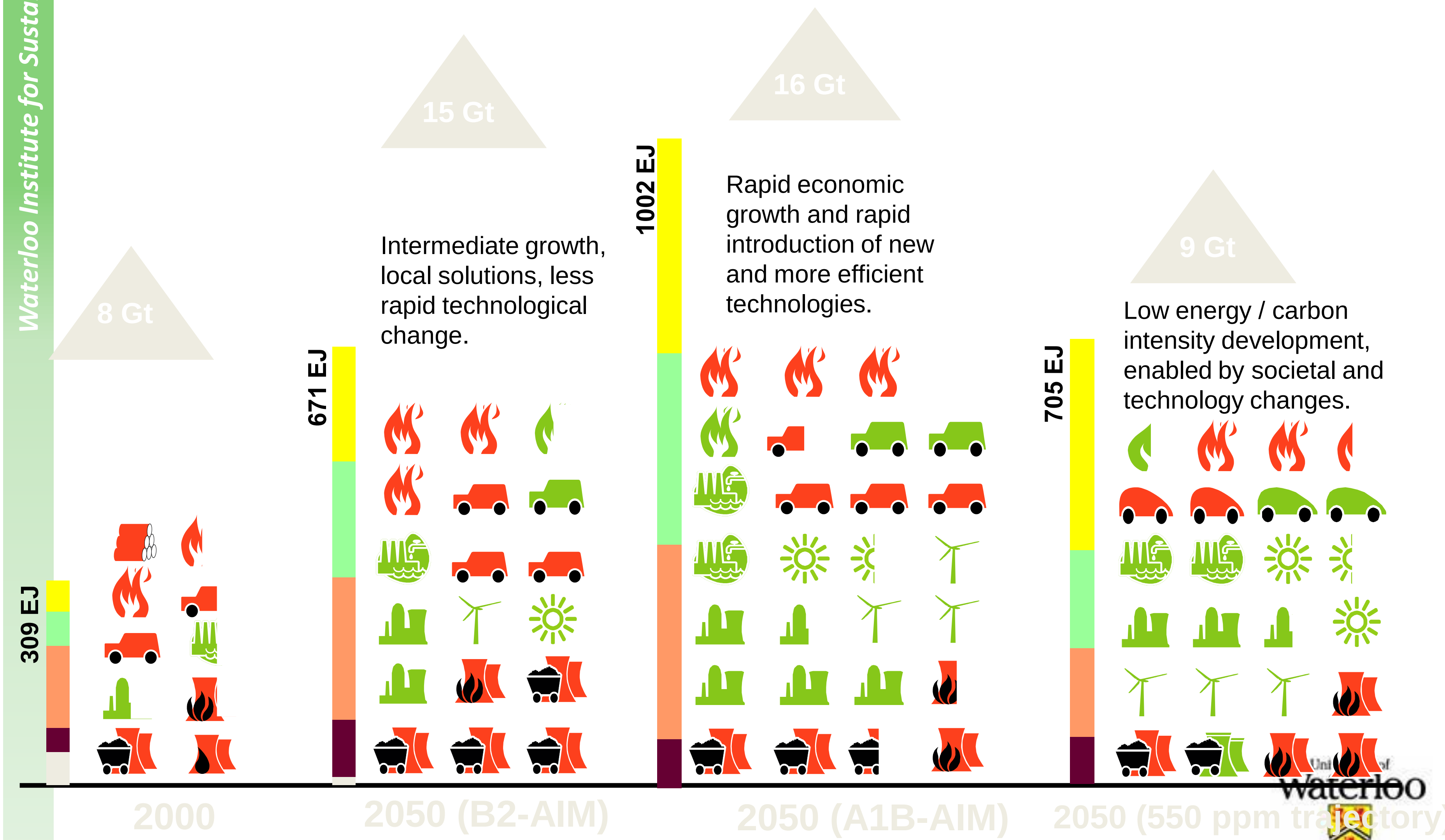
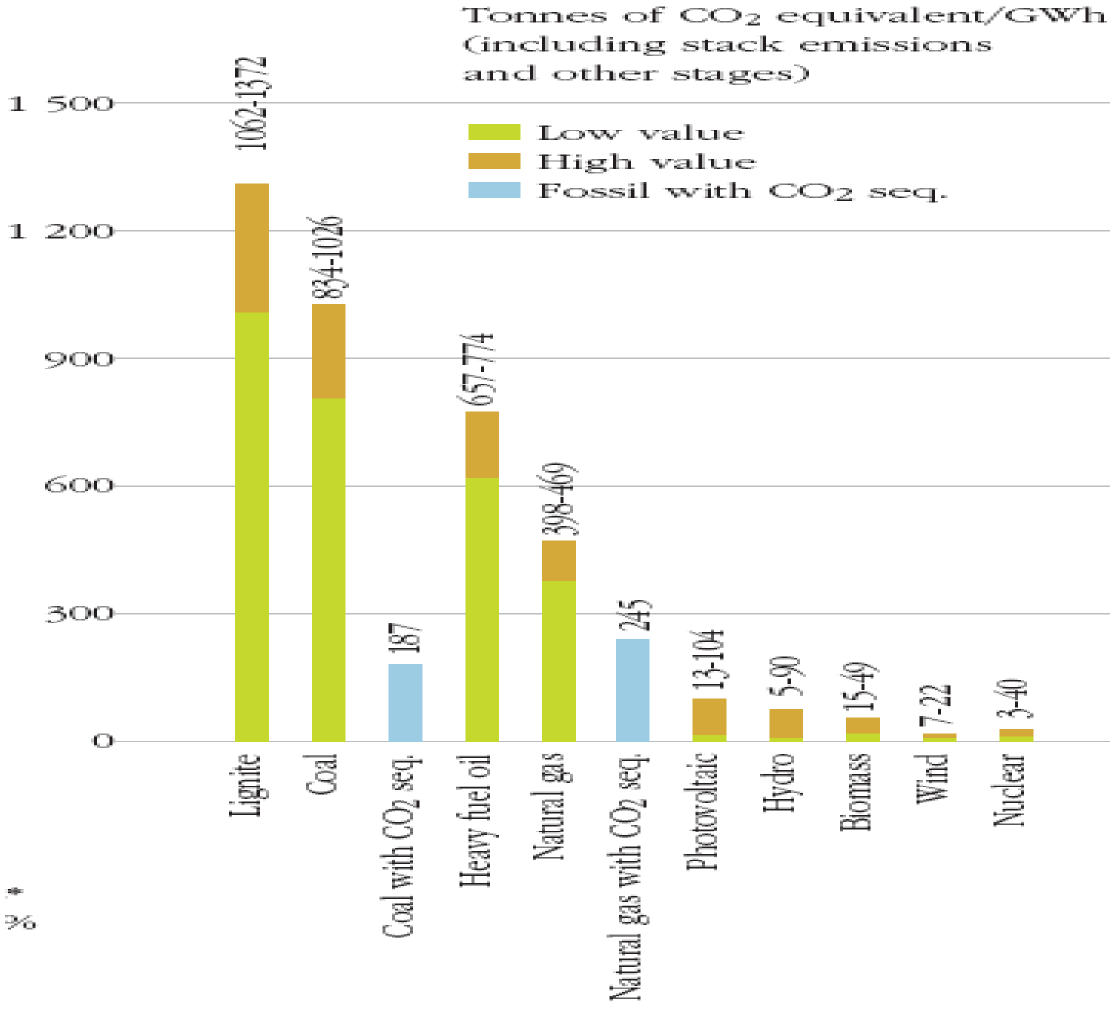
# A Balanced Mix of Options




Source: WBCSD, 2007

# Greenhouse gas emissions for electricity generation options

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# One View


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# Another View

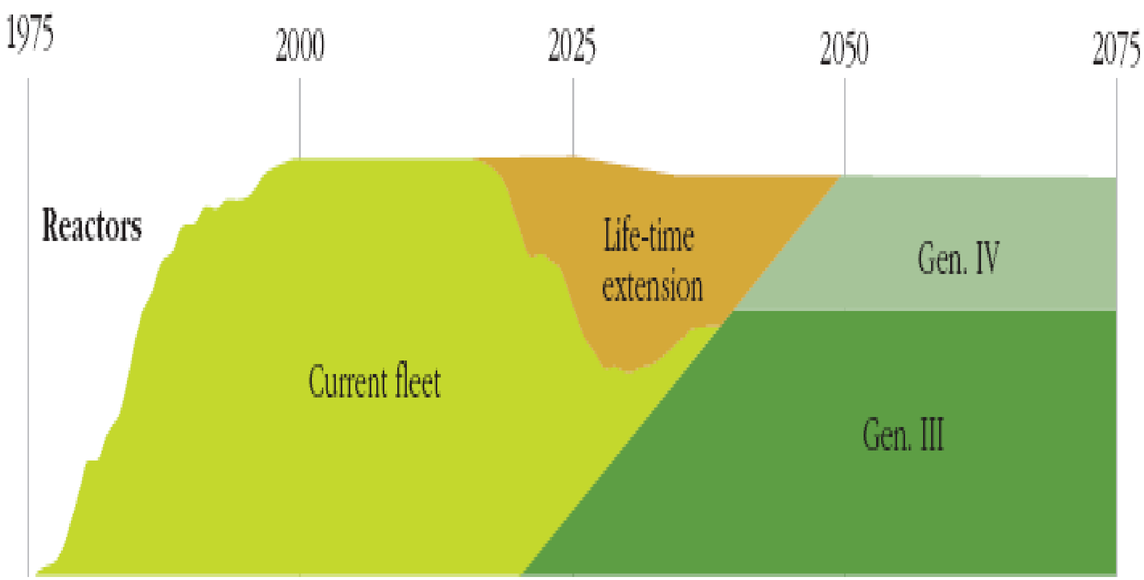
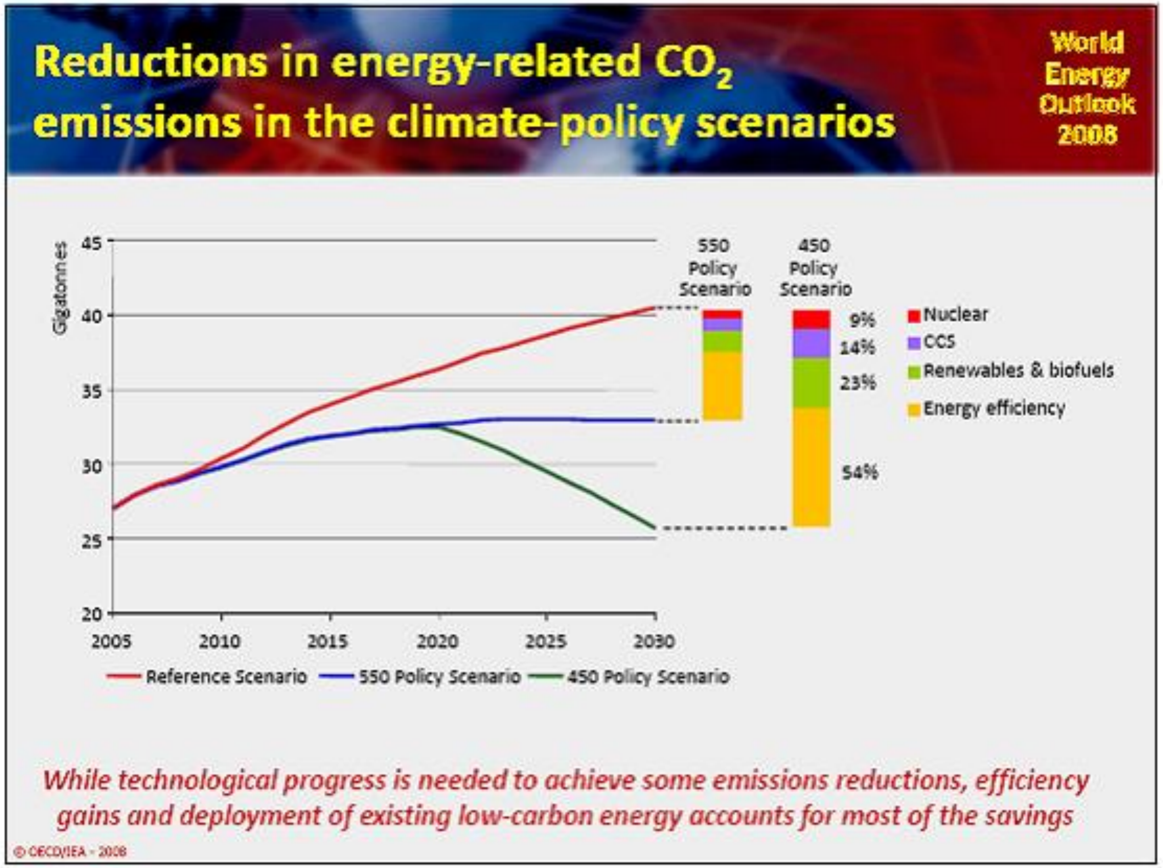



