Decarbonizing Canada’s Transport Sector:

Will the Car Owner Become the Grid Operator?

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Tesla Campus Event
University of Waterloo,
E6 2024
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I. Global Energy Transition Challenge

II. Sustainable Electric Mobility: A Promising Solution

III. Cars as ‘Virtual Power Plants’: Even More Revolutionary?

THE GLOBE AND MAIL
CANADA'S NATIONAL NEWSPAPER

The Globe and Mail, Friday, Dec. 14, 2007 G

The Globe and Mail, Monday, June 30, 2008

The Globe and Mail, Monday, Aug. 24, 2009

SUSTAINABLE MOBILITY

The case for hybrids: a long view

JATIN NATHWANI
Professor and Ontario Research Chair in Public Policy for Sustainable Energy Management, University of Waterloo

The negative response to Ontario's initiative to promote plug-in hybrid electric vehicles – the government will offer buyers an incentive of up to $10,000, beginning next year – is largely misplaced and unwarranted, a case of a hammer looking for a nail.

Coming so soon after a major bailout of General Motors, the policy has been seen by many as preferential to GM, whose Chevrolet Volt will be the first mass-produced electric vehicle. Many recession-weary Ontarians see it as subsidizing the purchases of a few affluent consumers. But while these reactions are understandable, they take a narrow view. The initiative's long-term environmental and economic benefits offer a compelling rationale.

Electric vehicles offer one of the most promising opportunities for reducing carbon intensity in the province's transport and electricity sectors. If well integrated with the power system, the vehicles can store electricity produced by intermittent sources of generation, such as wind and solar, removing one of the more intractable impediments to renewable energy. Eventually, Ontarians should be able to charge their batteries cheaply at night, when demand is low, then sell any unused electricity back to the grid during peak hours. This will be profitable for car owners and will save the utilities money by effectively reducing peak demand.

Canadians tend to understand that electric cars will benefit the environment, but they may fail to realize how much money they could save. Charged at night, electric vehicles are cheaper to run by at least a factor of four, compared to current gasoline prices. Adding the cost of "externalities" – damage caused by air pollution and greenhouse gas emissions – then the case for plug-in hybrids is compelling. If Ontario is able to phase out coal power around 2014, the case becomes stronger still.

Transport statistics indicate that a vehicle with limited electric range is more than adequate for most people, most of the time. While urban and suburban commuters would see the most benefit, a rural setting does not render a plug-in hybrid useless – it simply requires that the gas engine complete the journey. The key to widespread adoption is ensuring that policy makers and auto makers not fixate on pure electric vehicles. Extended-range electric vehicles with onboard gas engines, such as the Volt, would allow most drivers to eliminate gas from their commute, and the ability to refuel with gas would provide the flexibility consumers demand from a primary vehicle.

Transport-sector oil dependence has flummoxed researchers, auto makers and policy makers for decades. Efficiency standards, the most widely used policy tool in government's regulatory kit, are better than nothing but unlikely to achieve a substantial reduction in the use of fossil fuels. Fuel-efficient cars begat more fuel-efficient cars and, consequently, more driving that has maintained upward pressure on fossil fuel consumption. The change required is a transition to a different source of power to the car's drive-train, namely electrons to displace gasoline molecules. True, electricity is a partial solution. But given the emergent low-carbon footprint of Ontario's electricity sector, it will prove the most versatile and powerful vector of change.

While the benefits of electric transportation could be enormous, and the cost savings significant, it's a long-term proposition. In the first generation, electric-car technology will be uneconomical for both auto makers and consumers. Getting to the second and third generations, where battery costs drop through innovation and economies of scale, means smart planning now.

We should take the long view and see Ontario's incentive in that light: not as subsidy, but as groundwork for a better future. The electric vehicle is a critical change in the march from fossil fuels to sustainable mobility.

Globe & Mail, Monday June 30 2008

News

ELECTRICAL POWER

A winning formula for sustainable mobility

Mix low-carbon electricity and high-calibre automotive expertise

JATIN NATHWANI
Professor and Ontario Research Chair in Public Policy for Sustainable Energy Management, University of Waterloo

ANTHONY JENKINS
THE GLOBE AND MAIL

Perhaps 30 years hence, we may reflect upon today's high oil prices as a blessing in disguise that paved the way for a reshaping of Ontario's auto sector enabled by the electric grid. The pain at the pumps for all, the anger of the auto workers at the prospect of losing their livelihoods and the relentless pressures of the global energy markets ought to focus our minds and sharpen the search for credible solutions.

We need to get beyond the overheated rhetoric and the finger-pointing to develop alternate pathways for environmentally sustainable mobility at reasonable cost.

A strategic convergence of the power and the transport sectors is a key part of the answer, achievable in the near to mid term (five to seven years). The primary limitations are a lack of clear policy focus on innovation and our collective inability to marshal resources and align strategic developments across sector interests, agencies and different levels of government. There exists an enormous potential to displace gasoline and to reduce cost to consumers by use of electricity through plug-in hybrid electric vehicles.

A conventional hybrid derives all its energy for the drive train from gasoline. The plug-in hybrid is fundamentally different. It derives most of its energy from the electricity grid and supplements any additional needs with a gasoline engine in a seamless fashion. It combines the best of both worlds – the advantages of an electric vehicle charged during "off-peak" times on the power grid and gasoline only when needed for unlimited driving range.

Given that more than half of cars are driven less than 50 kilometres a day, this flexibility offers peace of mind to the consumer and a promising path for meeting the demanding standards of reliable low-cost transportation. From a strategic perspective, electrification of the transportation sector can deliver substantial environmental benefits (low greenhouse gas emissions), lower cost to consumers and increased revenues to utilities. Reducing the dependence on oil-based transportation has the added benefit of moderating the pressures on security of long-term supply in a global marketplace driven by explosive demand from emerging economies.

The electricity infrastructure is designed to meet the highest expected "peak" demand for power. The system operates at near capacity for a few hundred hours (about 5 per cent of the time) a year. For the remainder of the time, the power system is capable of generating and delivering a substantial amount of energy needed to fuel the car batteries at "off-peak" hours.

For example, Ontario's requirements vary from day to day with a peak demand of about 26,000 MW, dropping to about half of that at night. Fuelling cars on the grid from 10 p.m. to 6 a.m. provides a lucrative opportunity to charge several million vehicles. This would also provide valuable storage capacity on the grid to help improve the overall utilization of the system and to accommodate increased penetration of intermittent renewable generation resources, such as wind power.

Southern California Edison estimates that four million vehicles could be charged without exceeding peak load. Studies show 84 per cent of cars, pickup trucks and SUVs in the United States could be supported by the existing infrastructure with a gasoline displacement potential of greater than 50 per cent of the country's oil imports. A detailed nationwide analysis of U.S. greenhouse gas emissions that takes into account emissions from the electricity sector and the plug-in hybrid vehicles, confirms significant environmental benefits – cumulative greenhouse gas reductions that range from 3.4 to 10.4 billion metric tonnes over the 2010-2050 time frame.

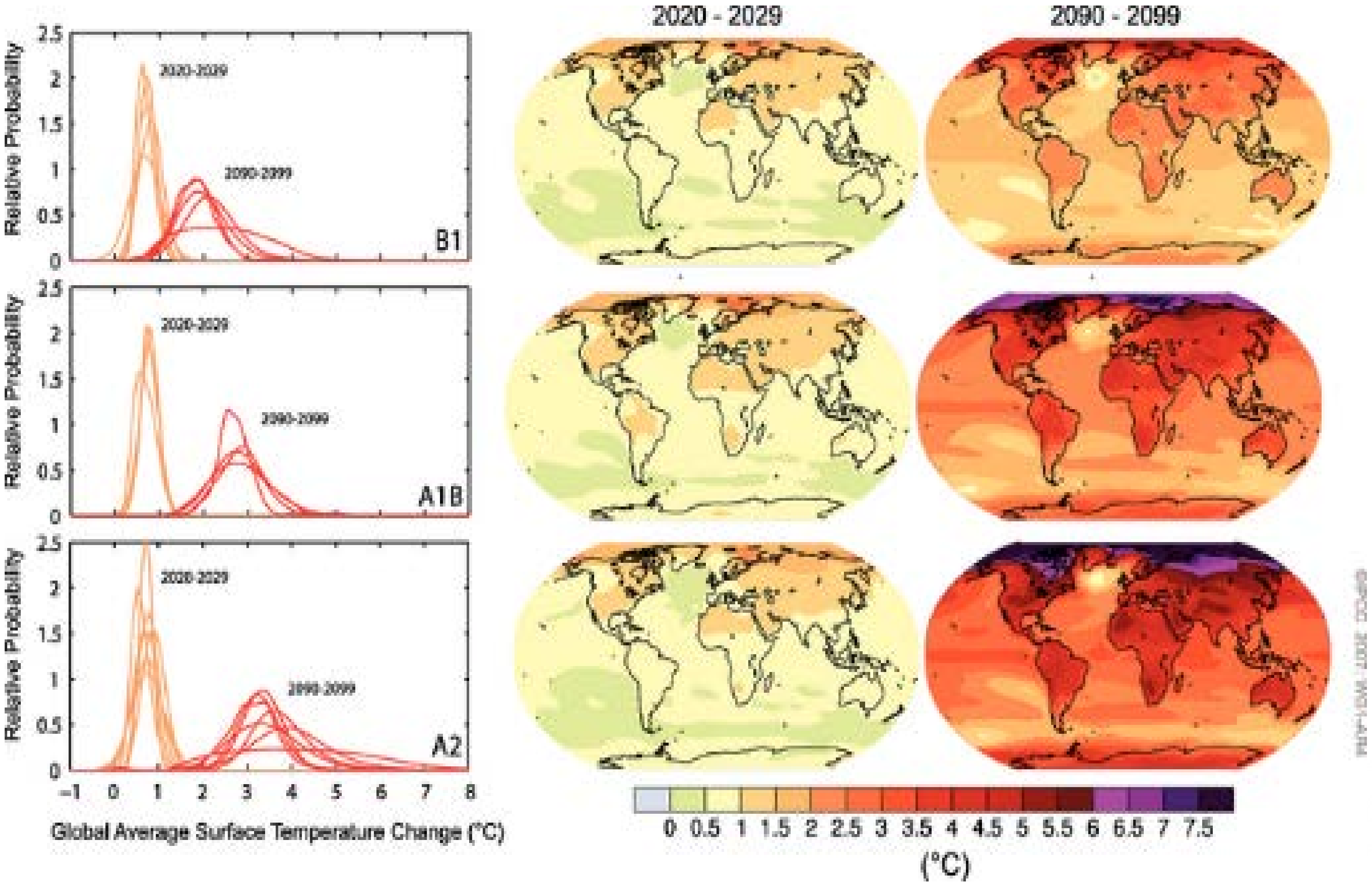
So what's in it for the consumer? A visit to the gas station perhaps once a month rather than once a week. (And the costs would be lower still if the "smart grid" can deliver price differentiated "off-peak" energy at a lower cost.) An electrically charged vehicle is cheaper to fuel by a factor of four over an equivalent conventional vehicle. It runs on about a dollar per gallon compared to four dollars per gallon at current prices. Higher initial costs, however, may be a barrier to consumers.

It's important, however, not to confine our thinking only to the auto sector. By increasing overall electricity consumption without a major requirement for upgrades to the existing electricity infrastructure, fixed costs could be spread over a larger base with benefits to consumers. The low carbon intensity of Canada's power sector can make it a powerful tool for de-carbonizing the economy and the transport sector in particular. Any significant use of plug-ins would help moderate the pressures on global oil demand and increase security of supply.

The low carbon intensity of Canada's power sector is a huge advantage that has not been recognized or leveraged to good effect. What we need is to develop an in-depth consideration of policy options and strategic alternatives for rapid implementation.

A century ago, Lord Selborne, the first lord of the Admiralty, dismissed the idea of fuelling the British navy with something other than coal. "The substitution of coal for oil is impossible," he pronounced, "because oil does not exist in this world in sufficient quantities." Winston Churchill, seven years later, saw that oil would increase speed and reduce fuelling time – strategic advantages – and committed the navy to the new fuel. Are electrons about to do the same to oil a century later?