*Fig. 12: Deployment of generation-III and -IV reactors in the 21st century*

*Source: EDF, ENC, 2002*

# Moderate Steps, Moderate Results

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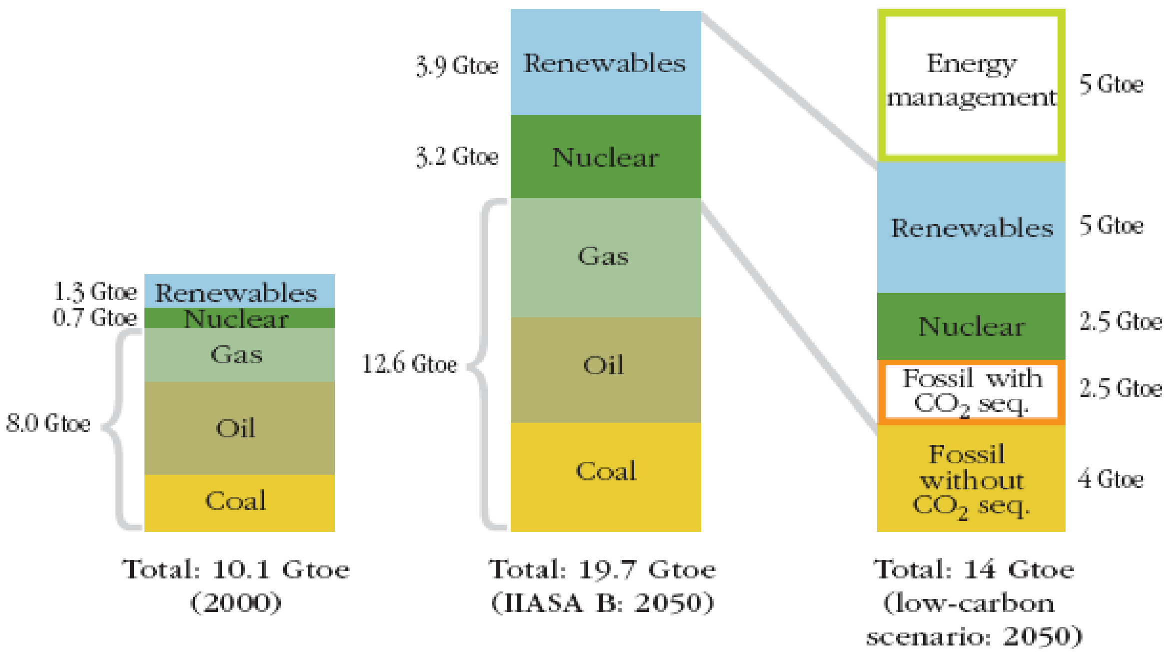
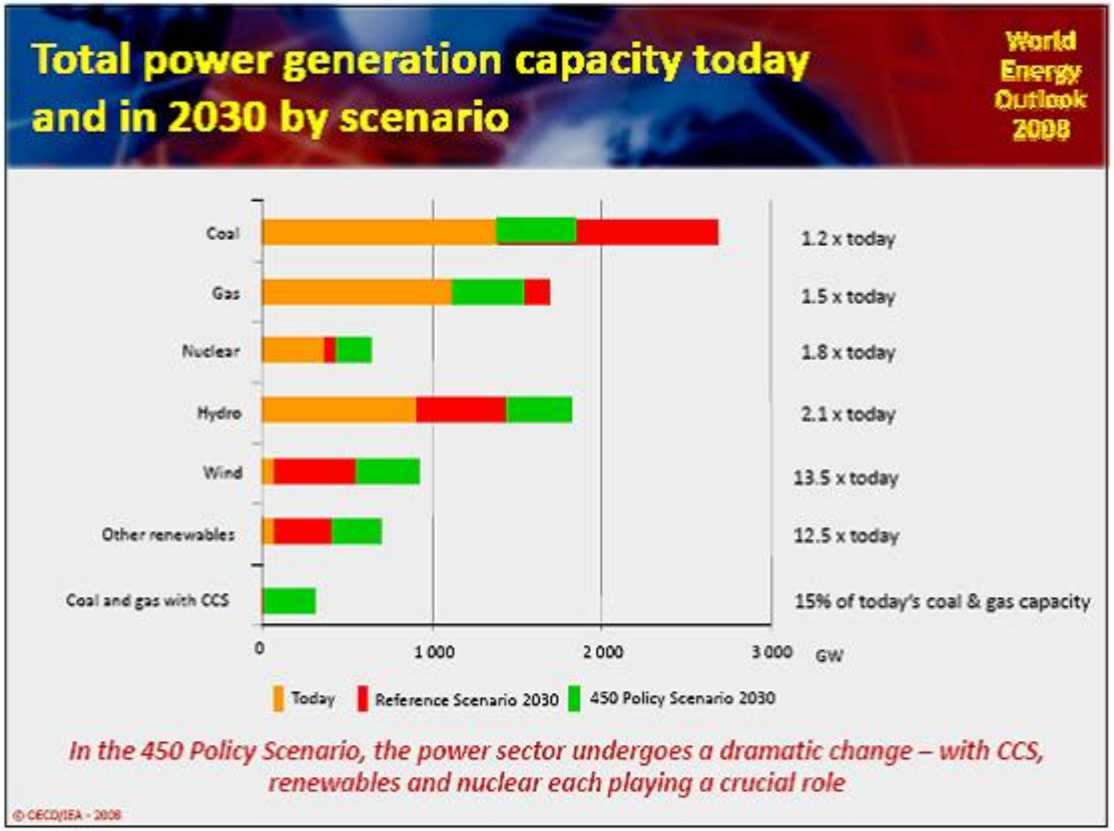
# An expansive view

*Fig. 8: Possible role of nuclear energy in different scenarios for 2050: example of a 14-Gtoe/year scenario [22] where nuclear energy would represent 2.5 Gtoe (corresponding to an installed capacity of 1 300 GWe)*

*Seq. = sequestration*

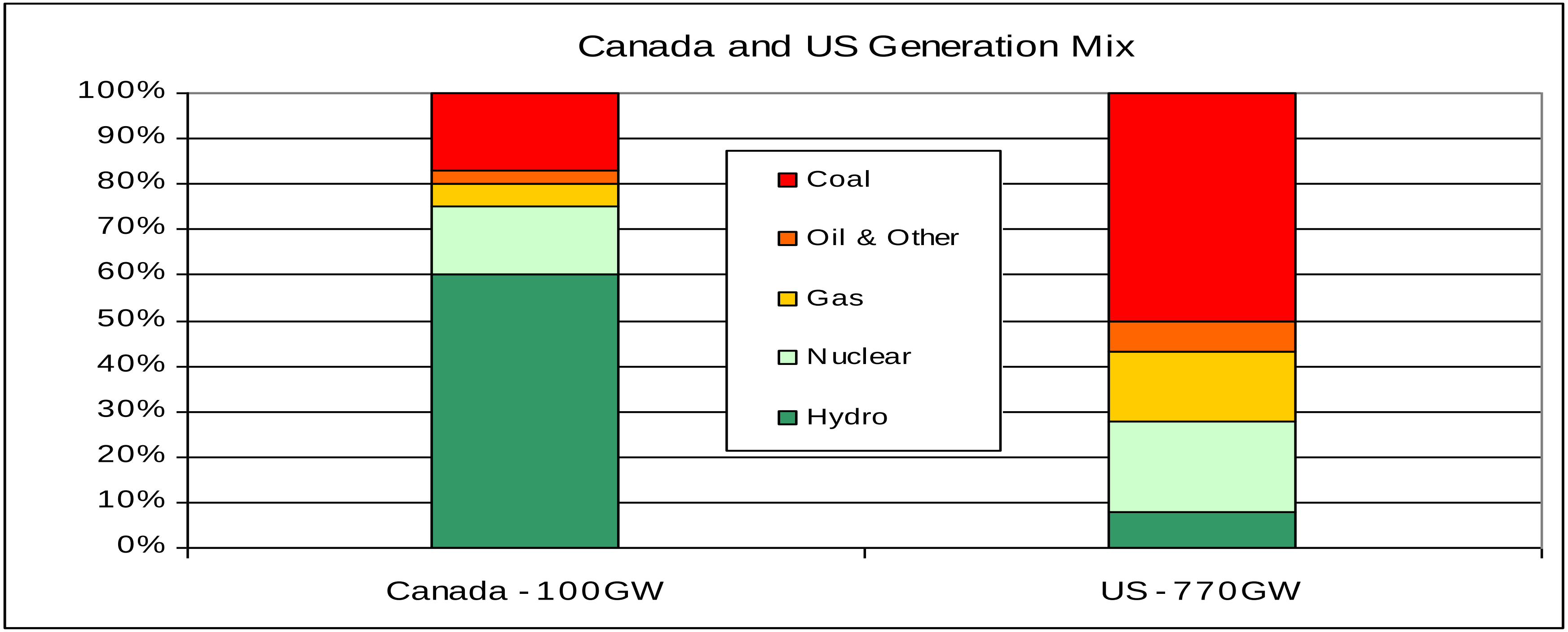


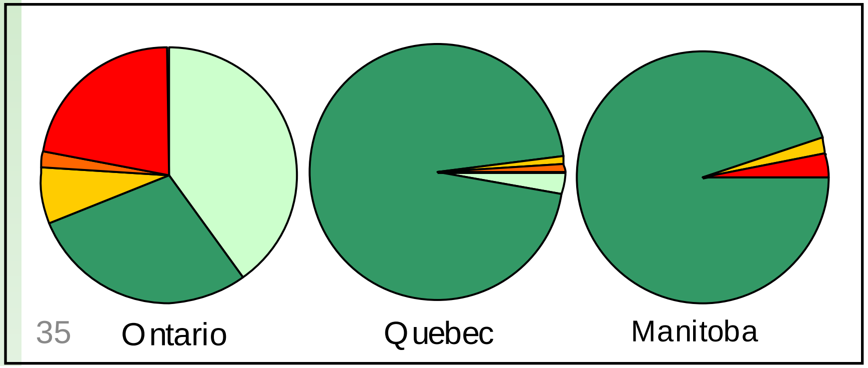

Total power generation capacity today and in 2030 by scenario
World Energy Outlook 2008
Coal
Gas
Nuclear
Hydro
Wind
Other renewables
Coal and gas with CCS
0
1 000
2 000
3 000
GW
1.2 x today
1.5 x today
1.8 x today
2.1 x today
13.5 x today
12.5 x today
15% of today's coal & gas capacity
Today
Reference Scenario 2030
450 Policy Scenario 2030
In the 450 Policy Scenario, the power sector undergoes a dramatic change – with CCS, renewables and nuclear each playing a crucial role
© OECD/IEA - 2008

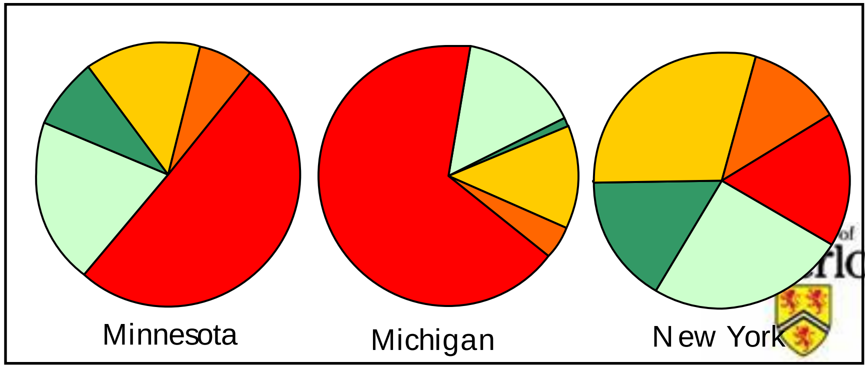
# Canada’s Low Carbon Electricity Advantage

- What role for electricity as driver for economic development?
- Should we promote electricity trade with neighbouring states given emerging advantage from the low carbon mix?
- Is it not to an advantage to plan with from a regional perspective rather than a “basic minimum” Ontario only focus?

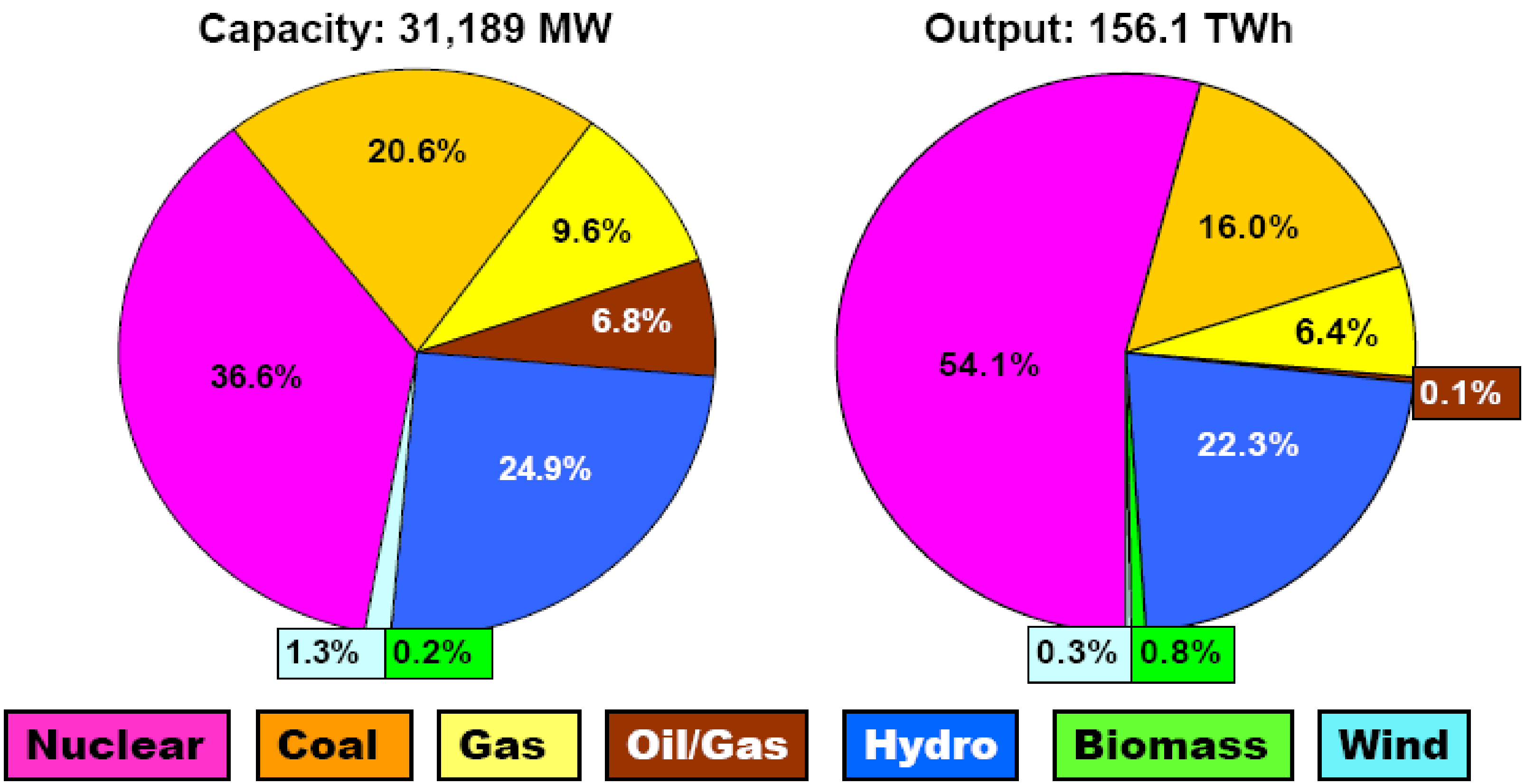
# Electricity Trade: Canada's clean energy offers a strategic environmental and economic advantage



# Ontario Electricity Generation Capacity and Output in 2006




Source: Ontario Ministry of Energy, 2007.

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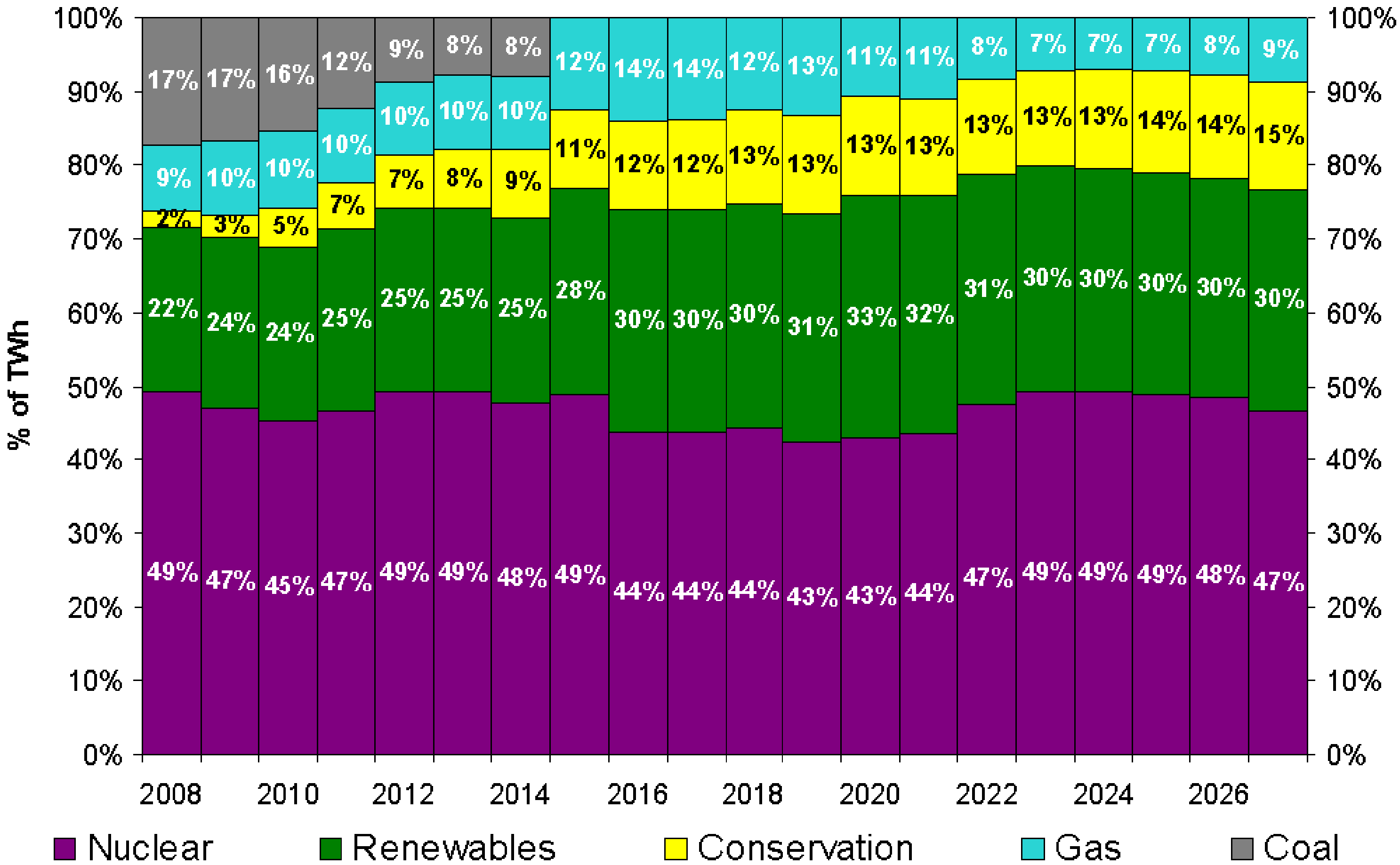
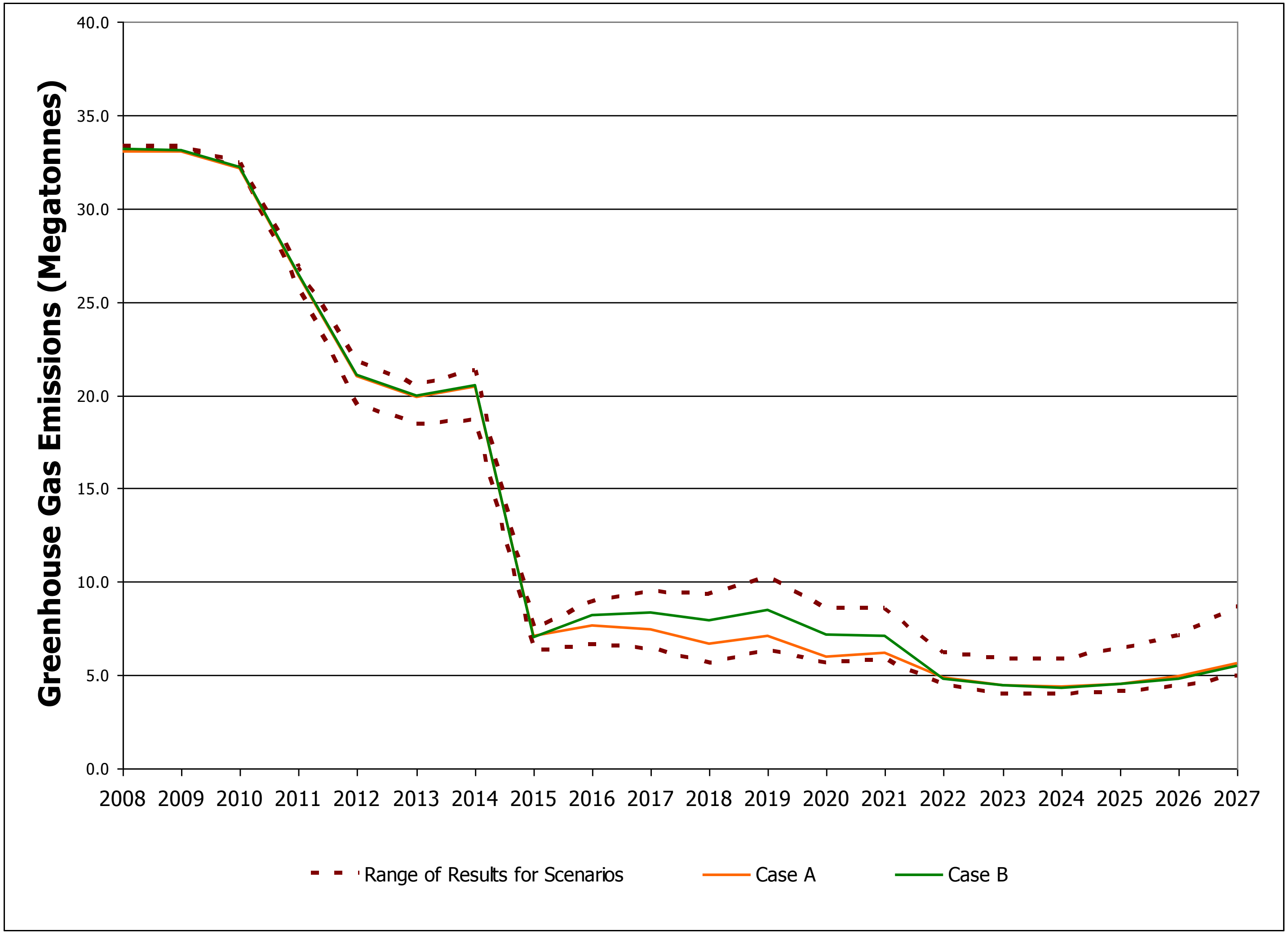
# Ontario's power sector is going (will be) "green"




Source: OPA

# Ontario GHG emissions problem essentially resolved




Source: OPA

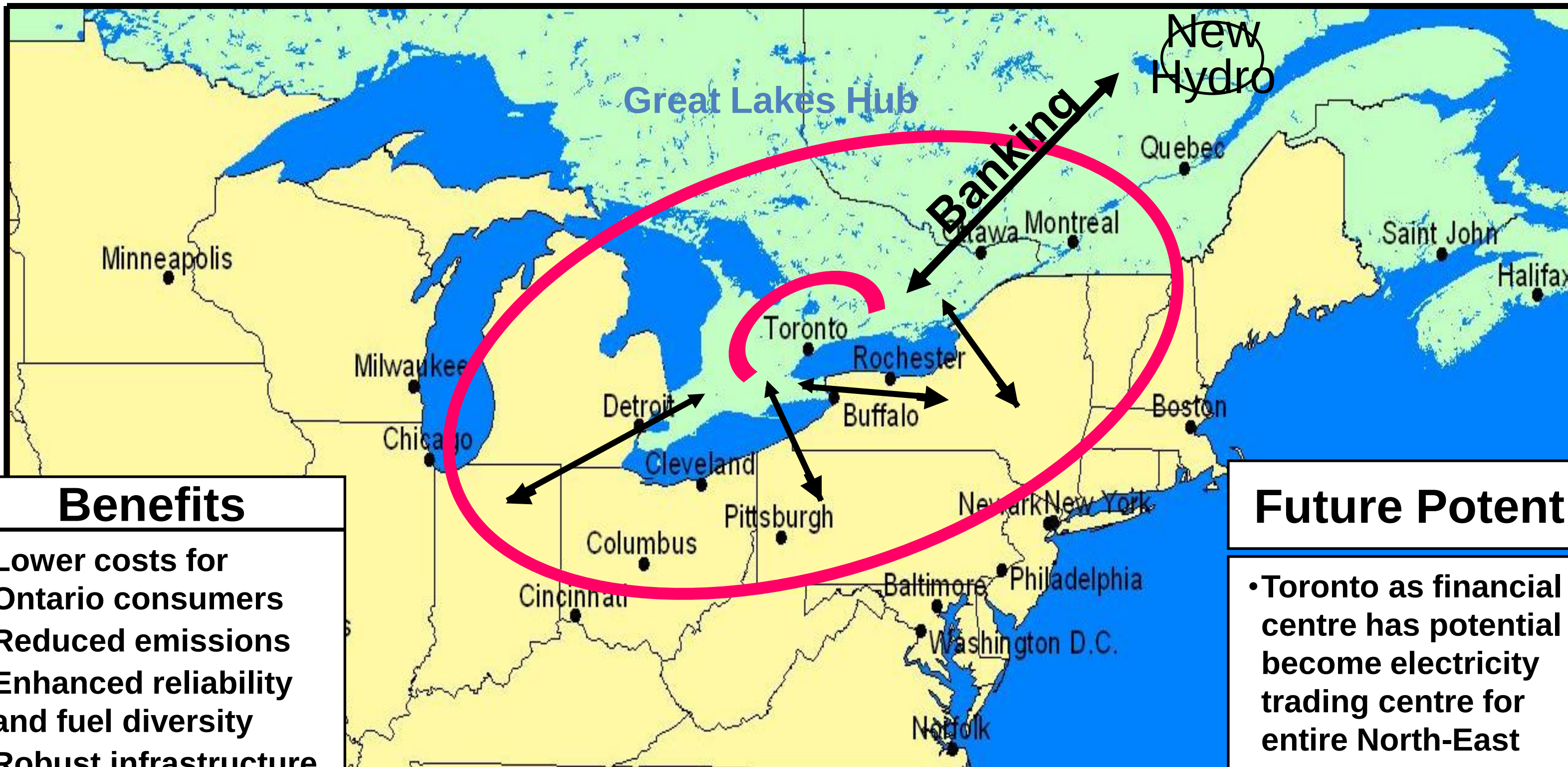
# *Carbon intensity* of electricity production

| | |
|---|---|
| France | 83 |
| Sweden | 87 |
| Canada | 220 |
| Austria | 250 |
| Belgium | 335 |
| European Union | 353 |
| Finland | 399 |
| Spain | 408 |
| Japan | 483 |
| Portugal | 525 |
| United Kingdom | 580 |
| Luxembourg | 590 |
| Germany | 601 |
| USA | 613 |
| Netherlands | 652 |
| Italy | 667 |
| Ireland | 784 |
| Greece | 864 |
| Denmark | 881 |

Ontario → 250 (2007)
50 (2015)

Source: David J.C. Mackay, 2009
Carbon intensity of electricity production (g $CO_2$ per kWh electricity)