Climate Change Is the Driving Force



THE GLOBAL ENERGY CHALLENGE

🔴

85/15

🟢

ALL NEW GROWTH MUST BE MET BY NON-CARBON SOURCES

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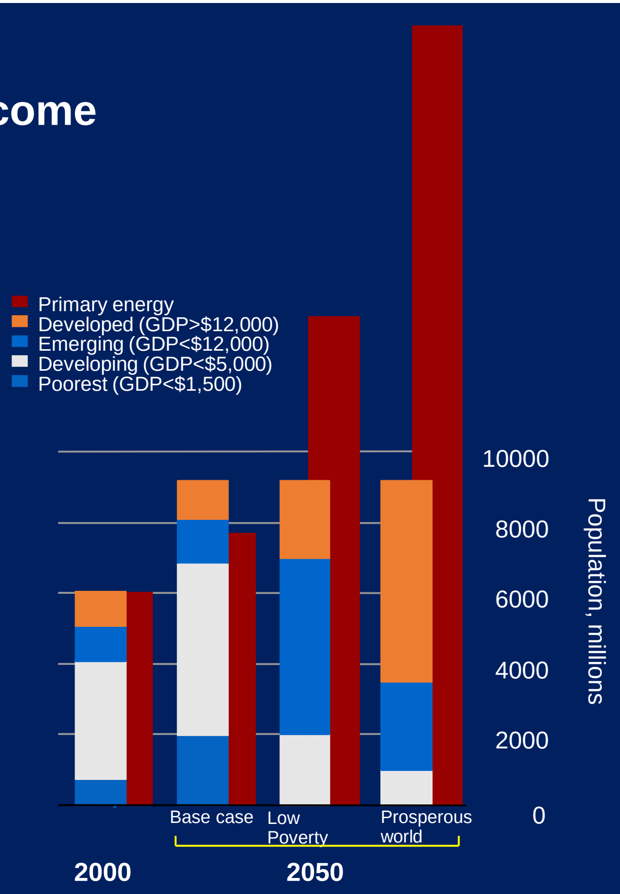
PROJECTED GROWTH IN ENERGY DEMAND

Global population divided into income groups:

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

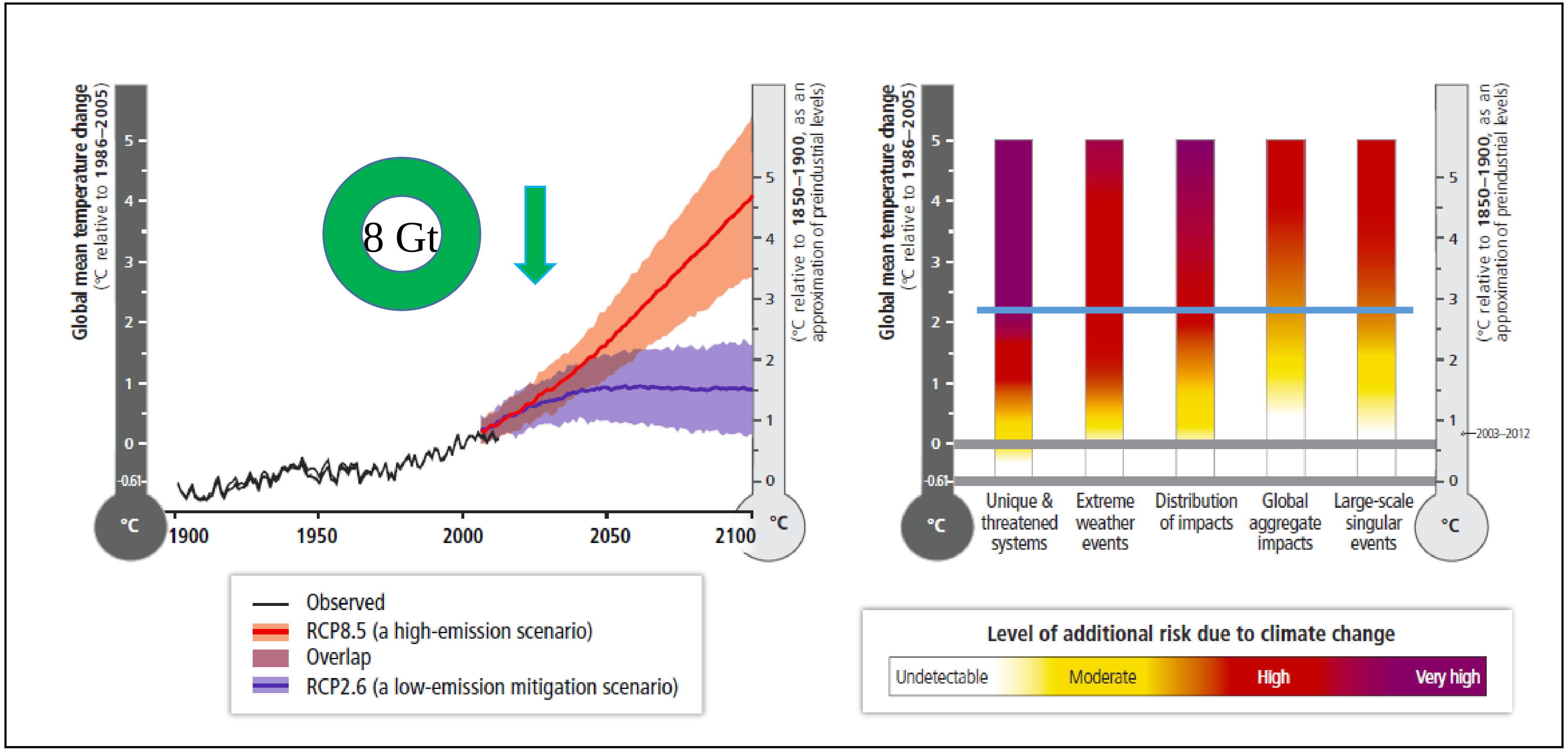
Shifting the development profile to a “low poverty” world means energy needs double by 2050

Shifting the development profile further to a “developed” world means energy needs triple by 2050

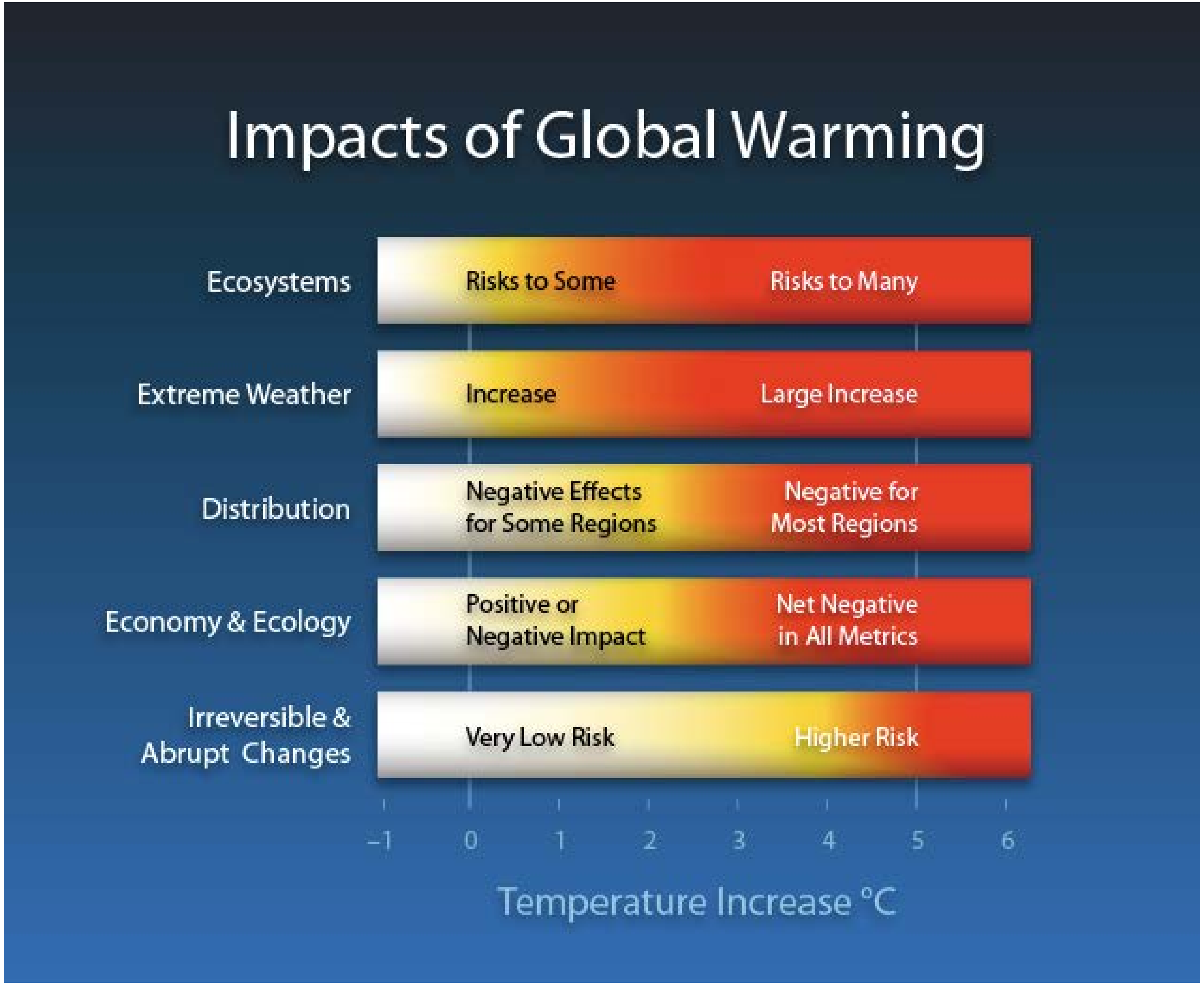


Source: WBCSD 2007 (Adaptation of IEA, 2003)

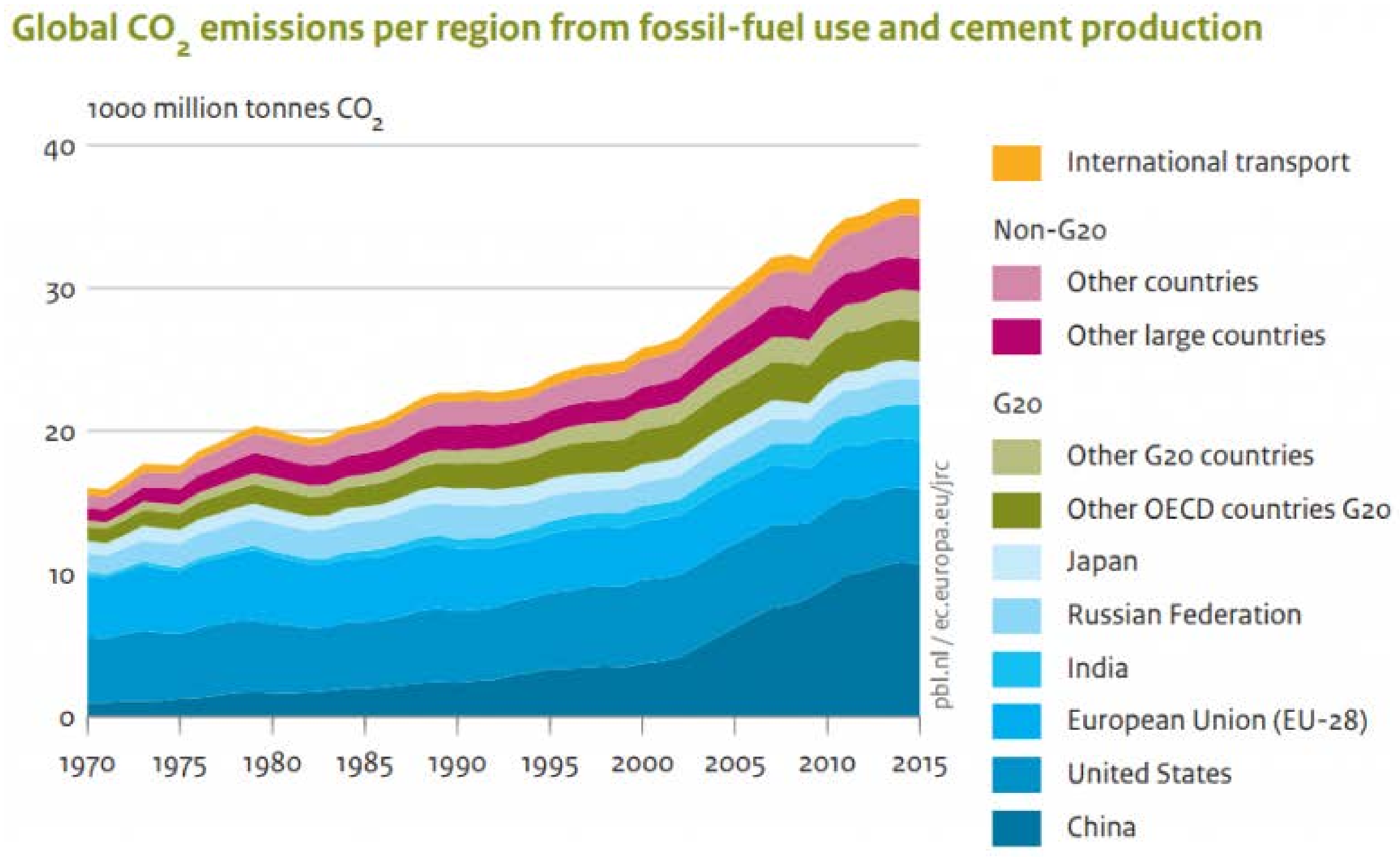
CLIMATE CHANGE & EMISSIONS REDUCTION



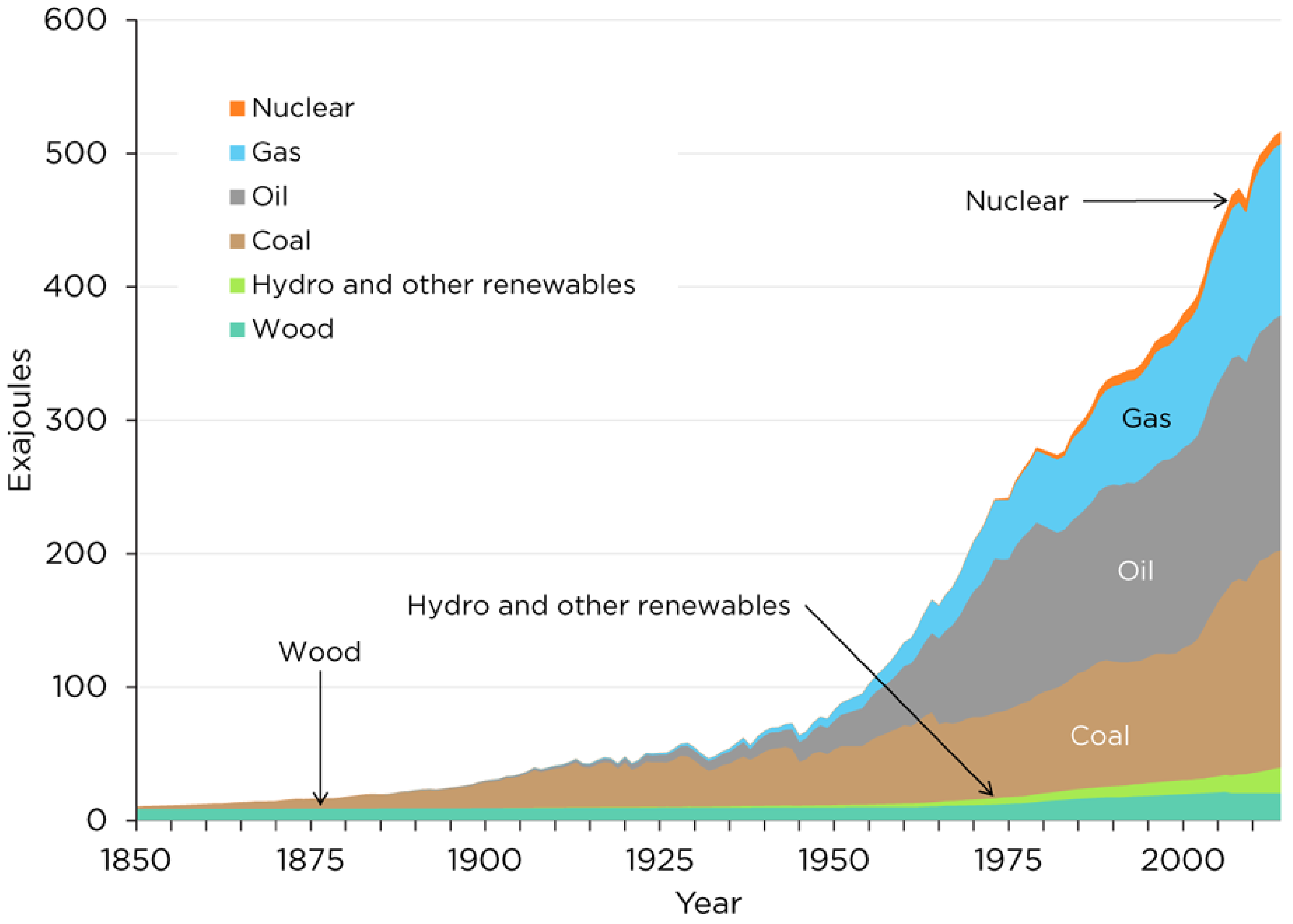
Source: IPCC Synthesis Report 2014


Impacts of Global Warming
Ecosystems
Risks to Some
Risks to Many
Extreme Weather
Increase
Large Increase
Distribution
Negative Effects for Some Regions
Negative for Most Regions
Economy & Ecology
Positive or Negative Impact
Net Negative in All Metrics
Irreversible & Abrupt Changes
Very Low Risk
Higher Risk
–1
0
1
2
3
4
5
6
Temperature Increase °C

EMISSIONS ARE STILL RISING


Global CO_2 emissions per region from fossil-fuel use and cement production

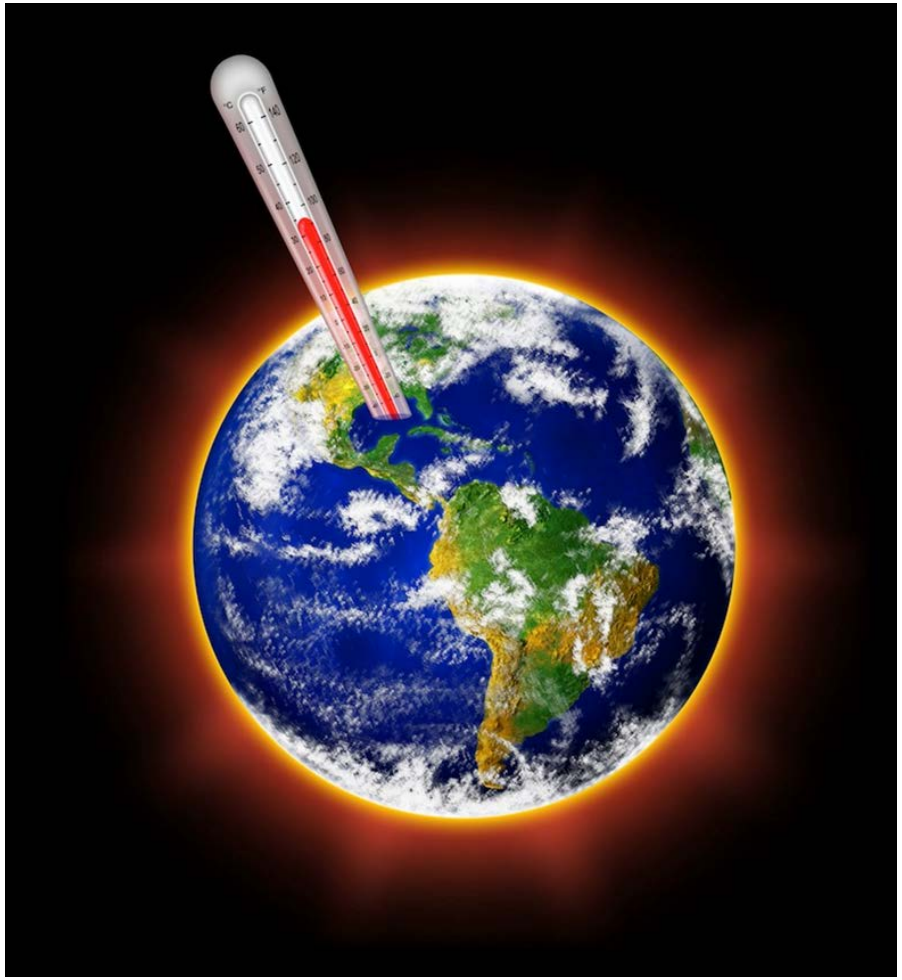
FOSSIL FUELS CONTINUE DOMINANCE



85=85

Source: Data compiled by J. David Hughes. Post-1965 data from BP, *Statistical Review of World Energy*. Pre-1965 data from Arnulf Grubler, "Technology and Global Change: Data Appendix,"(1998).

Climate Change Threat Will Remain a Driving Force For the Rest of the Century



Need to Change Fuels in a Hurry

Is the Electric Car the Signature Disruptive Innovation?

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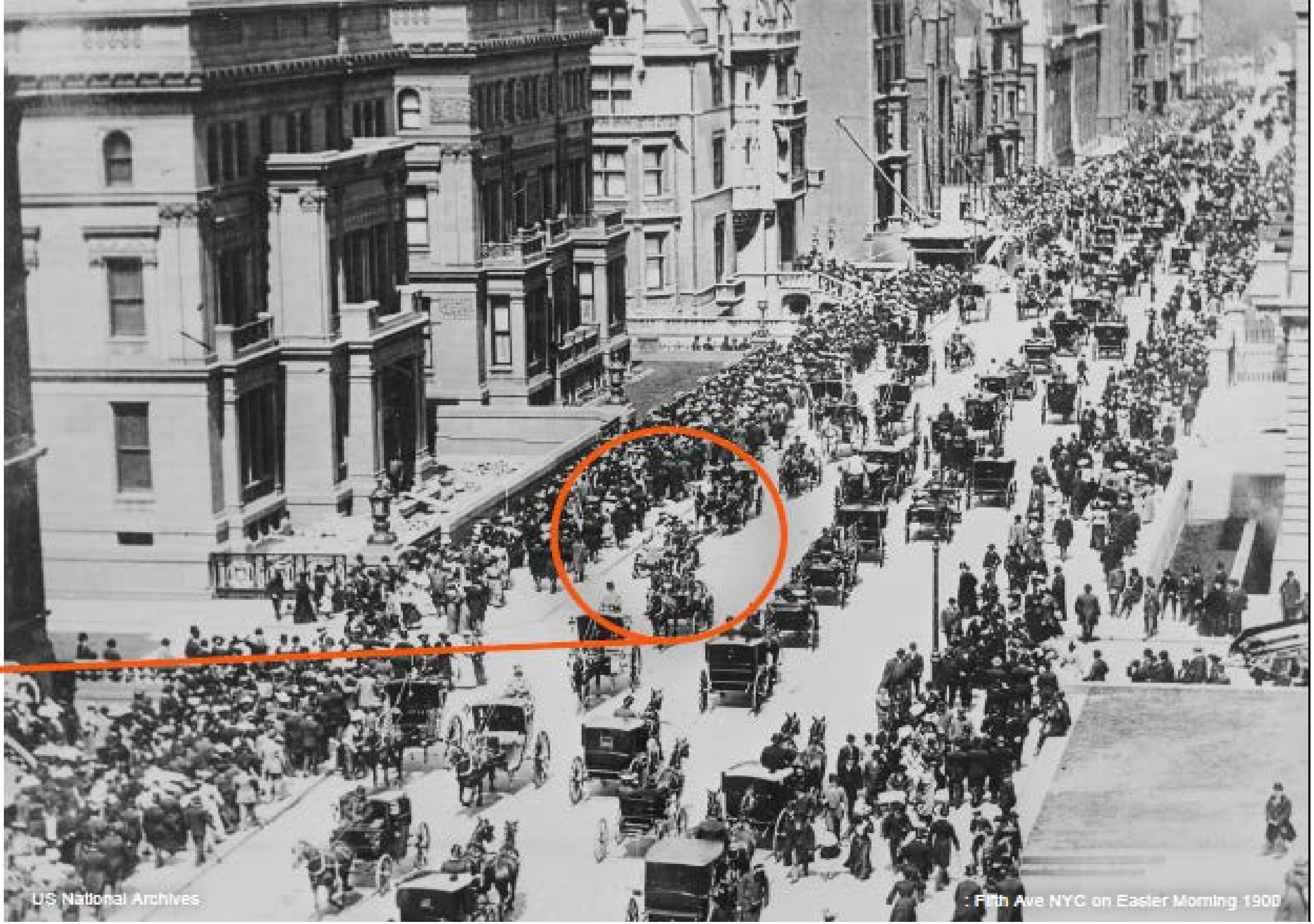
5th AVE NYC

1900

Where is **the car?**



US National Archives

: Fifth Ave NYC on Easter Morning 1900

5th AVE NYC

1913

Where is **the horse?**

George Grantham Bain Collection

Photo: Easter 1913, New York. Fifth Avenue looking north.

401 Toronto 2017

Where is the EV?

401 Toronto

2030

Where is

the

Gasoline Car?

The coming energy revolution…

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…will be led by scientists, innovators and entrepreneurs

Credits: Nokero; University of Waterloo

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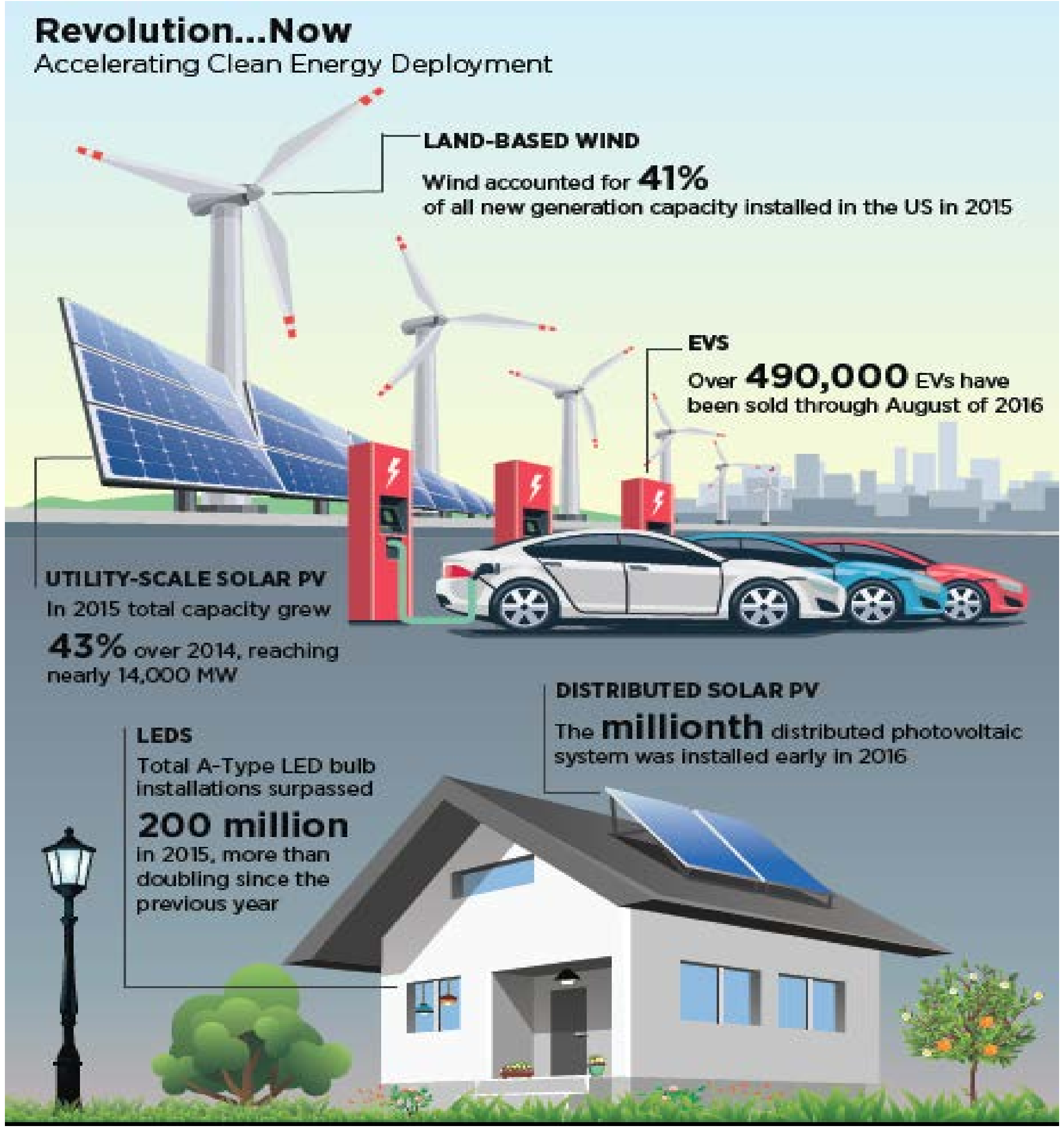
CRITICAL TECHNOLOGIES