# Ontario as an electricity hub




## Benefits

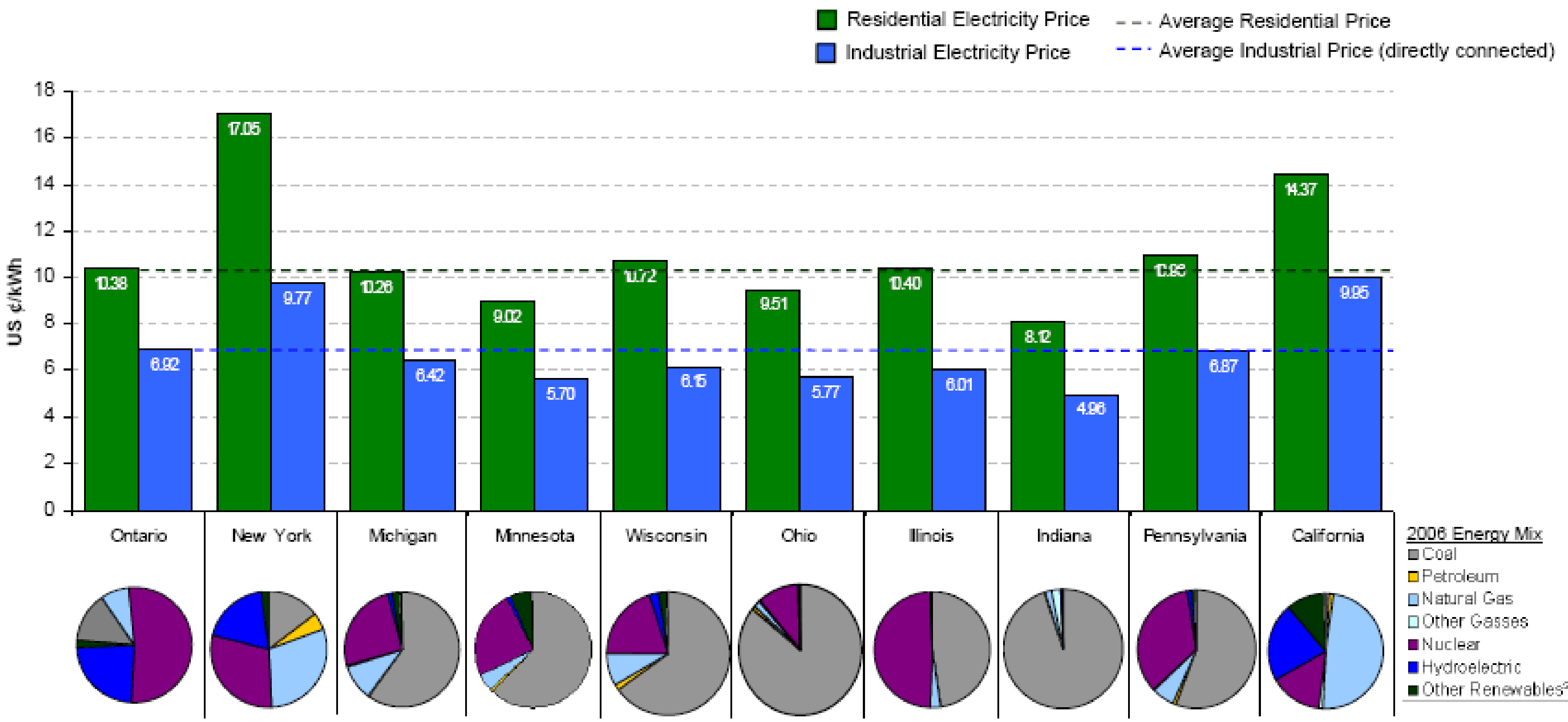
- Lower costs for Ontario consumers
- Reduced emissions
- Enhanced reliability and fuel diversity
- Robust infrastructure attracting investment/jobs

Market Size: 320,000MW

## Future Potential

- Toronto as financial centre has potential to become electricity trading centre for entire North-East
- Hub as a platform for future generation and transmission investments

# Electricity Price[1] and Energy Mix[2] Comparison by State




Notes:
1) 2007 price of electricity to end-use customers (including taxes).
2) 2006 energy mix by production data is currently available data from the EIA and NEB.
3) "Other Renewables" include biogenic municipal solid waste, wood, black liquor, other wood waste, landfill gas, sludge waste, agriculture byproducts, other biomass, geothermal, solar thermal, photovoltaic energy, and wind. (See "Notes" tab. Example: EIA, New York)

Sources:
Detailed Assumptions
- 2007 Ontario Residential Price: average distribution costs found from 2007 Comparison of Distributor Costs plus Ontario's 2007 commodity (includes GAM and OPG rebate), transmission, wholesale and debt retirement charges provided by IESO, p.24, Monthly Market Report Dec 2007
- 2007 Ontario Industrial Price: Ontario's 2007 commodity (includes GAM and OPG rebate), transmission, wholesale and debt retirement charges provided by IESO, p.24, Monthly Market Report Dec 2007
- 2007 US Prices – EIA, File 5.6b, Electric Power Monthly - March 2008
- 2006 Ontario Energy Mix, NEB, Energy Futures Report, Table 5.4
- 2006 US Energy Mix: EIA, Table 5, State Electricity Profiles 2006

Ontario Power Authority

# Can we achieve the advantage without Investment in Aging Infrastructure?



- What is the nature of the challenge?
- What is the best approach for attracting investment for renewal of the aging infrastructure?
  – Both physical and human?
- What is in the public interest vs private interest?
  - Costs are shared by all (access to transmission by distant renewable resources) or
  - Costs allocated to "individual"—perfect power for me
    – (on-site storage, DG)
- What is the best approach for generation vs wires?
  – Market driven price signals or PPA for generation?
  – Power purchase contracts?
  – Transmission as regulated?

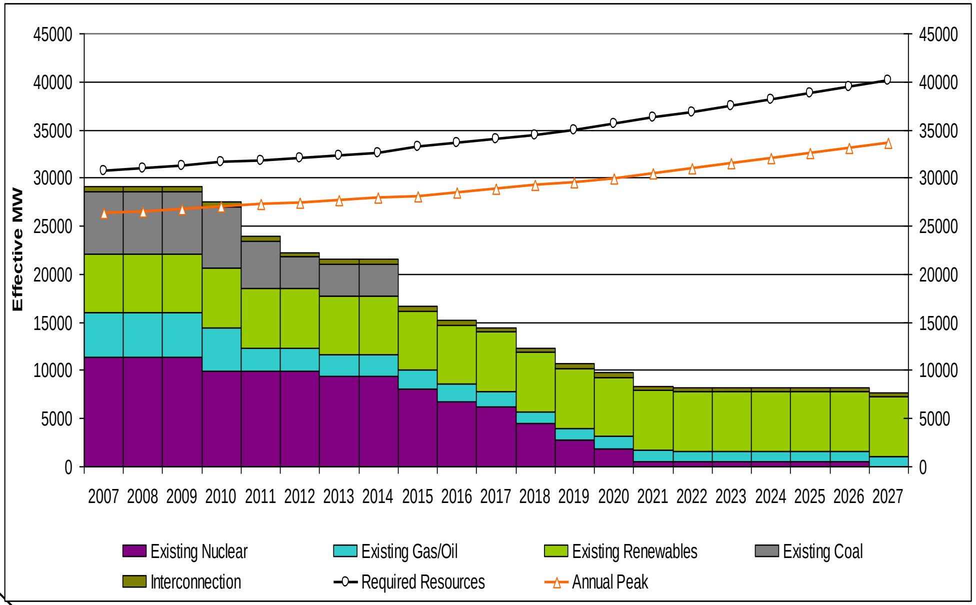
# Ontario's $60-70 Billion Challenge

## Generation Resources
- Renewables
- Conventional
- Distributed

## Transmission
- Siting
- Approvals

## CDM
- Conservation
- Efficiency
- Demand Response

## Investment
- Financing
- Barriers




## Governance
- Policies
- Incentives

## Industry Structure
- Markets
- Regulation

## Environmental Sustainability
- Future Generations
- Equity

## Technology
- R&D
- Human Capital

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# 1990- 2005: A Long Deep Sleep?

## Maxed Out the Old System…Experiment with Market Structures?

A+ Grade for squeezing value out of existing assets during a long capital averse period

Competition

- Bought the North American electricity grid 15 extra years
  - Capacity factors up 20%+
  - Transmission maximized to support wholesale trading
- Shifted more risk to customers
- Enron/ Califronia/Alberta…and then Ontario 2003 Demand/Supply Crisis and emergence of the hybrid market
- We've squeezed all that we can and now we need to change paradigms
- We need to introduce innovation and real-time management
- Risks are shifting back to utilities

# Our Aging…Infrastructure…Renewal

## *Human & Intellectual Capital*

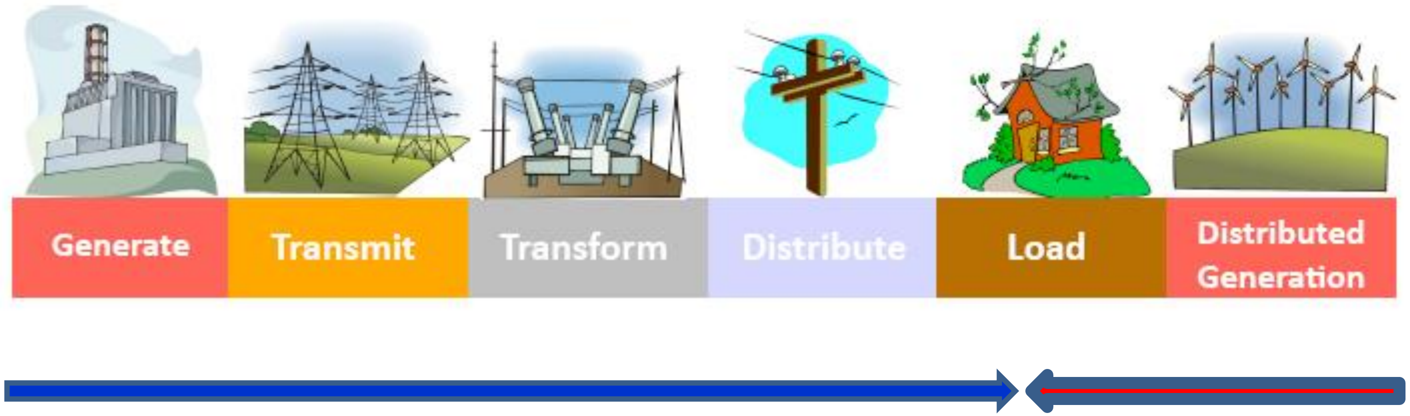
- 1/3-1/2 of current employees will retire within next 5-10 years
- A more diverse workforce reflecting communities
- Training and Competencies
- Savvy, younger, flexible

## *Physical*

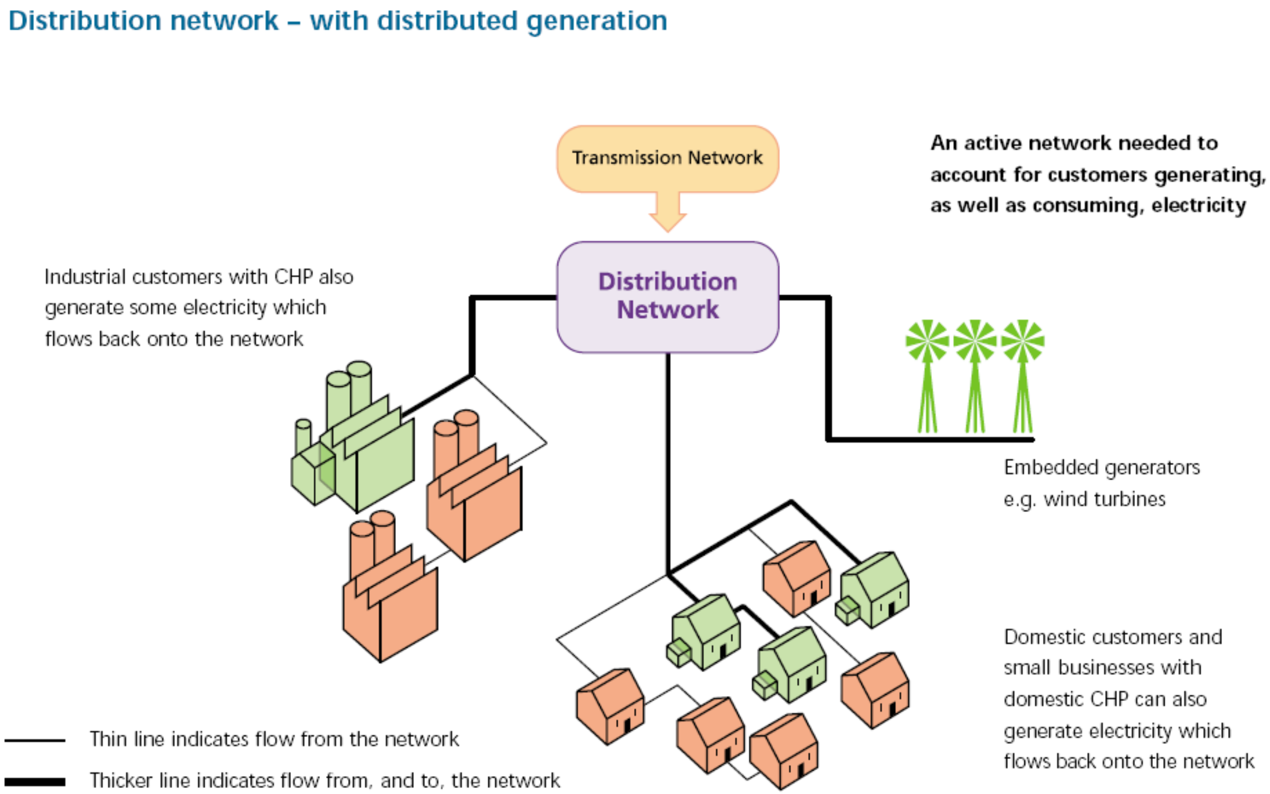
- Massive replacement and expansion of assets
- New renewables
  - Large scale (wind, distant hydro..)
  - Distributed & micro power solar, fuel cells, stirling engines
- New nuclear
- Strategic transmission
- Smart intelligent networks
- Demand-response

**Renewal of our infrastructure will cost billions…**

# System With Distributed Generation

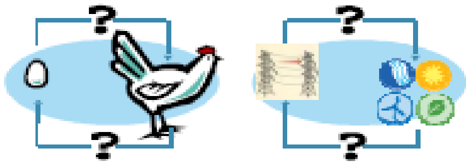


# Paradigm shift: power flows both ways




 Source: Ofgem 2003

# New Challenges to T&D Planning

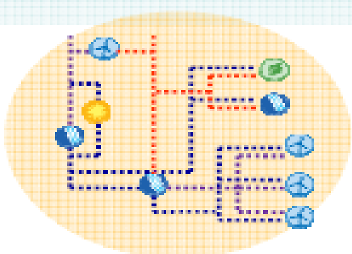


"Chicken and the egg"

Can't develop generation unless there is transmission/distribution;
but can't build transmission/distribution unless there is firm commitments from generators

"One step behind"

Lead time:
Generation 2-5 years
Transmission 5-7 years
Distribution 2-3 years



"every type, everywhere"

Renewable generation can be small or large, and generally distributed
Transmission comes in fixed size and to specific locations
Distribution, somewhat more flexible