Revolution...Now

Accelerating Clean Energy Deployment

LAND-BASED WIND

Wind accounted for **41%** of all new generation capacity installed in the US in 2015

EVS

Over **490,000** EVs have been sold through August of 2016

UTILITY-SCALE SOLAR PV

In 2015 total capacity grew **43%** over 2014, reaching nearly 14,000 MW

DISTRIBUTED SOLAR PV

The **millionth** distributed photovoltaic system was installed early in 2016

LEDS

Total A-Type LED bulb installations surpassed **200 million** in 2015, more than doubling since the previous year

1. Sensors / Internet of Things
2. Artificial Intelligence / Machine Learning
3. Robotics
4. Solar PV
5. Energy Storage
6. 3D Printing
7. 3D Visualization
8. Mobile Internet & Cloud
9. Big Data / Open Data
10. Unnamed Aerial Vehicles / Nano Satellites
11. eMoney / eFinance

Source: US DOE, 2016 ‘The Future Arrives for 5 Clean Energy Technologies

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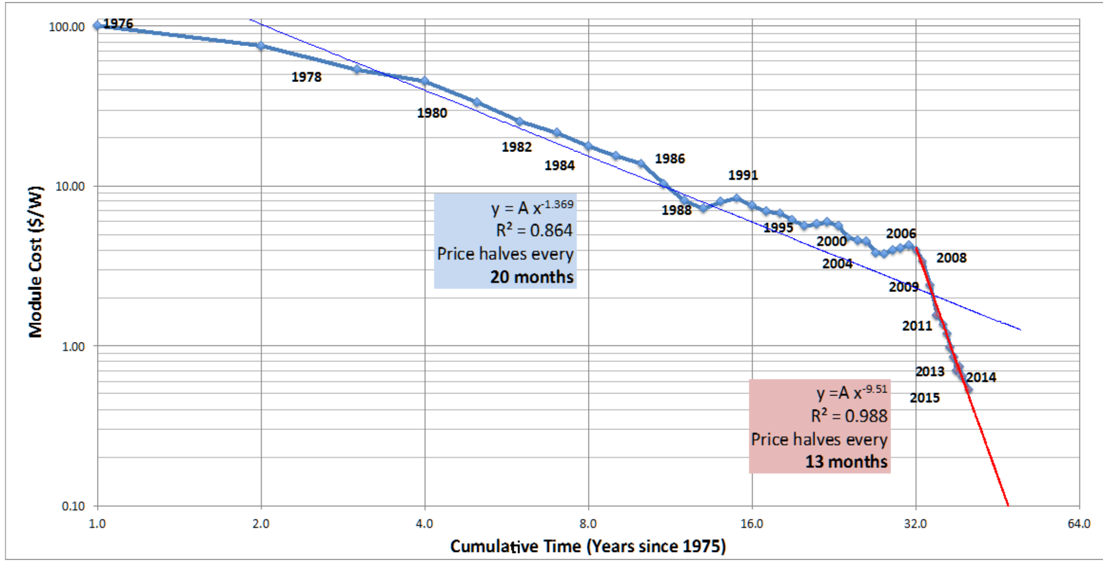
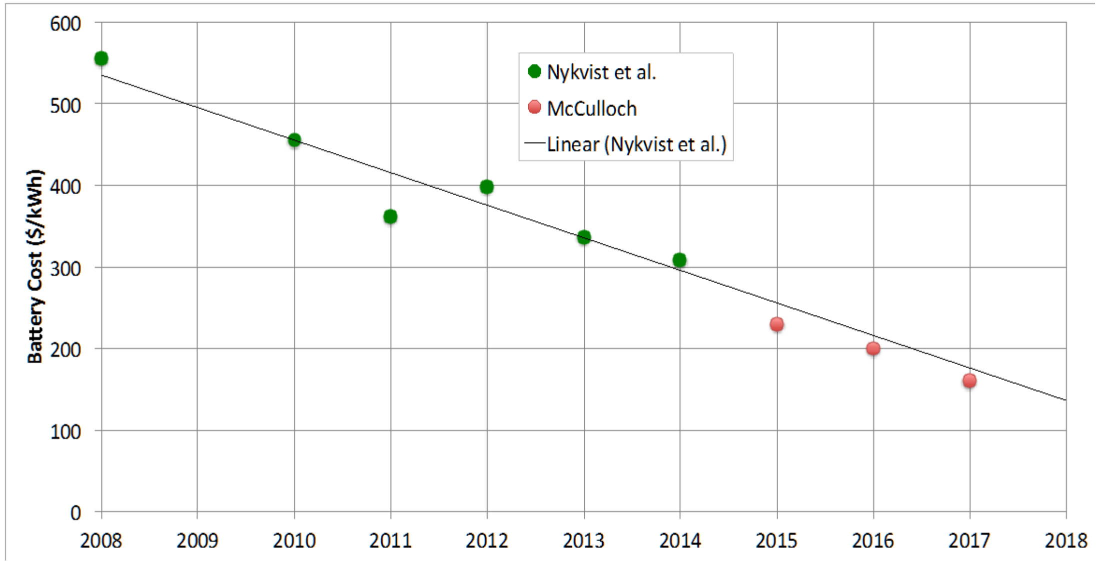
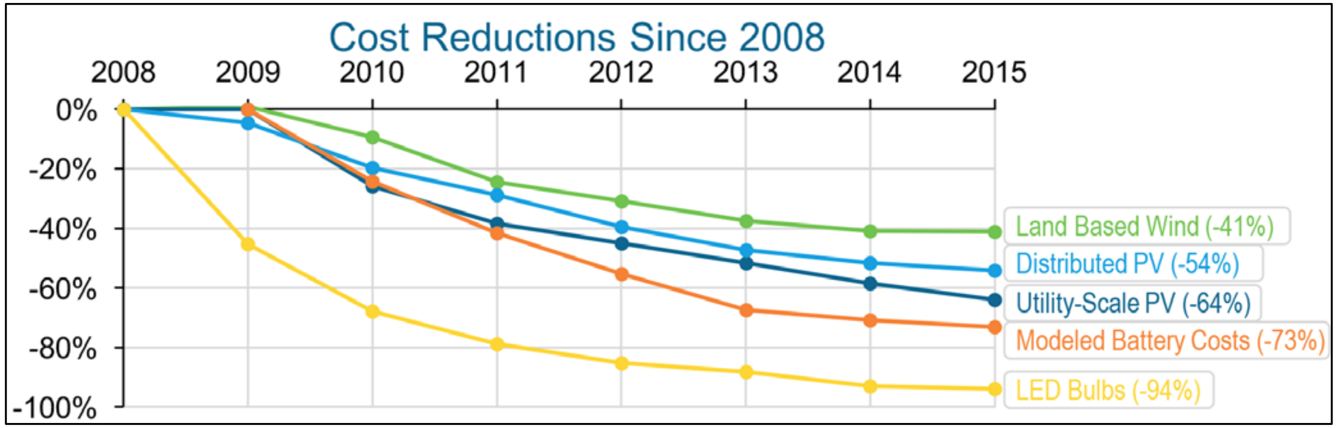
Solar costs are falling dramatically since 2008



Battery price are also falling

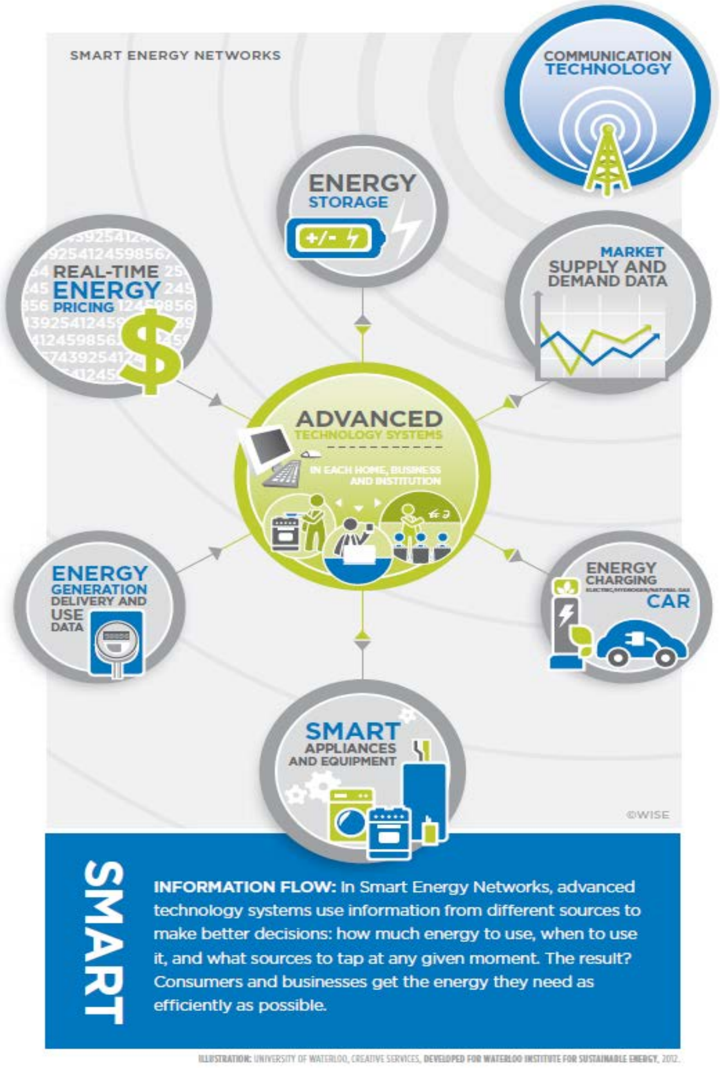


Future Arrives for 5 Energy Technologies



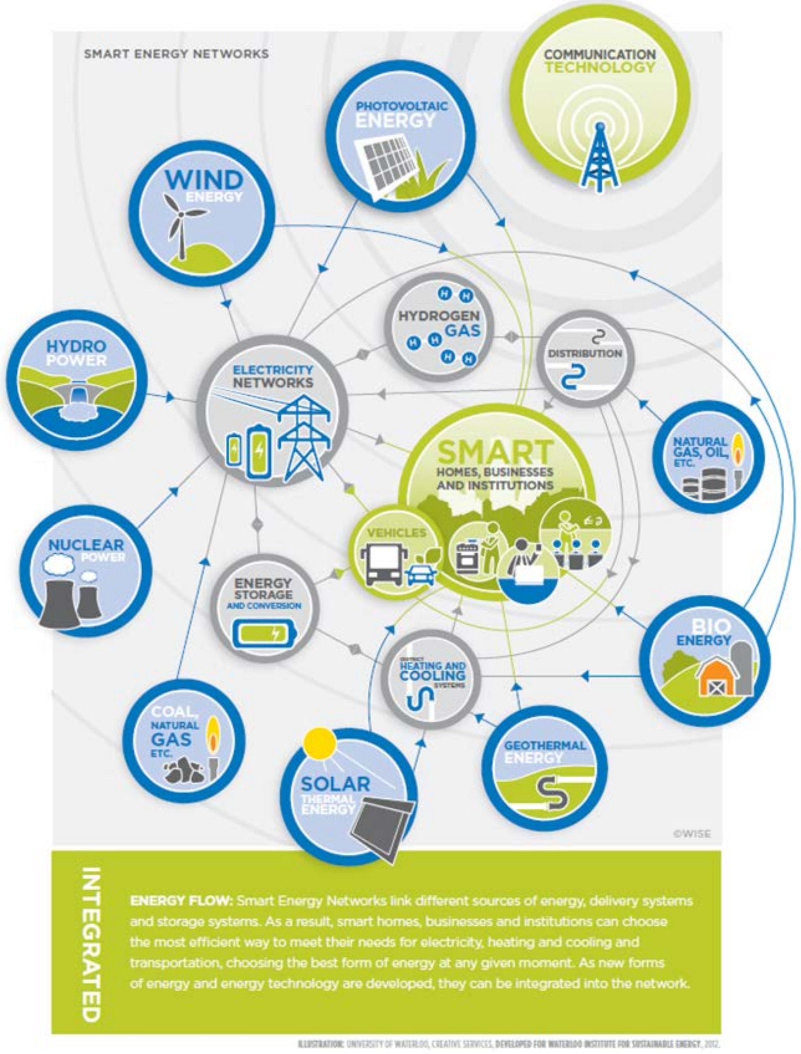
SMART ENERGY NETWORKS

ICT AS CRITICAL ENABLER



INFORMATION FLOW: In Smart Energy Networks, advanced technology systems use information from different sources to make better decisions: how much energy to use, when to use it, and what sources to tap at any given moment. The result? Consumers and businesses get the energy they need as efficiently as possible.