OPA Ontario Power Authority



University of Waterloo

# DG Technologies 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

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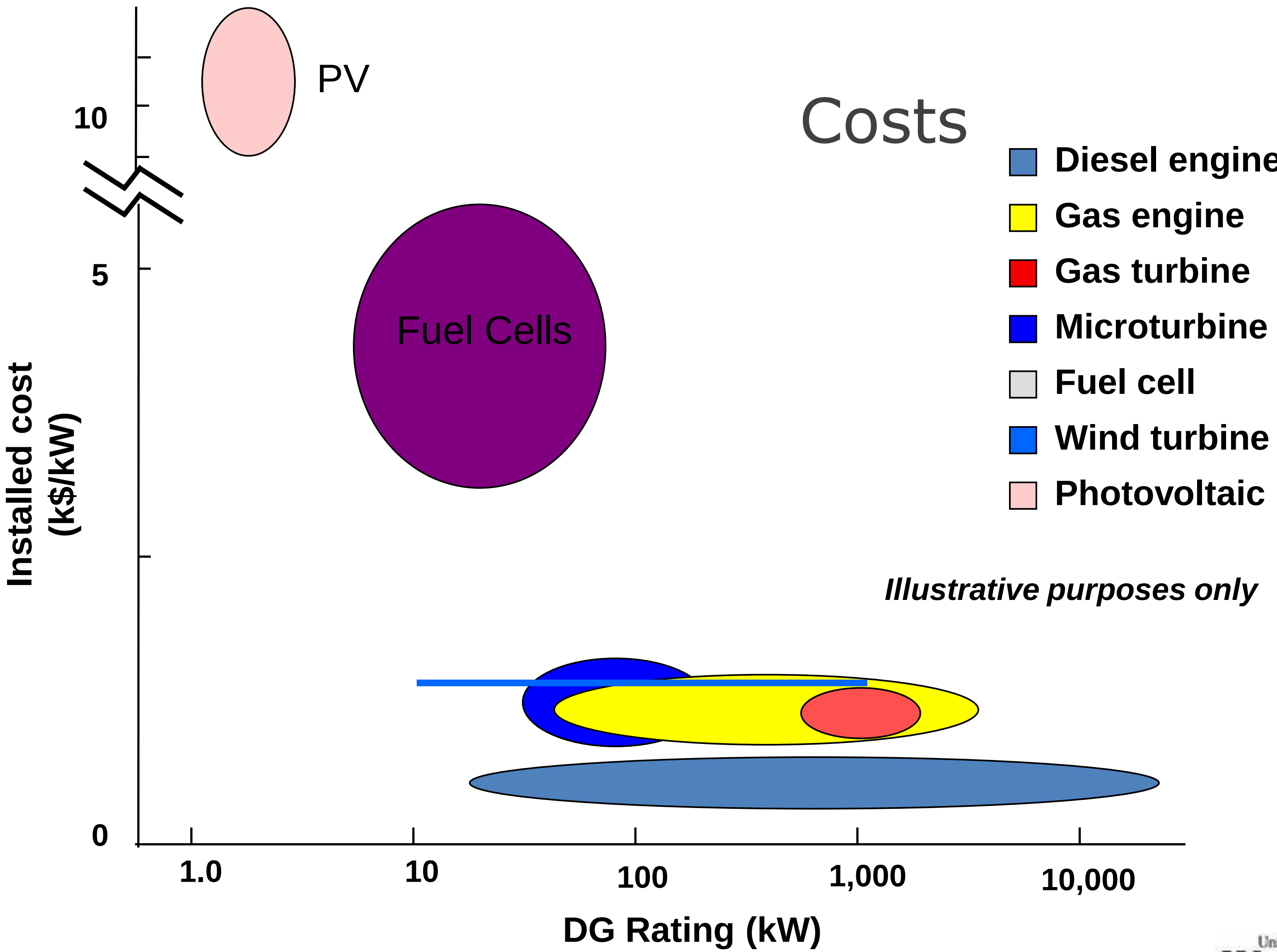
# Distributed Generation Resources: Cautions

- Performance has not equaled promise
- Fuel cells, micro turbines, solar photovoltaics
  - Still too expensive
- Fundamental business case?
  - Availability of "cheap" fossil based energy either as back-up or primary use
- Transmission and Distribution
  - Capital deferral, utilization, congestion (some potential but not demonstrated)
  - Integration with distribution system required and can be costly

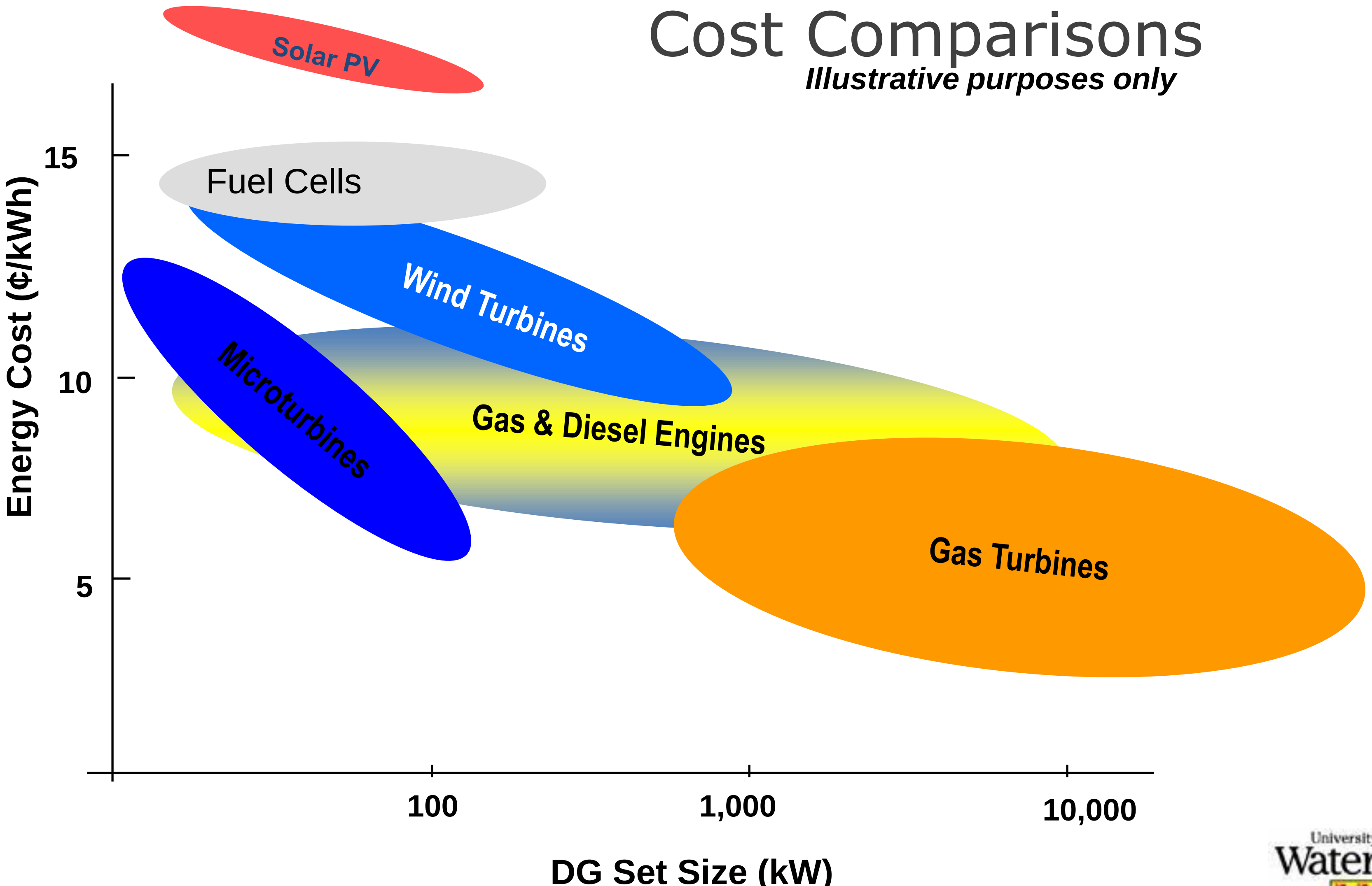
# Costs




Source: OPA: IPSP DP#4, 2007

# Cost Comparisons

***Illustrative purposes only***




Source: OPA: IPSP DP#4, 2007

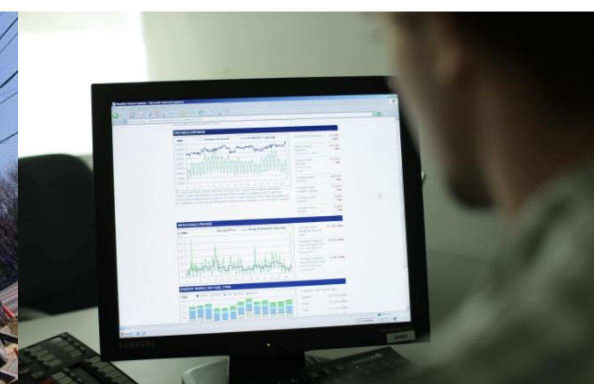
# Innovation to spur economic Development

- Why the smart grid and whereto?
  - Why not simply re-build at minimum cost?
- What are the benefits?
- Why innovation is lacking?
- What role can innovation play to
  – Reduce cost,
  – Improve reliability of service
  – Improve environmental performance
  – Enhance Ontario's economic performance?

# 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





# Forum Members

- Paul Murphy, IESO President and CEO
- Michael Angemeer, President and CEO, Veridian Corporation
- David Collie, President and CEO, Burlington Hydro
- Norm Fraser, COO, Hydro Ottawa
- Anthony Haines, President, Toronto Hydro Electric System
- David McFadden, Chair, Ontario Centres of Excellence
- Keith Major, SVP - Property Management, Bentall LP
- Jatin Nathwani, Professor/Executive Director, Waterloo Institute of Sustainable Energy, University of Waterloo
- Paul Shervill, VP – Conservation and Sector Development, OPA
- Wayne Smith, VP – Grid Operations, HydroOne

# Why Smart Grids?




# What is a Smart Grid?

- Smart grids comprise sensors, monitors and information technology – bringing together all elements of the electricity system
- They include distributed generation, accommodate electric vehicles and provide greater consumer choice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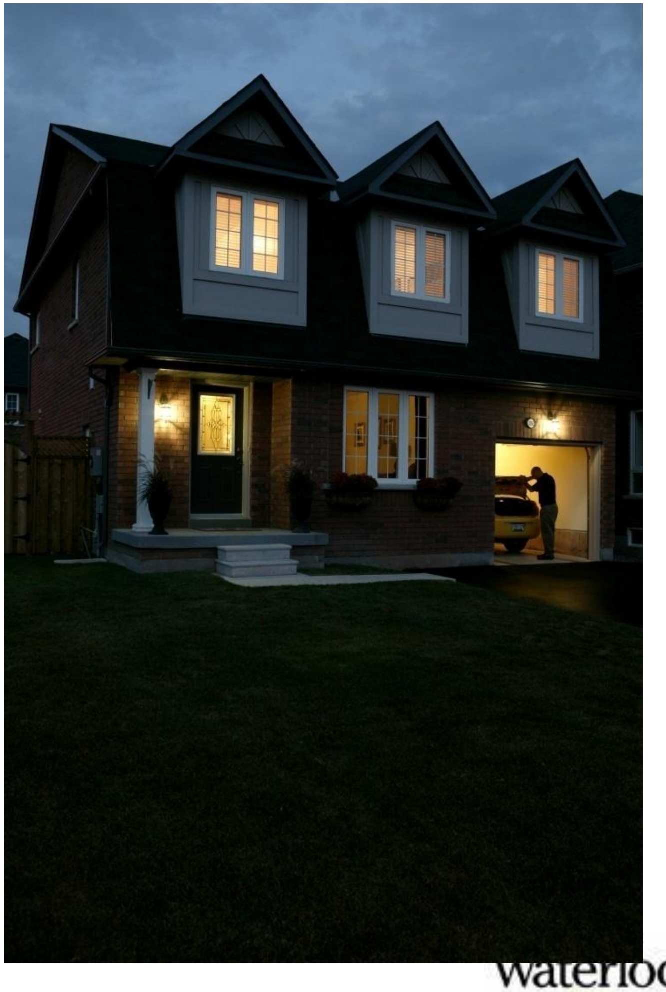
# The “not so smart grid”

# 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



# 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

# Ontario Reality: Need for Innovation

- **Large infrastructure investment**
  - Generation
  - Transmission
  - Distribution
- **Fundamental culture change**
  - Conservation
  - Environmental Stewardship
  - Clean air and water
  - Climate change
- **Aging workforce**
- **Governance and Policies**
  - Green Energy Act
  - " Hybrid market structure"
  - Strengthening investor confidence

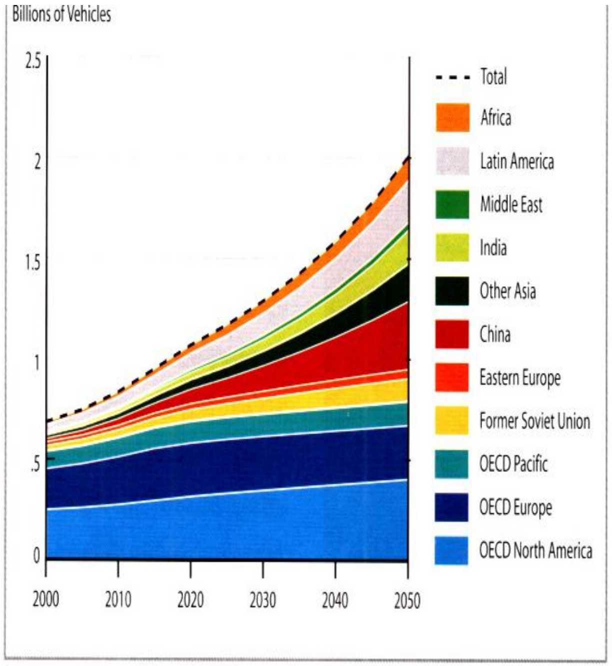
# The GEA Sets the Framework for a Smart Grid…

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<br>• Time-of-use rates<br>• In Home Displays<br>• 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<br>• More distributed generation, used more efficiently<br>(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<br>• Storage opportunities<br>• Keeping room for innovative technologies | More Innovation |

# Need to change the lens through which we see the power sector

1. More positive frame
2. Electricity as driver of change
3. Boost economic development
4. Act as the "cleaning agent" for the transport sector by using electrons to displace gasoline
5. Promote the long view




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.

**Don't step back in technology When we move forward to Energy Sustainability**

These technologies are **not** sustainable with today's population!!