ILLUSTRATION: UNIVERSITY OF WATERLOO, CREATIVE SERVICES, DEVELOPED FOR WATERLOO INSTITUTE FOR SUSTAINABLE ENERGY, 2012.



ENERGY FLOW: Smart Energy Networks link different sources of energy, delivery systems and storage systems. As a result, smart homes, businesses and institutions can choose the most efficient way to meet their needs for electricity, heating and cooling and transportation, choosing the best form of energy at any given moment. As new forms of energy and energy technology are developed, they can be integrated into the network.

ILLUSTRATION: UNIVERSITY OF WATERLOO, CREATIVE SERVICES, DEVELOPED FOR WATERLOO INSTITUTE FOR SUSTAINABLE ENERGY, 2012.

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ICT Performance and Costs

Sensors: 1,000X changes in 7 Years (2007 - 2014)

UNIT	CHANGE	COMMENTS
Number of Sensors	UP 1,000x ↑	From 10 million to 10 billion
Cost	DOWN 1,000x ↓	E.g., from $250/axis for gyros to $0.75 for three axis
Power consumption	DOWN 1,000x ↓	From W to mW and mW to µW, depending on sensor
Physical Size	DOWN 1,000x ↓	E.g., gyro from 2,000 mm^3 to 2 mm^3/axis
Number of Transistors	UP 1,000x ↑	From 1,000s per sensor to 1,000,000s/sensor

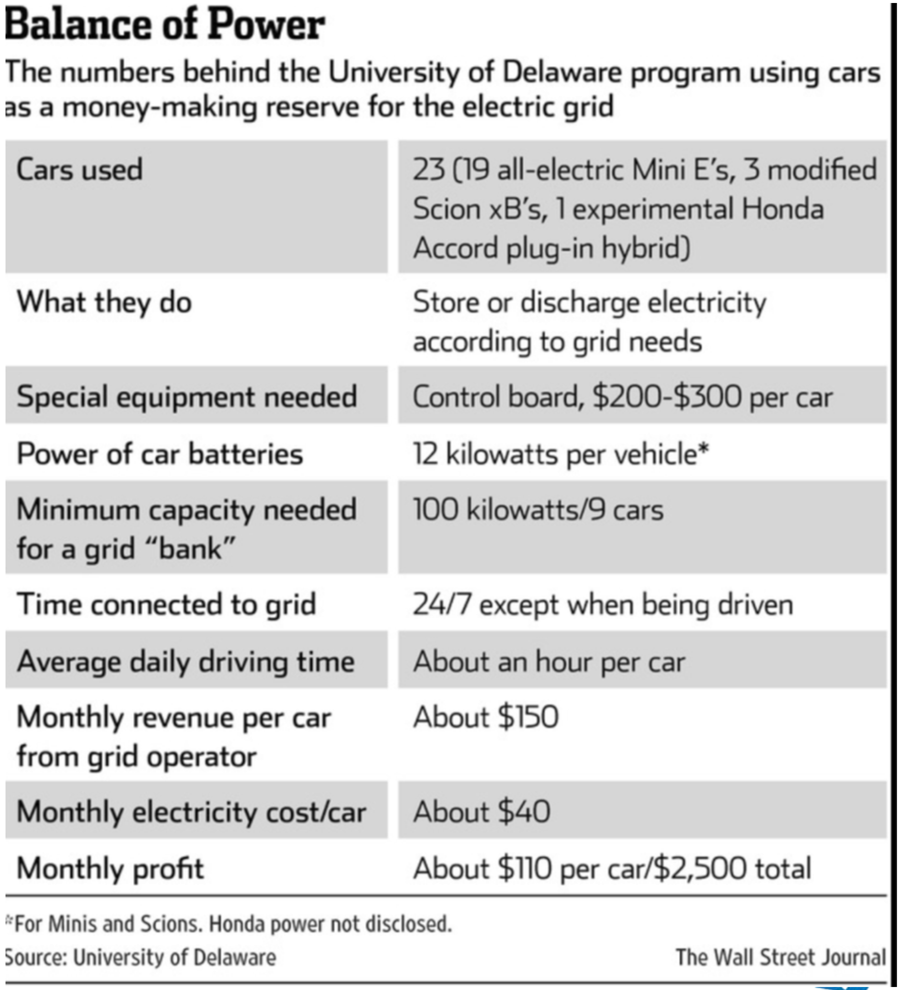
On the road to trillions of censors: Exponential Unit Growth

Source: Janusz Bryzek, TSensors

CARS CONTROLLING THE GRID?

Electric Vehicles Sell Power Back to the Grid

Delaware Test Fleet Makes Money by Serving as an Electricity Reserve



Balance of Power

The numbers behind the University of Delaware program using cars as a money-making reserve for the electric grid

Cars used	23 (19 all-electric Mini E's, 3 modified Scion xB's, 1 experimental Honda Accord plug-in hybrid)
What they do	Store or discharge electricity according to grid needs
Special equipment needed	Control board, \$200-\$300 per car
Power of car batteries	12 kilowatts per vehicle*
Minimum capacity needed for a grid "bank"	100 kilowatts/9 cars
Time connected to grid	24/7 except when being driven
Average daily driving time	About an hour per car
Monthly revenue per car from grid operator	About \$150
Monthly electricity cost/car	About \$40
Monthly profit	About \$110 per car/\$2,500 total

*For Minis and Scions. Honda power not disclosed.

Source: University of Delaware

The Wall Street Journal

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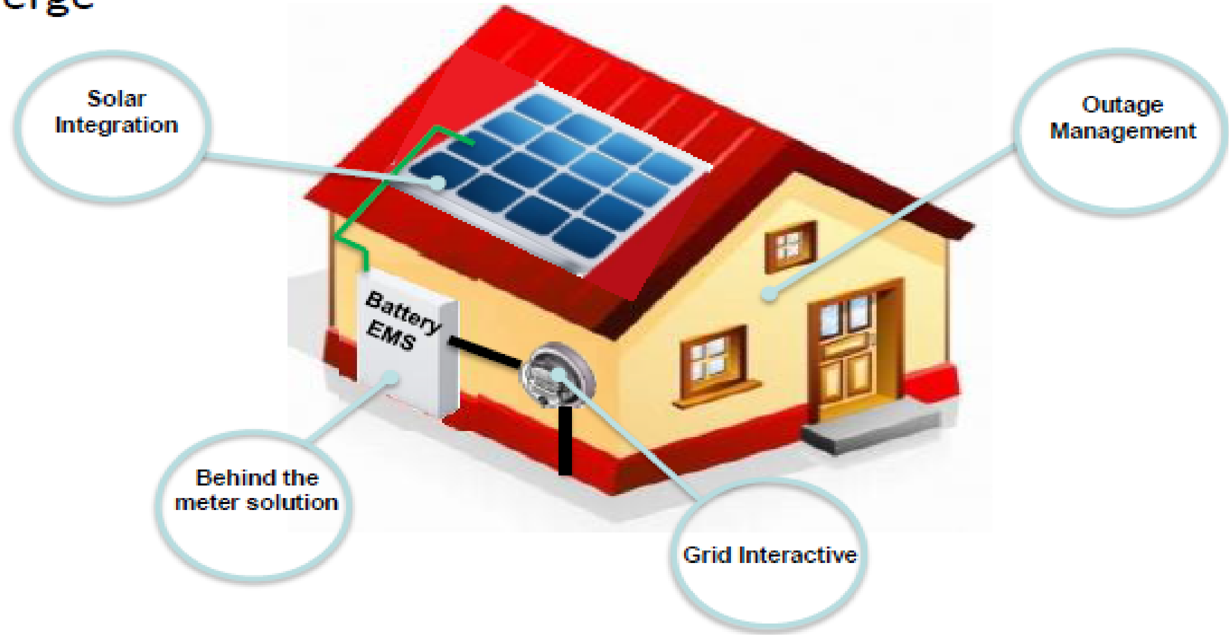
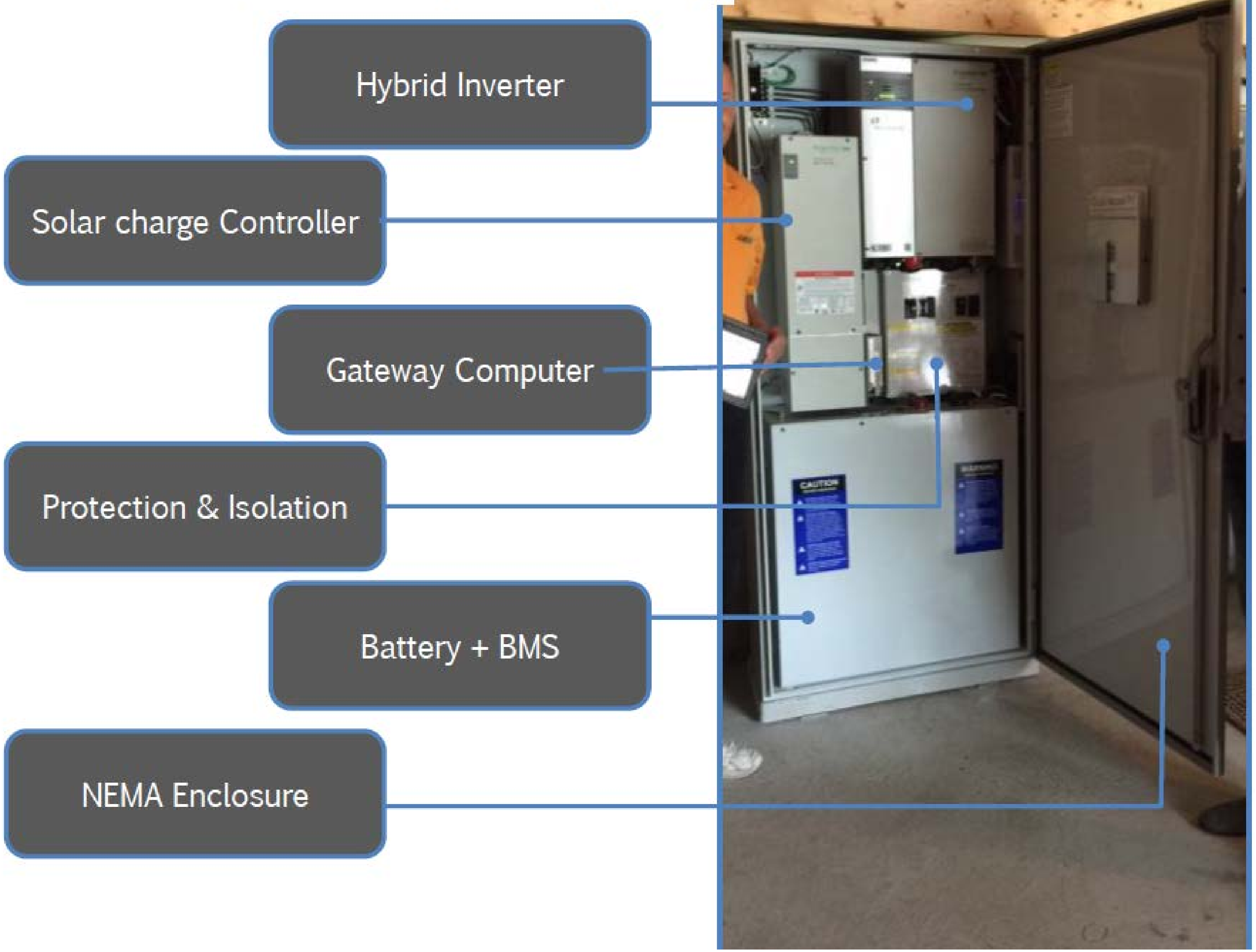
POWER.HOUSE VPP launched March 2016

IESO Conservation Fund for 20 homes:

- 20 targeted homes in PowerStream territory
- 5 KW solar array; Sunverge unit- 6.8 KW/11.4KWH battery and EMS
- Aggregation of distributed assets to create a Virtual Power Plant
- Technology partner: Sunverge
- Installation partner: RBI



Solar Integrated System (SIS)