**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!!!


Solar charging "Trinity" at GM proving grounds June 2007

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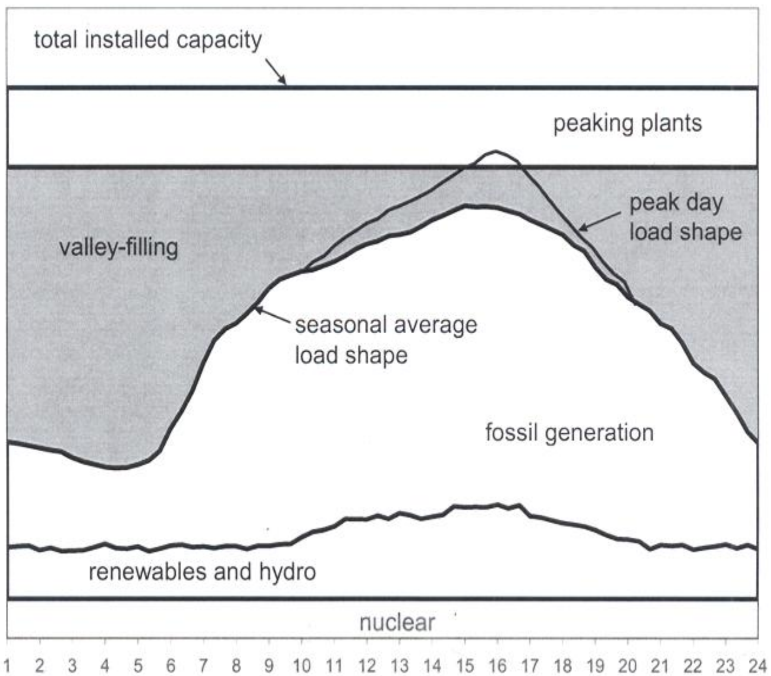
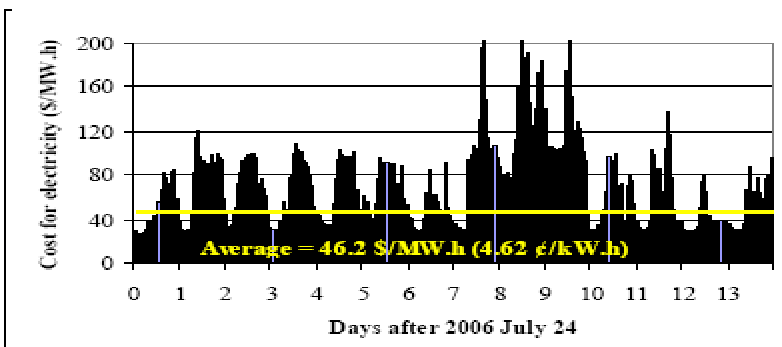
# Low cost electricity to displace gasoline
# "green electrons as substitutes for carbon"




- 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)



2 kW EV Charging Station

10 kW EV Charging Station

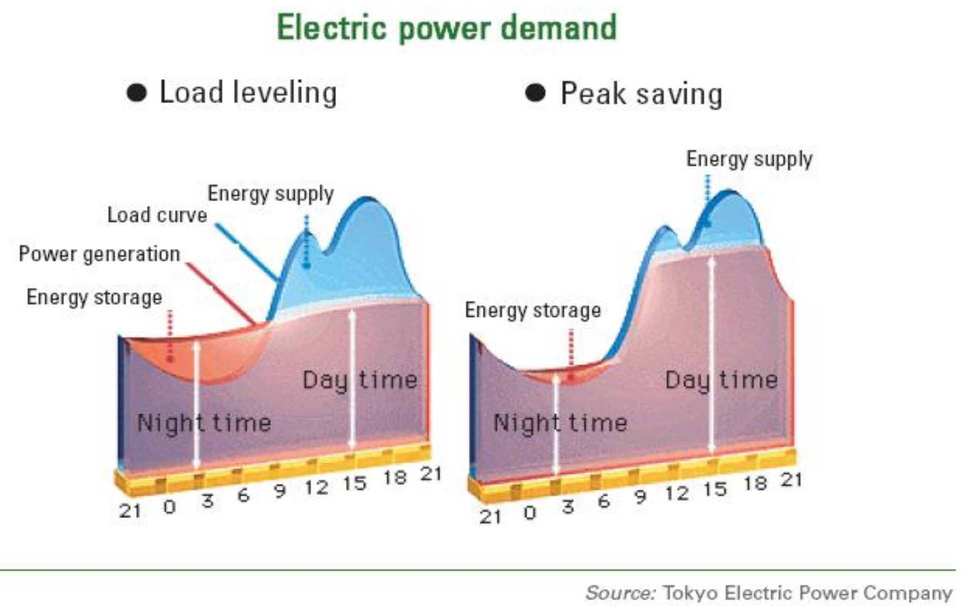
30 kW EV Charging Shade Structure

300 kW EV Charging

Source: steve@renewables.com

# Distributed Energy Resources- Energy Storage

- Electricity storage: Key requirement for a grid with large DG and renewables




- Convergence of grid and transportation infrastructures?

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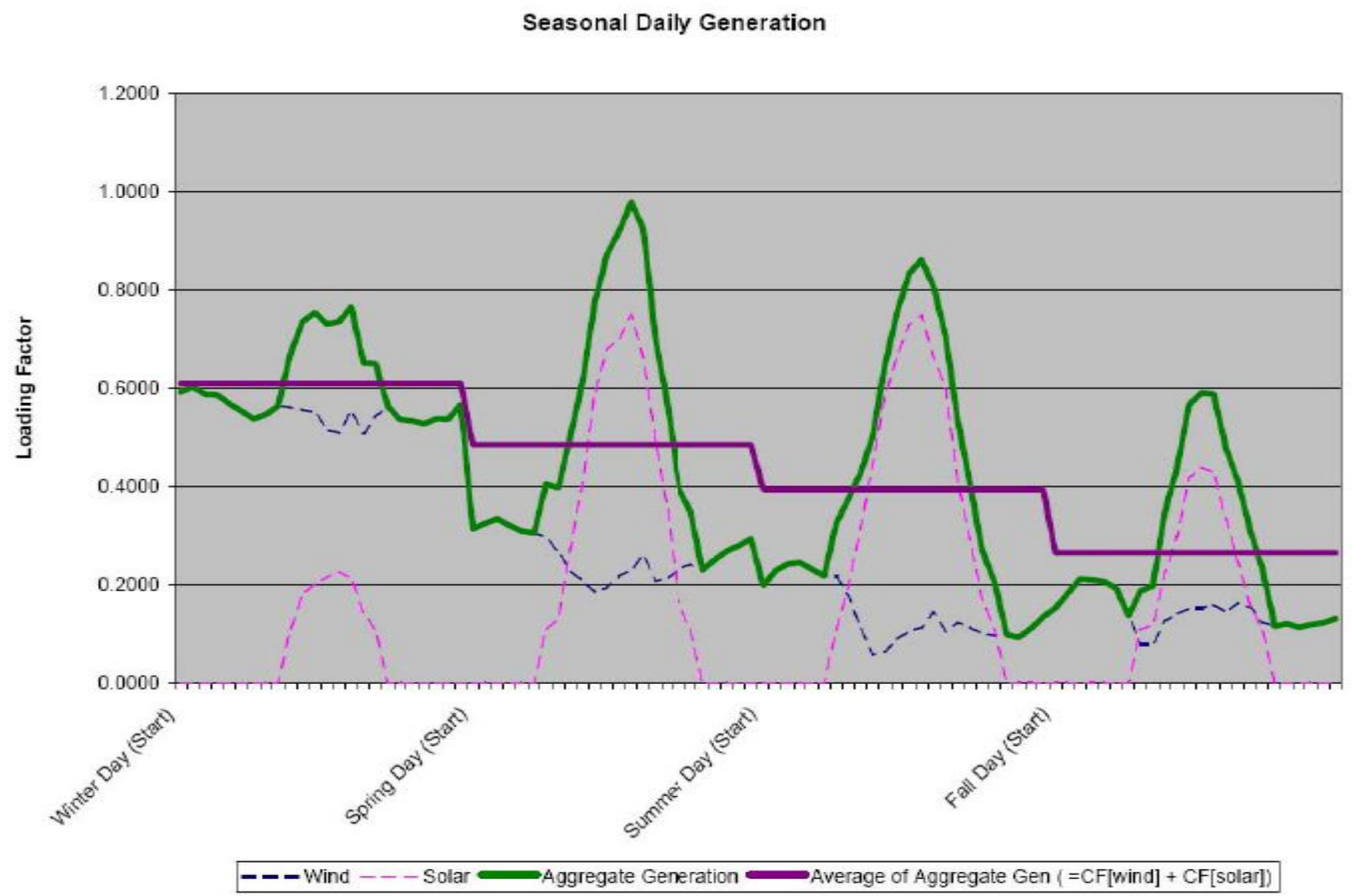
# Benefits of Diversity and Distributed Resources




 Source: R. Seethapathy, Hydro One Presentation to the Ont Smart Grid Forum

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# SUSTAINABLE ENERGY:
## Policies, Programs, Directions

- Social marketing
- Sustainable building
- Demand management
- Conservation behaviour

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

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


- $CO_2$ capture, storage & mitigation
- Clean diesel engines
- Clean coal technology
- Nuclear power plant reliability

- Sustainable energy policy and 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 , Civil Society Engagement**

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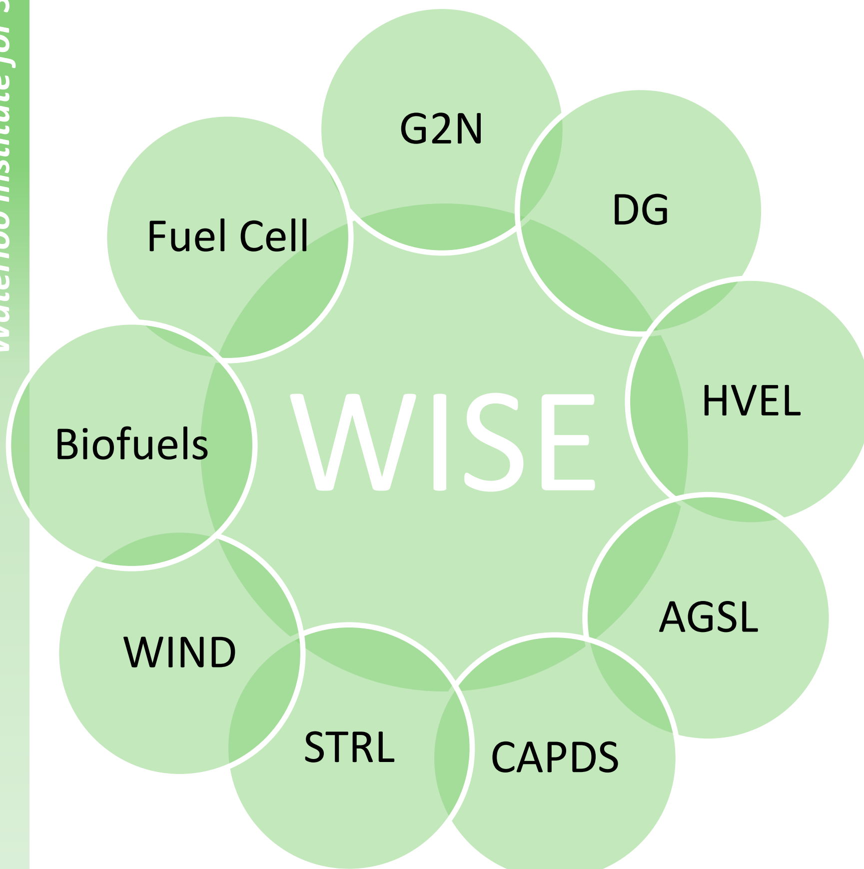
# The Waterloo Institute for Sustainable Energy (WISE)




## G2N Giga-to-Nano Lab

- Andrei Sazonov, Electrical & Computer Engineering

## DG Distribution Generation Lab

- Ehab El-Sadaany, Electrical & Computer Engineering

## 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 Lab

- David Johnson, Mechanical & Mechatronics

## Biofuel/Biomass Lab

- Ray Legge, Biometric Engineering & Environmental Engineering

## Fuel Cell Lab

- Michael Fowler, Chemical Engineering

# Select Highlights

## 3 Signature Projects

***Decreasing Diesel Dependency in Remote Northern Communities***

- Off-grid hybrid power system provides a lower-cost, environmentally friendly solution for remote communities.

***Energy Consumption Management System Gives Consumers Control***

- A smart web-based tool gives consumers control to change the way they use energy, and move to on-site alternatives like solar and wind energy.

***Connecting Solar Farms to the Grid***

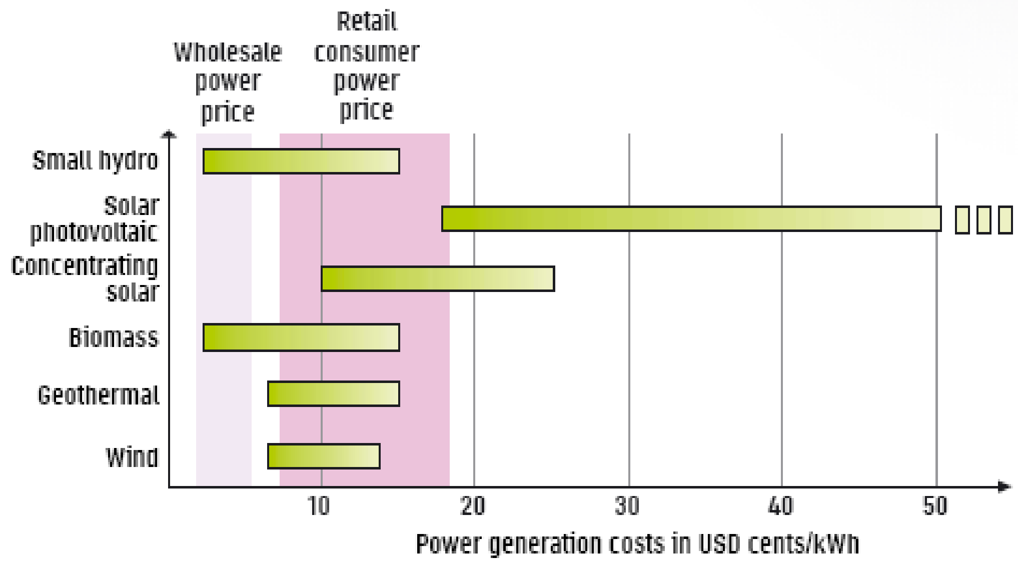
- UW and U Western are developing comprehensive solutions to help grid operators incorporate large-scale solar farms to their networks.