Hybrid Inverter

Solar charge Controller

Gateway Computer

Protection & Isolation

Battery + BMS

NEMA Enclosure

Other Installed Components

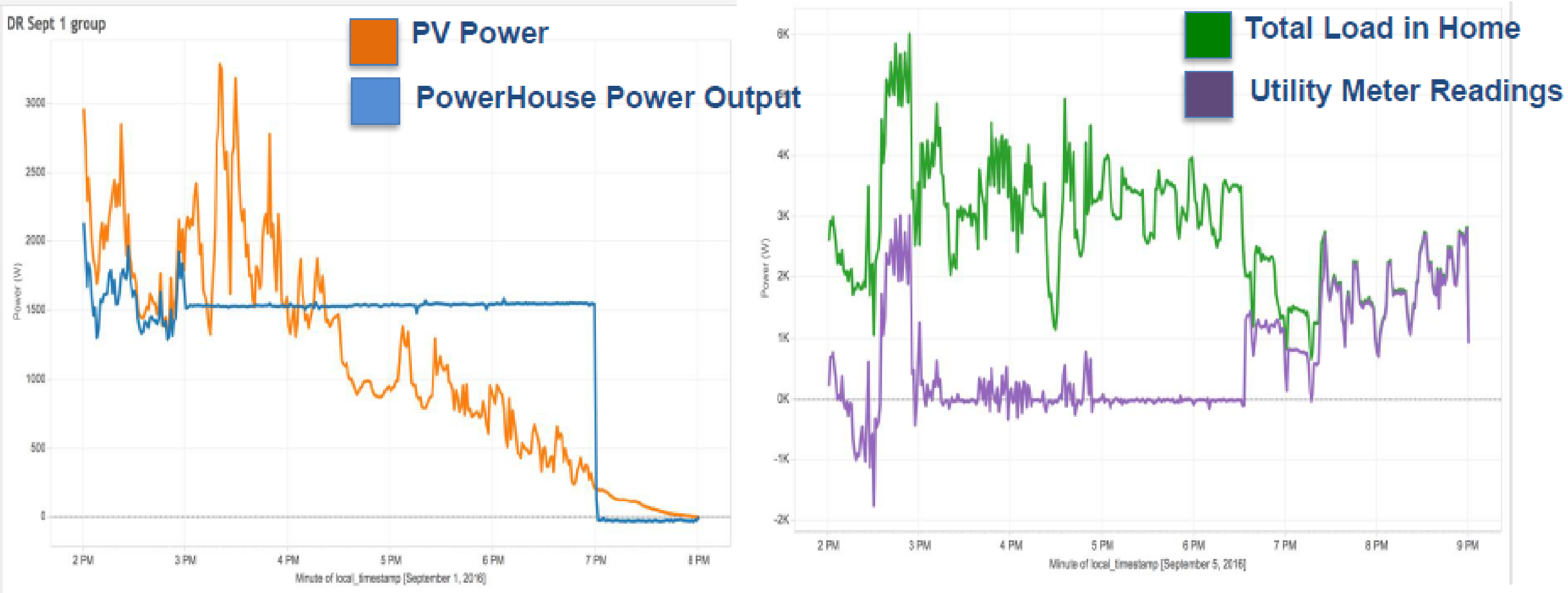
Solar Integrated System (SIS)

Battery Disconnect Switch

Arc Fault Circuit Interrupter (2 string)

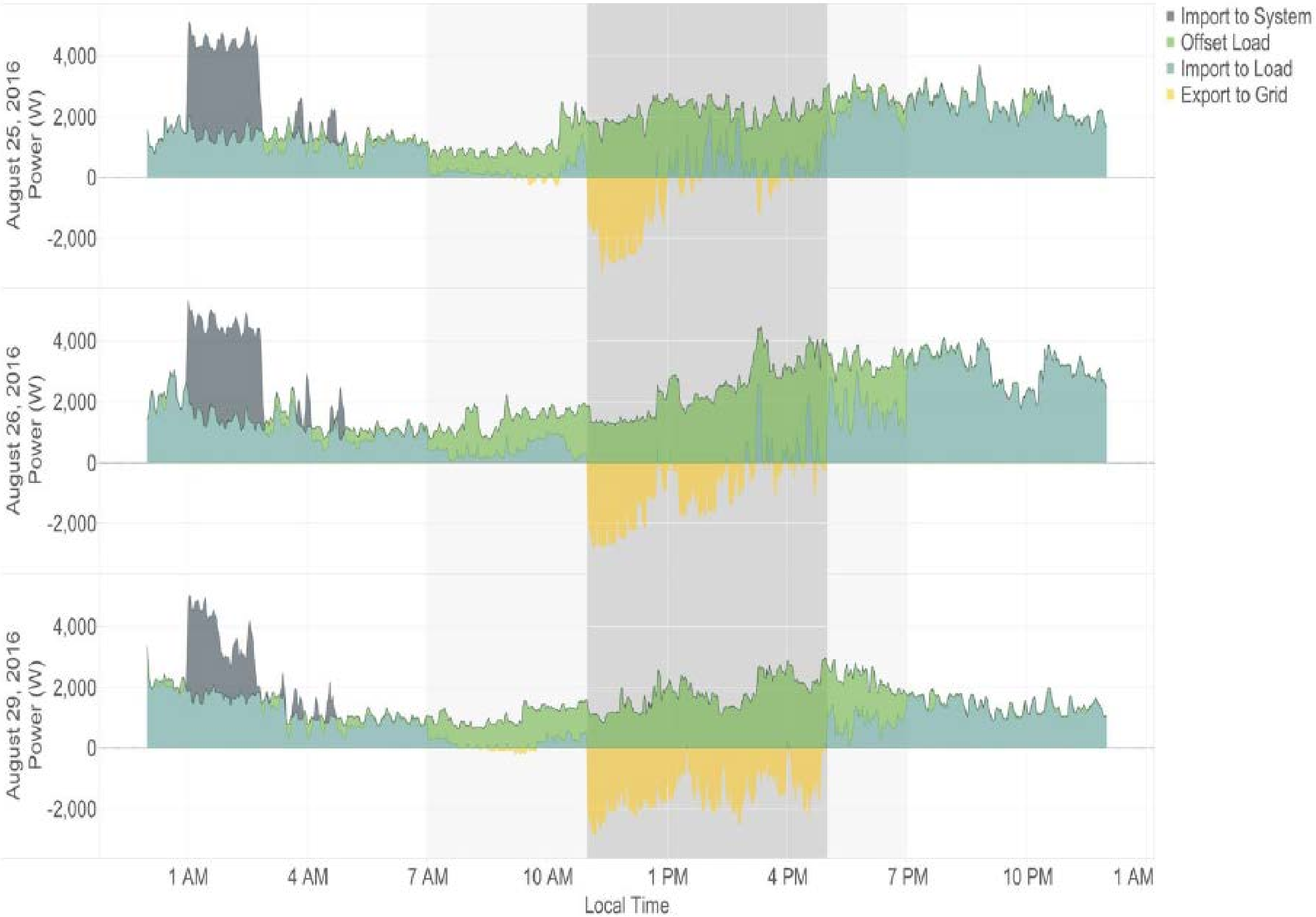
PV Disconnect Switch

Demand Response Summary



- Graphs show average response of group of units
- Two different approaches to providing DR
- Left graph shows constant power output
- Right graph shows effort to minimize impact on grid (target = 0 kW utility meter readings)

TOU Rate Management (using TOU arbitrage algorithm)



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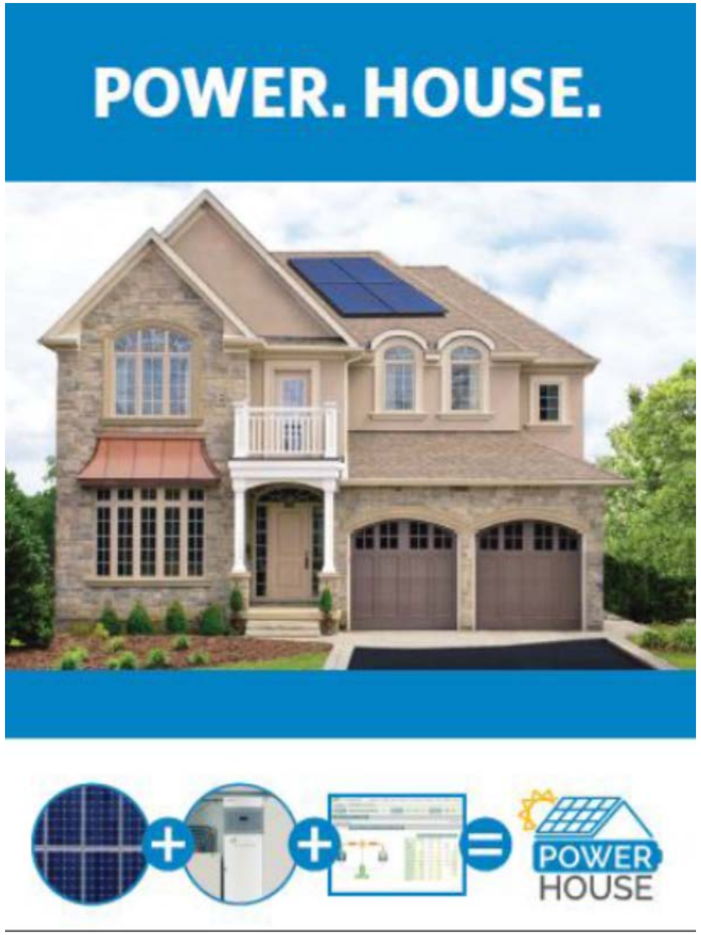
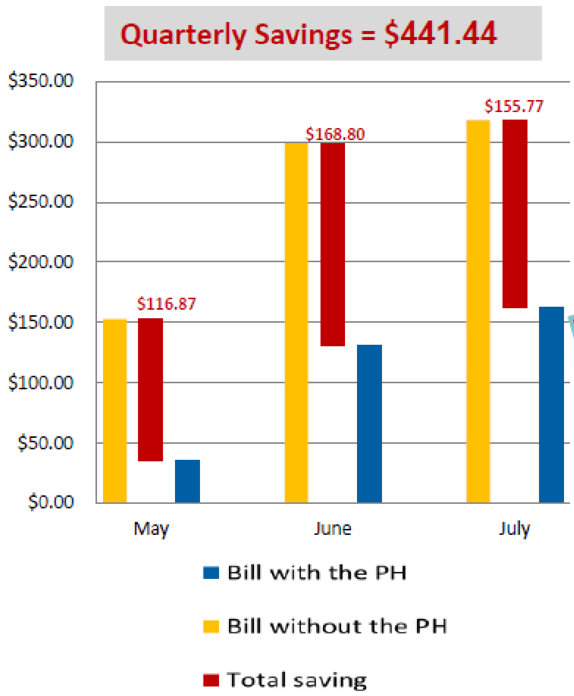
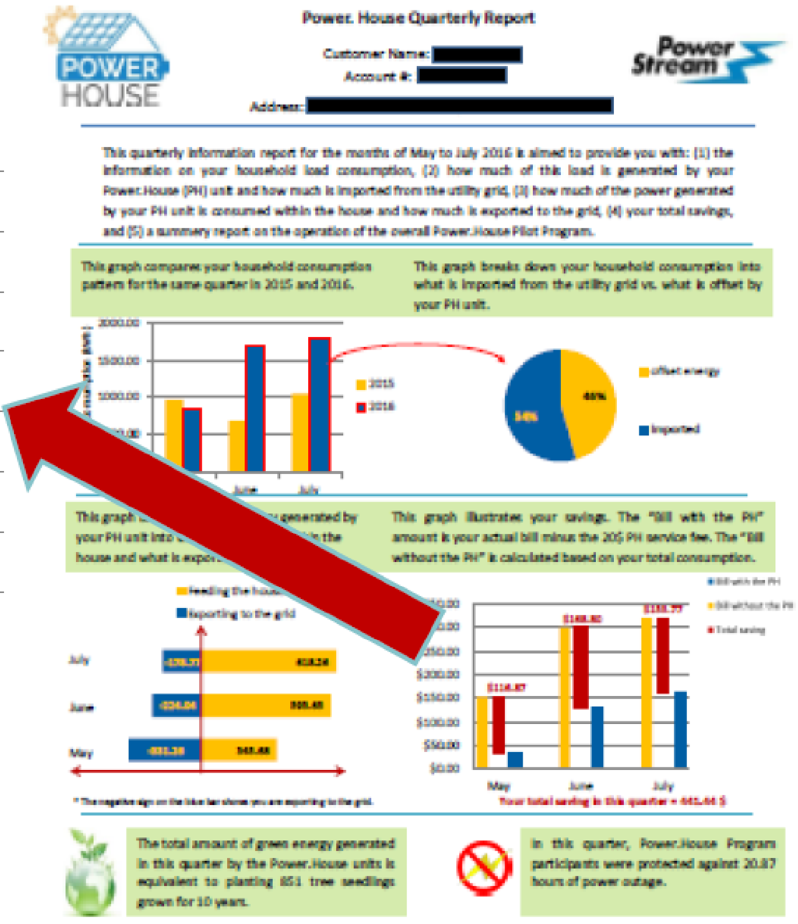
Buildings + EVs as Virtual Power Plants?



Quarterly Performance Report





Power. House Quarterly Report

Customer Name: [redacted]
Account #: [redacted]
Address: [redacted]

This quarterly information report for the months of May to July 2016 is aimed to provide you with: (1) the information on your household load consumption, (2) how much of this load is generated by your Power.House (PH) unit and how much is imported from the utility grid, (3) how much of the power generated by your PH unit is consumed within the house and how much is exported to the grid, (4) your total savings, and (5) a summery report on the operation of the overall Power.House Pilot Program.

This graph compares your household consumption pattern for the same quarter in 2015 and 2016.

This graph breaks down your household consumption into what is imported from the utility grid vs. what is offset by your PH unit.

This graph … generated by your PH unit into … the house and what is expo…

This graph illustrates your savings. The "Bill with the PH" amount is your actual bill minus the 20$ PH service fee. The "Bill without the PH" is calculated based on your total consumption.

* The negative sign on the blue bar shows you are exporting to the grid.

Your total saving in this quarter = 441.44 $

The total amount of green energy generated in this quarter by the Power.House units is equivalent to planting 851 tree seedlings grown for 10 years.

In this quarter, Power.House Program participants were protected against 20.87 hours of power outage.

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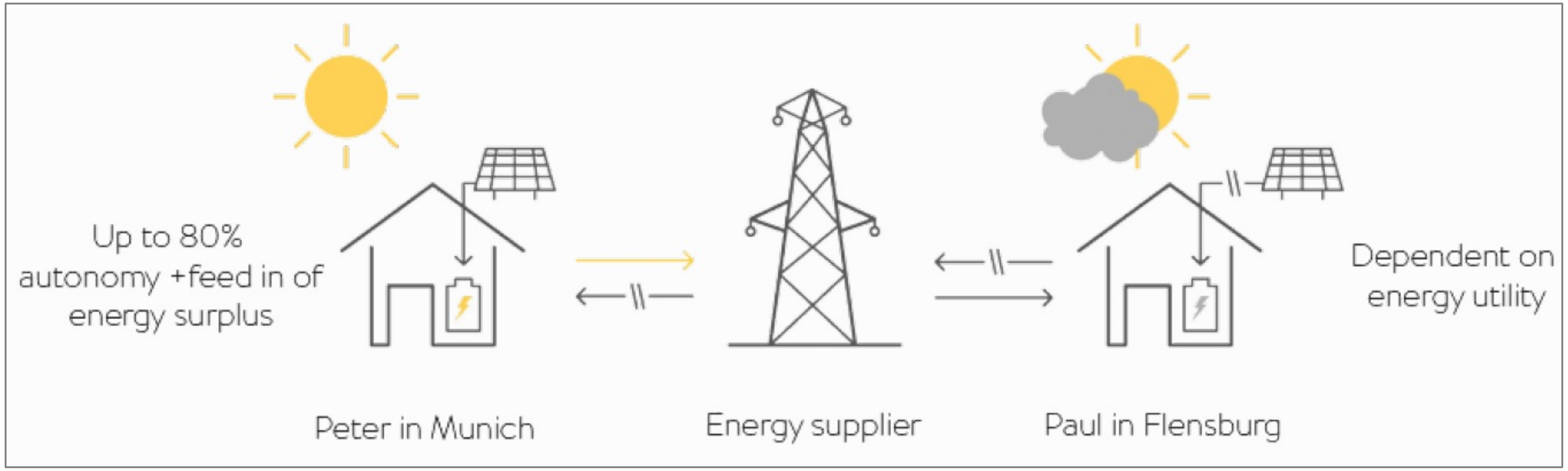
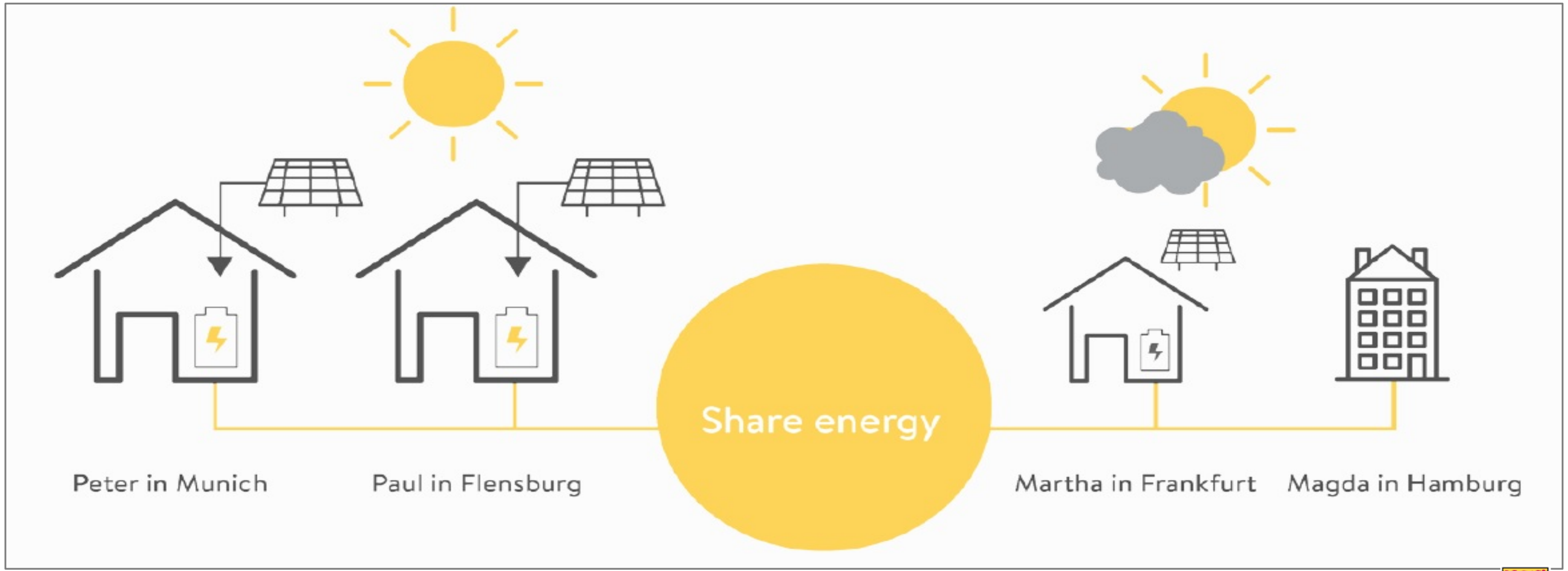
SONNEN SMART COMMUNITY

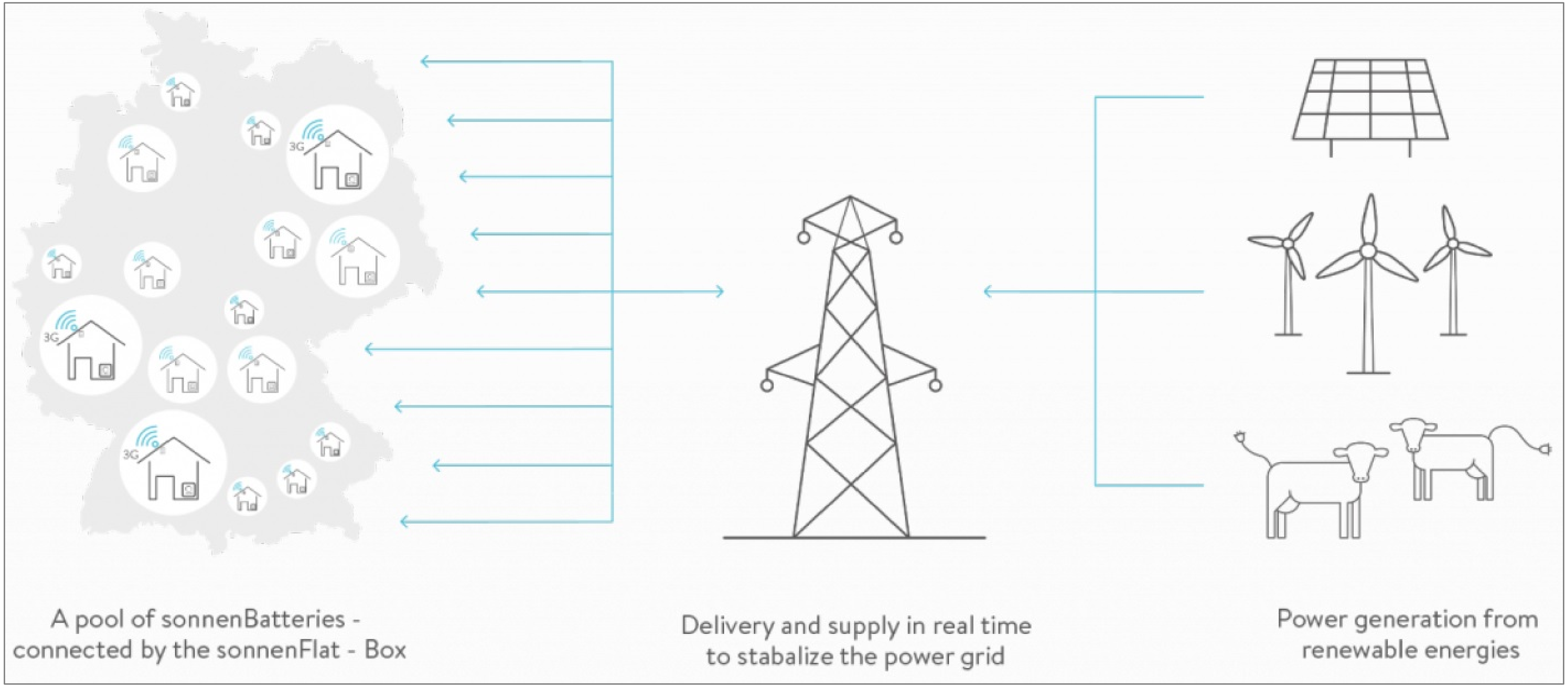


Without Sonnen Community



With Sonnen Community

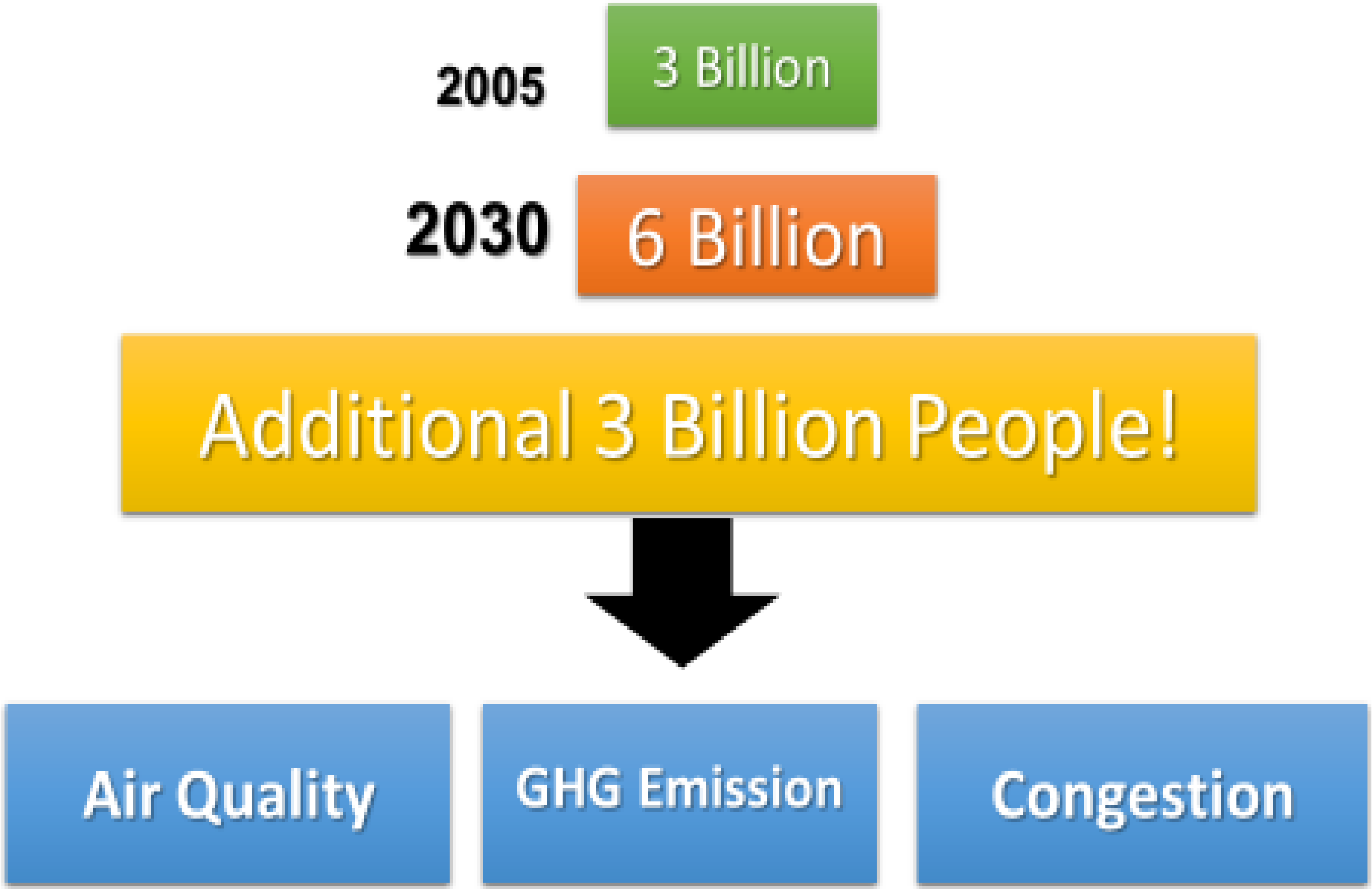
SONNEN SMART GRID



SMART URBANISATION

Chicago City Hall Green Roof.