- 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

# Affordable Solar

**Mission is a formidable challenge to get**

- **Below grid parity**
- **Affordable for the masses**
- **Nano-based > 50% efficiency**
- **Obviate expensive grid infrastructure**



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# Technology Innovations

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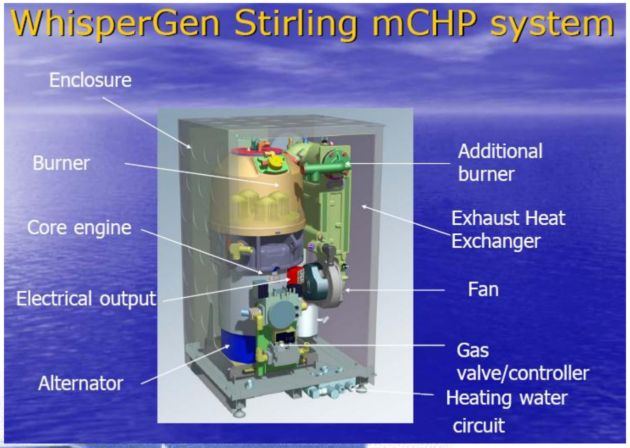


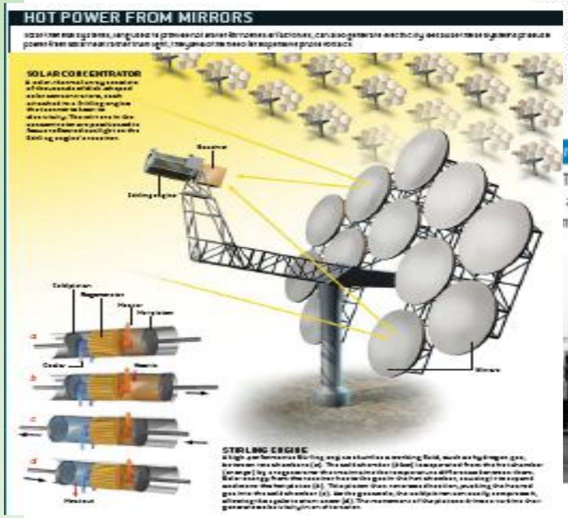


re 5: Transportability of 5.2-MW turbines to SRP substations

Turbines's 5.2-MW turbines and balance-of-plant equipment will be transportable by allowing Salt River Project to move the units to areas with the greatest distribution n need.

Source: David Gauntlett [25]

# Guideposts that may shape future directions

1. Energy flows through the global economy are massive: huge inertia
2. Scale and complexity of change suggests transition to a low GHG economy will take a long time
3. Growth, development, energy demand and environmental performance are intricately linked
4. Historical trends away from consumption of primary fuels directly to electricity will continue
5. The power sector will be characterized by a low carbon intensity
6. The electricity sector as the "cleaning agent" of the transport sector is an idea that is only beginning to emerge.
7. A balanced mix: renewables, nuclear, efficiency gains, conservation and clean(er) fossil resources would allow for sustainable prosperity and good environmental performance.

Waterloo Institute for Sustainable Energy

# The Waterloo Institute for Sustainable Energy (WISE)

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cell: 416 735 6262

Waterloo Institute for Sustainable Energy
519 888 4618
www.wise.uwaterloo.ca

# Background Material

# Nuclear Power in Society: Finding the Balance

## Cost

- What level of confidence do we have that nuclear can meet the test of affordability and provide true value to society?
- What are the costs of energy from nuclear fission?
- How do they compare with other low carbon energy sources?
- What lessons from the past?
- Are there any specific commercial arrangements or policy fixes required for the next generation reactors to deliver lower cost energy?
- Are resources of uranium (or fissionable material) adequate at reasonable cost to be considered sustainable for a major role in the global energy system?

# Nuclear Power in Society: Finding the Balance

## Safety

- Is the existing technology sufficiently safe?
- Are next generation reactors a pre-requiste for an expanded role in the future?
- What confidence can we gain from experience as it relates to design and safe operation to date?
- Is the risk of exposures to ionizing radiation from the fuel cycle low enough?
- Is the regulatory framework, both national and international, sufficiently robust to provide societal confidence in a continuing role for nuclear or even an expanded role?
- What is the best strategy for aligning safety goals with social acceptance?

# Nuclear Power in Society: Finding the Balance



## Waste

- **Can the nuclear waste be safely isolated given the state of existing technology?**
- **What confidence do we have in our present plans for the long term management of existing nuclear waste?**
- **What are the critical considerations for broader social acceptance?**

## Social, environmental, political,

- **Can nuclear be considered a sustainable solution without a social consensus on its role?**
- **What role or recognition for nuclear in any carbon "cap and trade" system?**
- **International trade: What are the risks of proliferation, how can they be mitigated and will there be a need for an updated NPT?**
- **What specific policy initiatives would be required to enable timely decisions on a commercial basis?**

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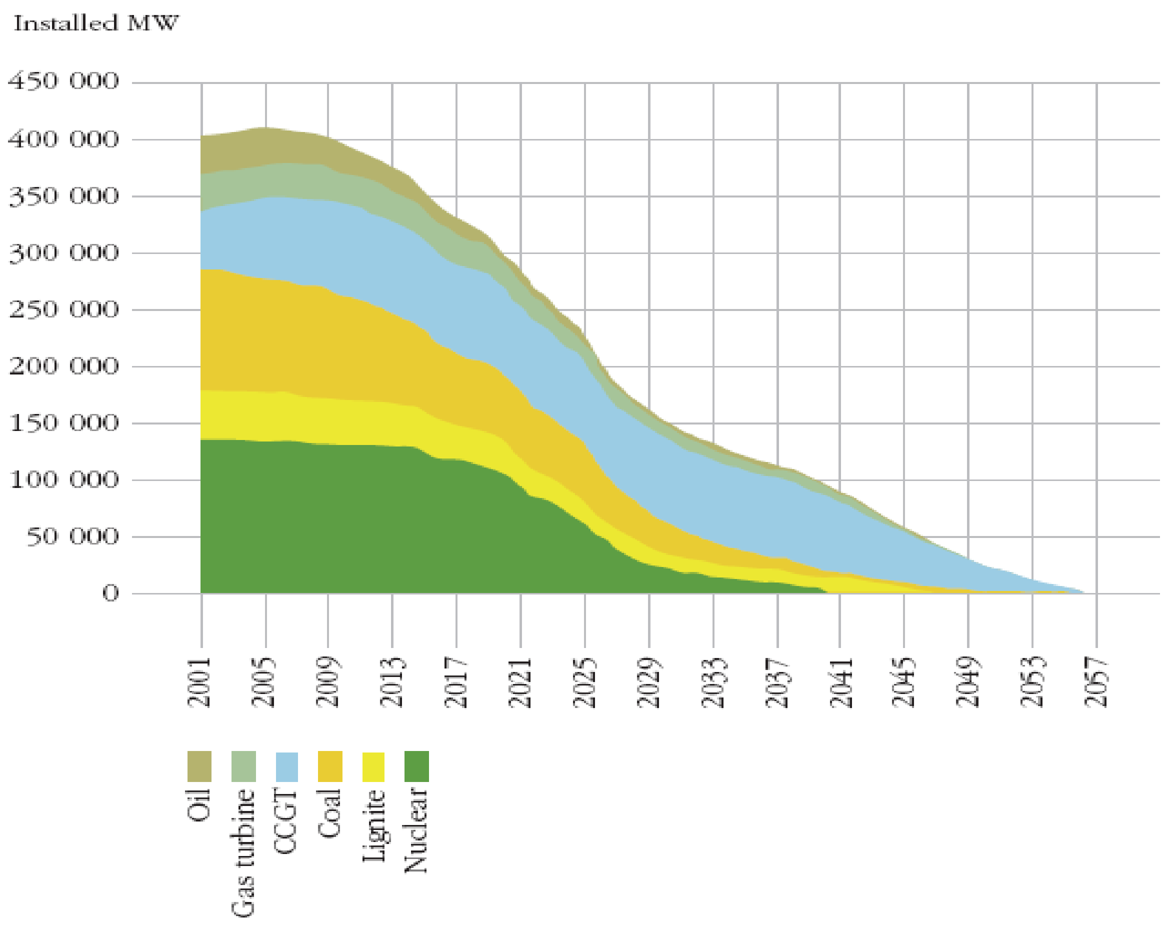
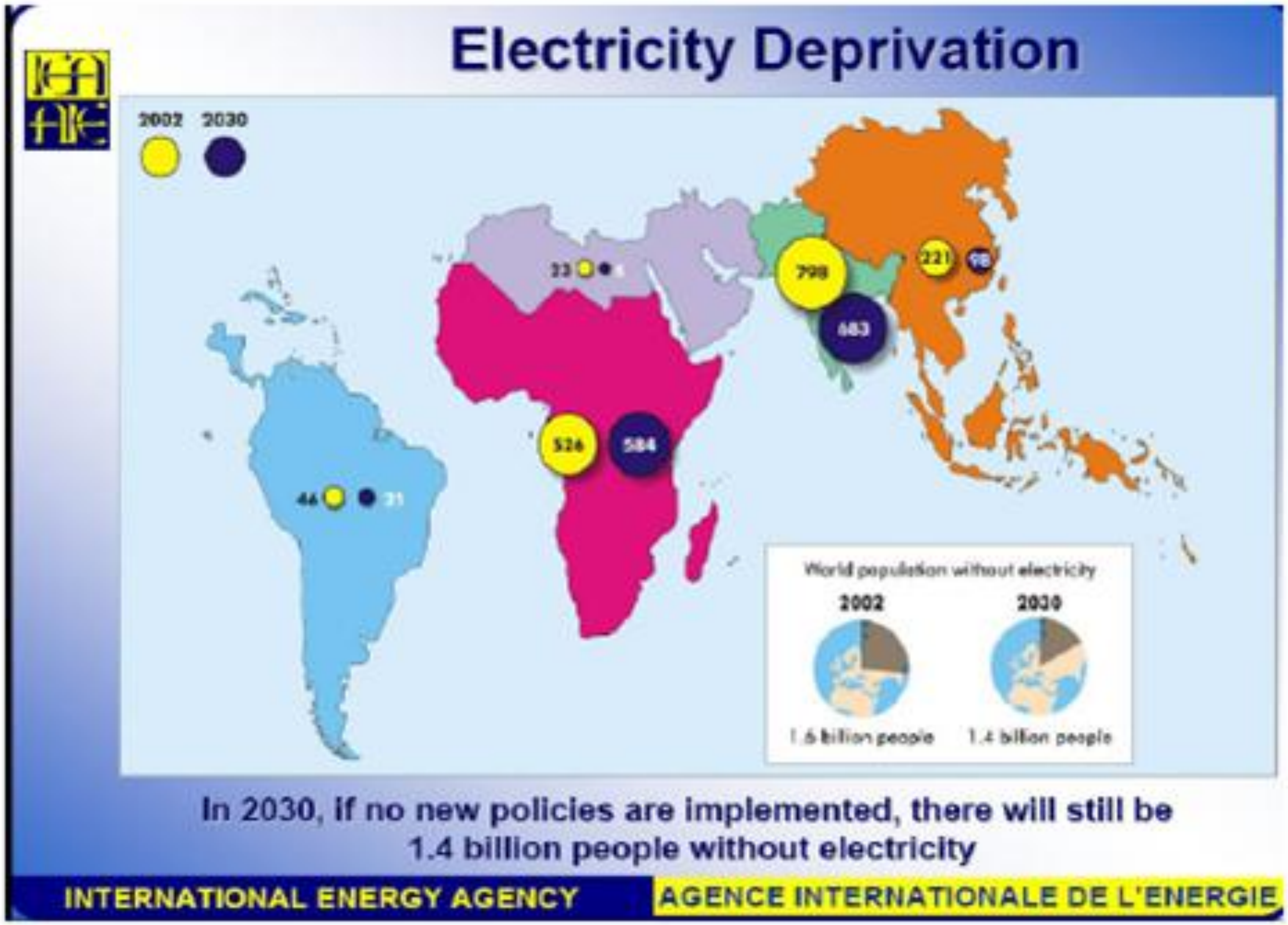
# Decline in installed generation capacity in Europe without new additions



# Moderate steps maintains continued misery



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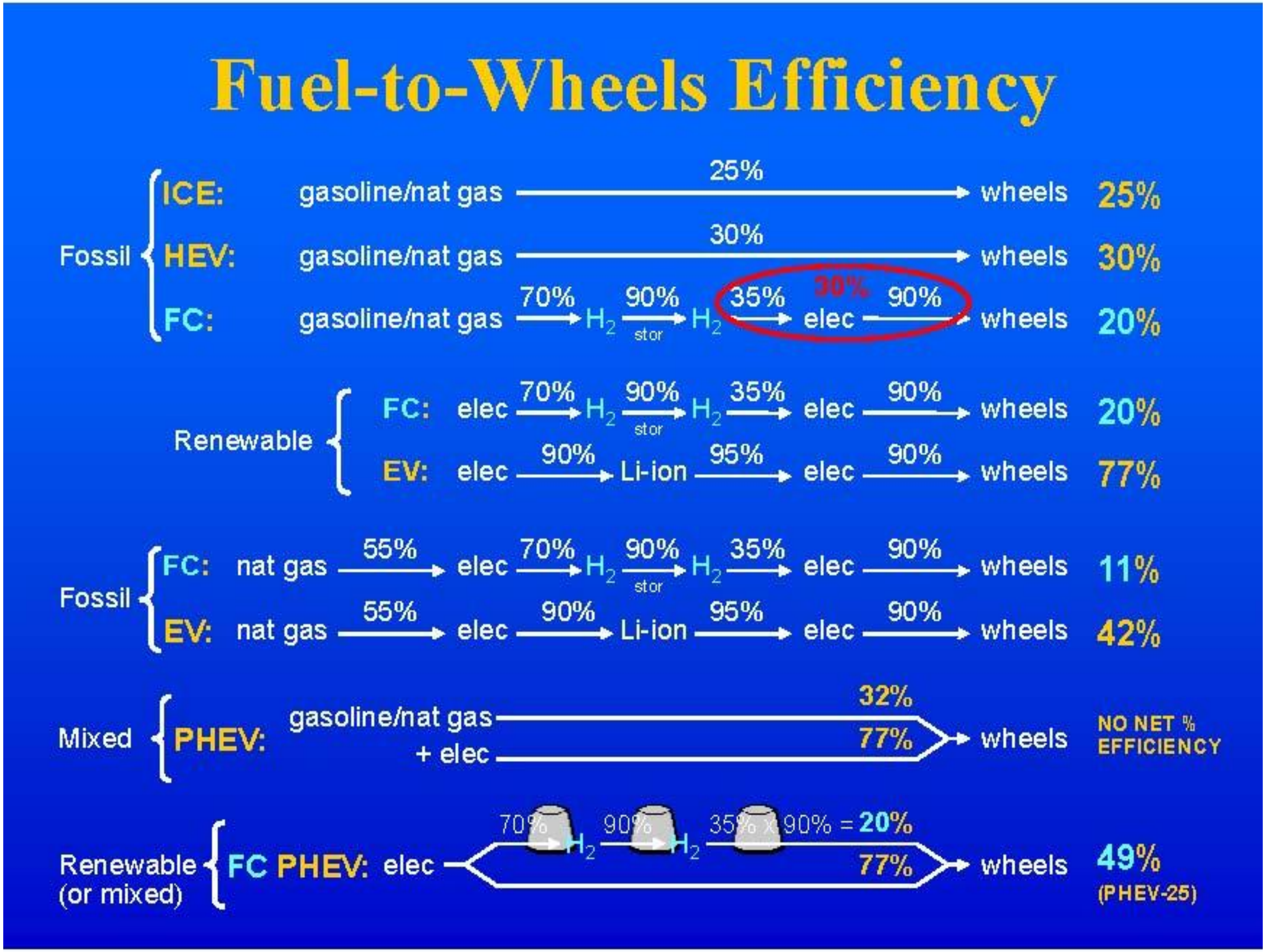


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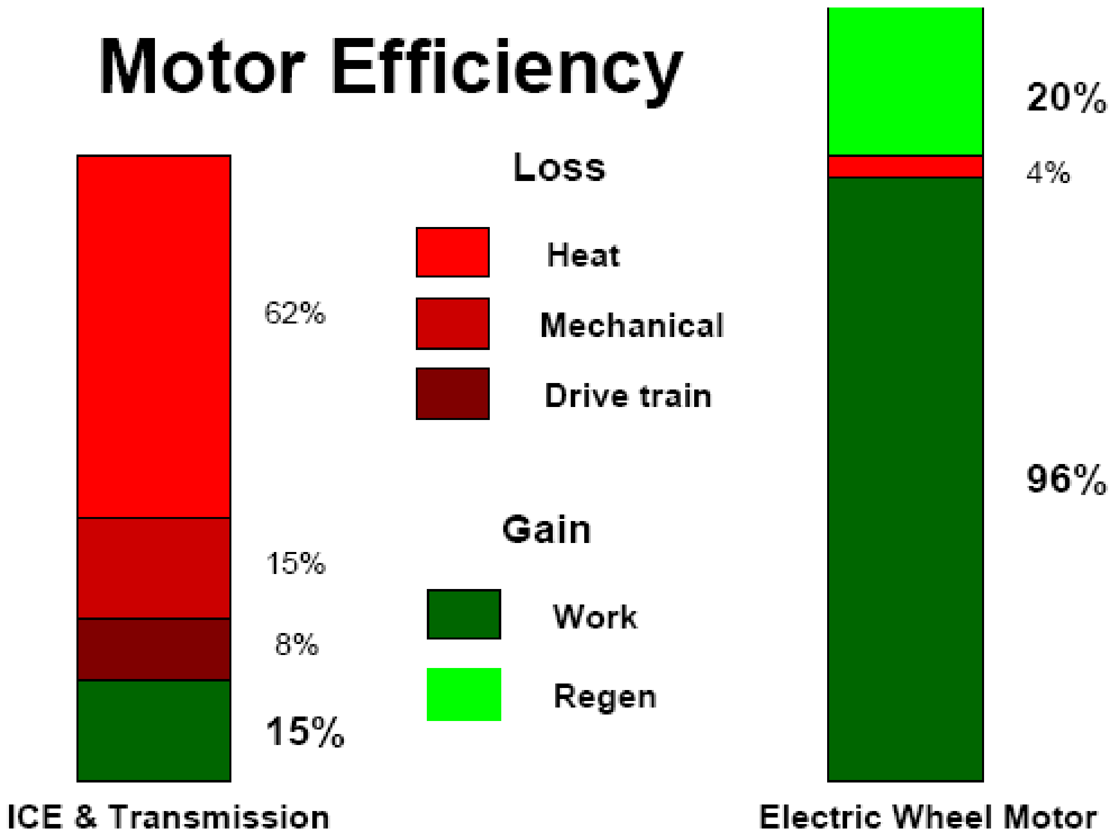

Motor Efficiency
Loss
Heat
Mechanical
Drive train
Gain
Work
Regen
62%
15%
8%
15%
ICE & Transmission
20%
4%
96%
Electric Wheel Motor

# Comparison of Electric Vehicle and Hydrogen

## Cost of Using Hydrogen

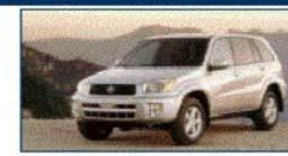
**2003 Honda FCX**

| Miles per kilogram of hydrogen | |
|---|---|
| 51 city / 48 hwy |  |
| Annual Fuel Cost: **$1515*** | |
| EPA Air Pollution Score | Best 10 (0–10 scale: 10) |
| Range | 170 miles |
| Fuel | Hydrogen |
| Fuel Cell | Polymer Electrolyte Membrane |
| Motor | 60 kW DC |
| Energy Storage Device | Ultracapacitor |

*Annual fuel cost is estimated assuming 15000 miles of travel per year (55% city and 45% highway) and a fuel cost of $5.05 per kilogram of gaseous hydrogen.

**2003 Toyota RAV4 EV**

**Electric Vehicle**



Possible Tax Incentives

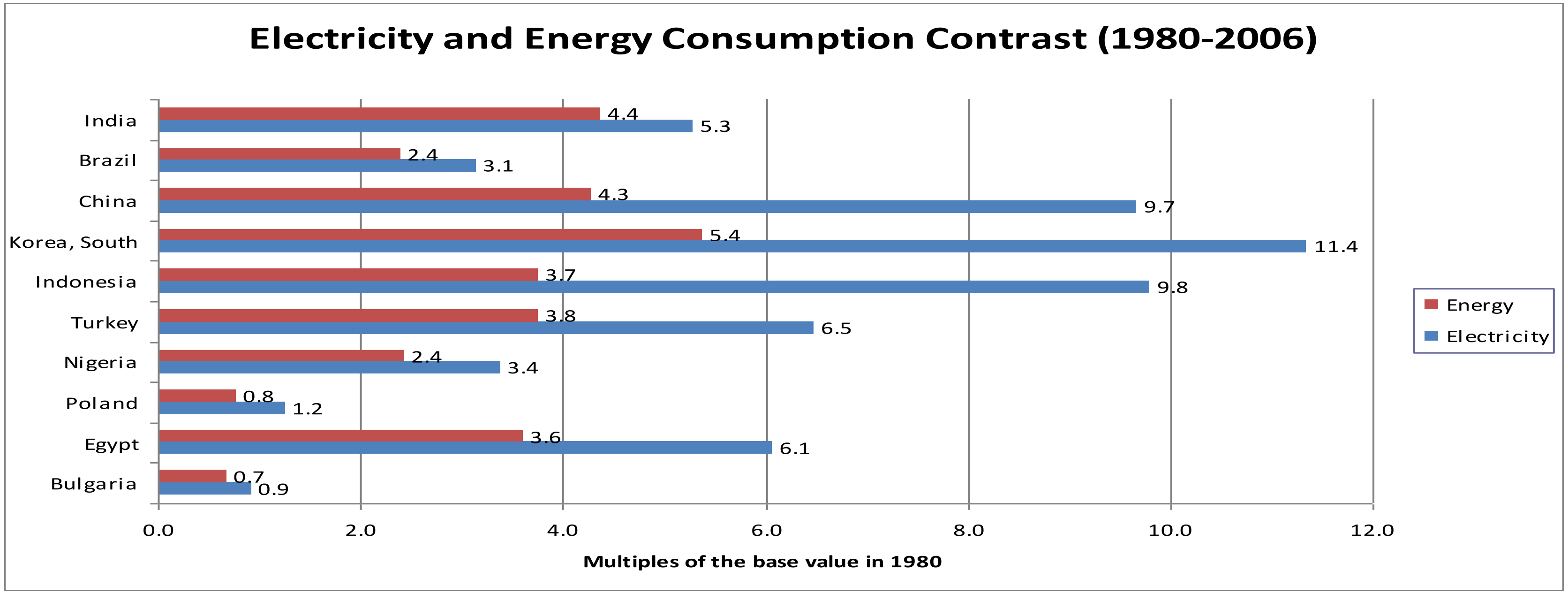
Use your Gas Prices    Switch to Metric units

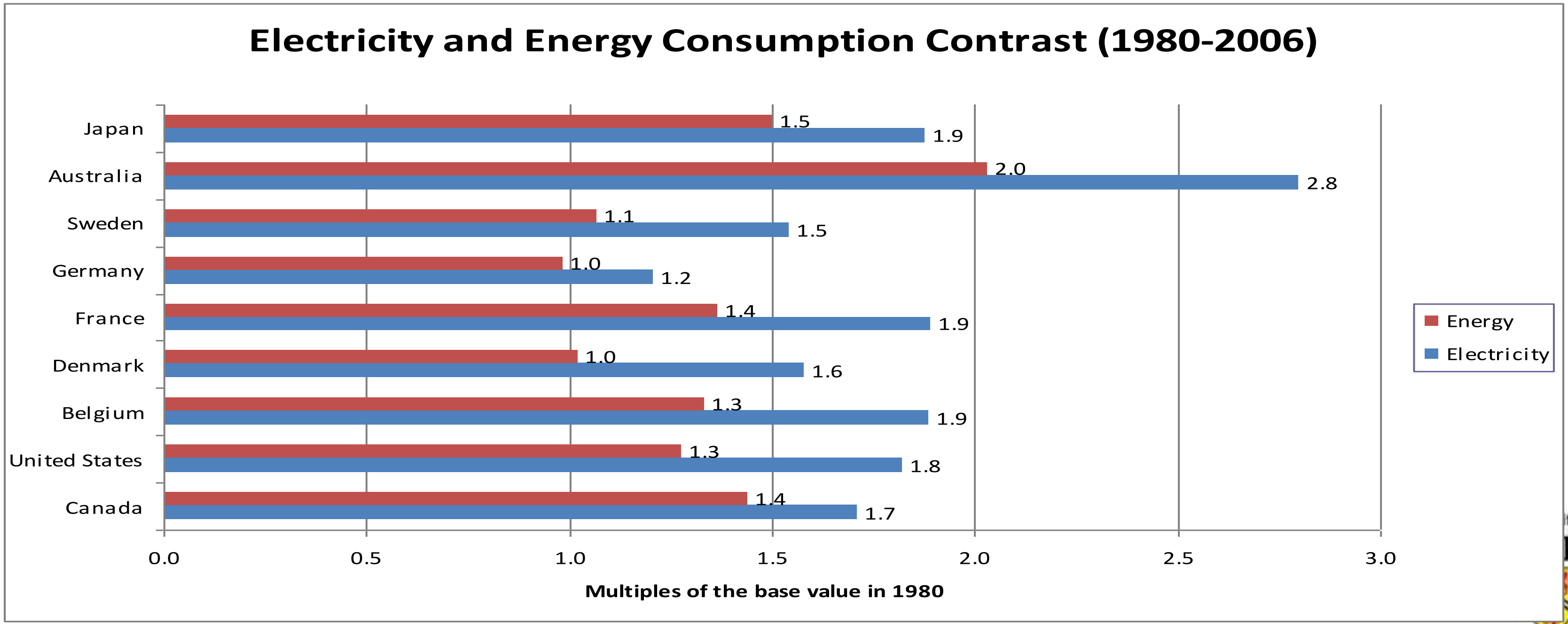
| Fuel Economy | |
|---|---|
| Fuel Type | Electricity |
| Energy Consumption(city) (kW-hrs/100 miles) | 27 |
| Energy Consumption(hwy) (kW-hrs/100 miles) | 34 |
| MPG (city) | 125 |
| MPG (highway) | 100 |
| MPG (combined) | 112 |
| Annual Fuel Cost @ 8¢/kWh | $362 |

| | |
|---|---|
| 2003 Honda Civic Gasoline Cost | $684 |
| 2003 Honda Civic Gas Hybrid Cost | $484 |
| 2003 RAV4 2WD Gasoline Cost | $860 |

- Hydrogen cost is worse than its efficiency!
- Electrolysis twice as costly as natural gas!
  - $3,000 per year for hydrogen Honda FCX.

Manitoba Hydro


Electricity and Energy Consumption Contrast (1980-2006)
India 4.4 5.3
Brazil 2.4 3.1
China 4.3 9.7
Korea, South 5.4 11.4
Indonesia 3.7 9.8
Turkey 3.8 6.5
Nigeria 2.4 3.4
Poland 0.8 1.2
Egypt 3.6 6.1
Bulgaria 0.7 0.9
0.0 2.0 4.0 6.0 8.0 10.0 12.0
Multiples of the base value in 1980
Energy
Electricity


Electricity and Energy Consumption Contrast (1980-2006)
Japan 1.5 1.9
Australia 2.0 2.8
Sweden 1.1 1.5
Germany 1.0 1.2
France 1.4 1.9
Denmark 1.0 1.6
Belgium 1.3 1.9
United States 1.3 1.8
Canada 1.4 1.7
0.0 0.5 1.0 1.5 2.0 2.5 3.0
Multiples of the base value in 1980
Energy
Electricity