Rapid Urban Population Growth = Increasing Mobility Needs



2005 3 Billion

2030 6 Billion

Additional 3 Billion People!

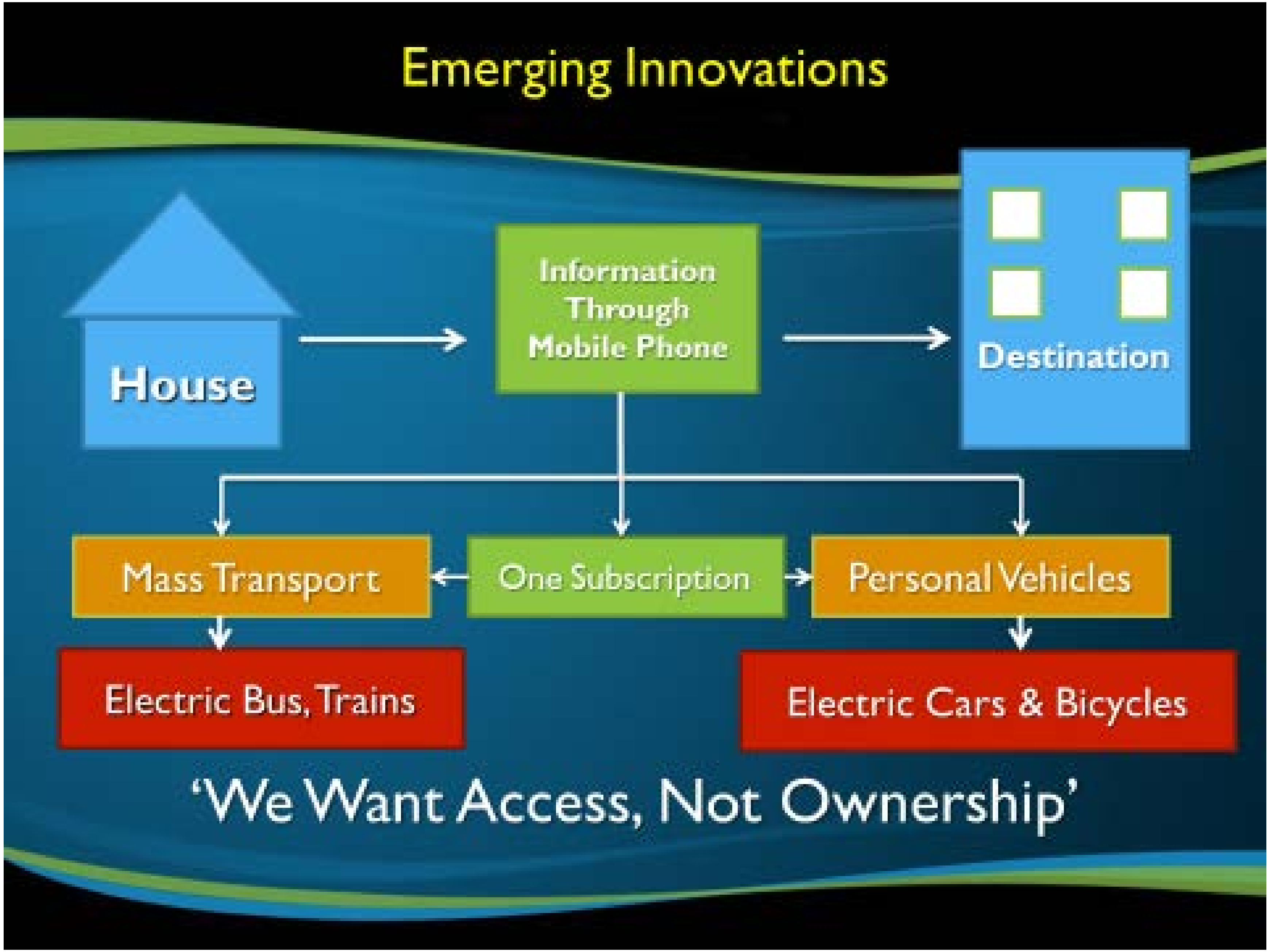
Air Quality

GHG Emission

Congestion

Shanghai, China

Jakarta, Indonesia



Emerging Innovations

House

Information Through Mobile Phone

Destination

Mass Transport

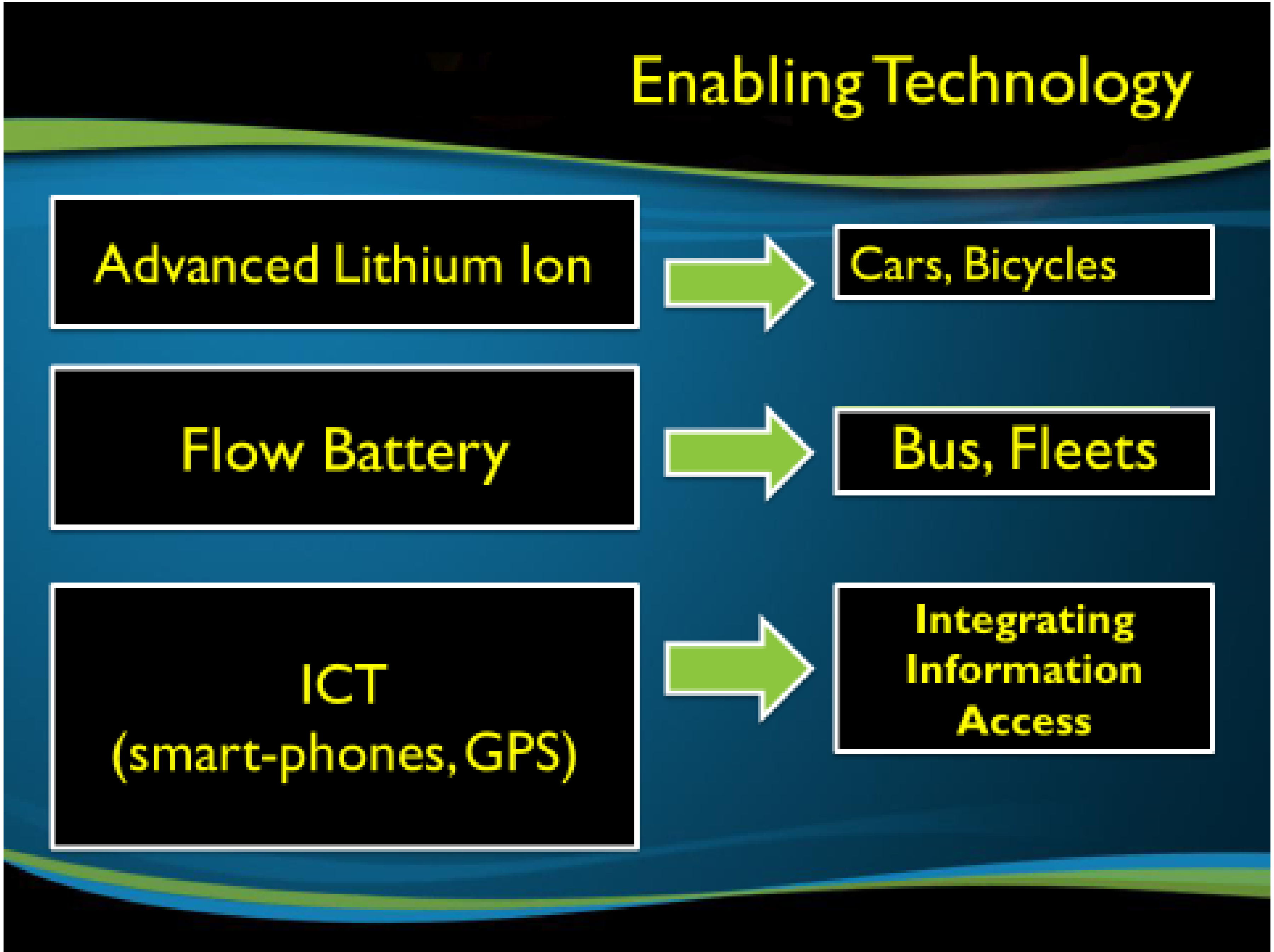
One Subscription

Personal Vehicles

Electric Bus, Trains

Electric Cars & Bicycles

‘We Want Access, Not Ownership’



Enabling Technology

Advanced Lithium Ion → Cars, Bicycles

Flow Battery → Bus, Fleets

ICT
(smart-phones, GPS) → Integrating Information Access

TaaS and BaaS:

CHARGING STATIONS as Gateway Infrastructure:

2 kW EV Charging Station

10 kW EV Charging Station

30 kW EV Charging Shade Structure

300 kW EV Charging

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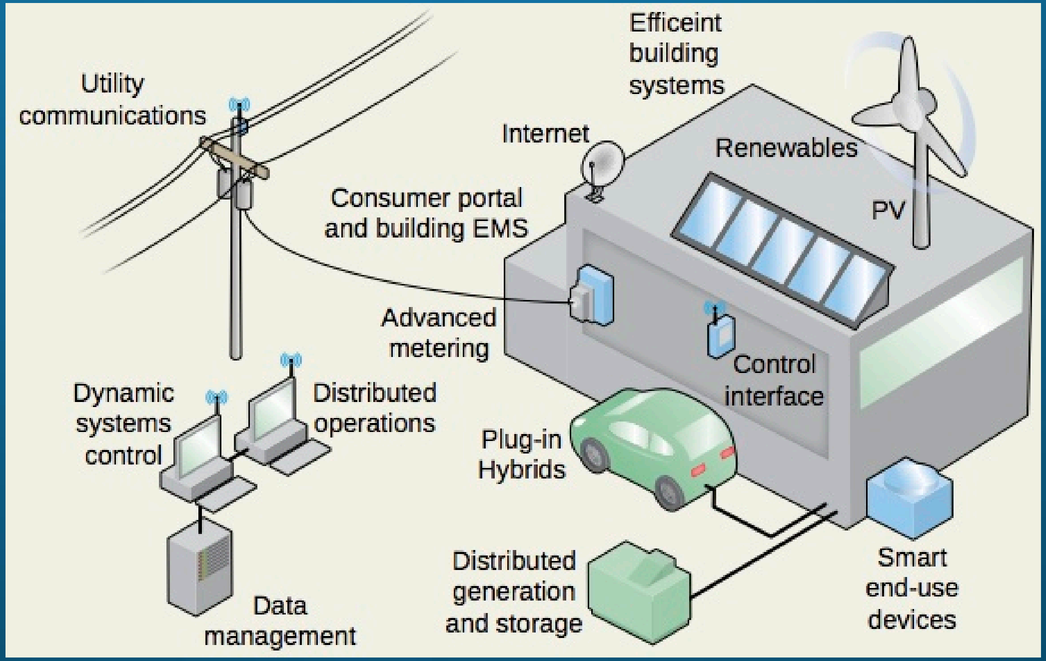
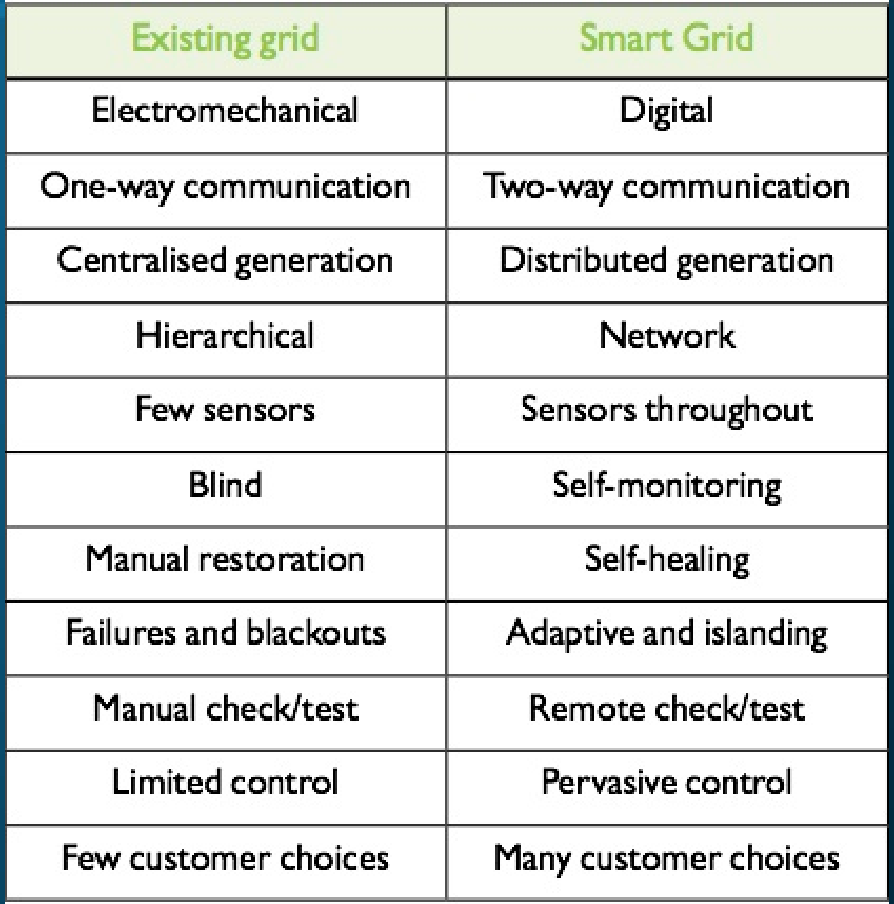
Smart Urbanization

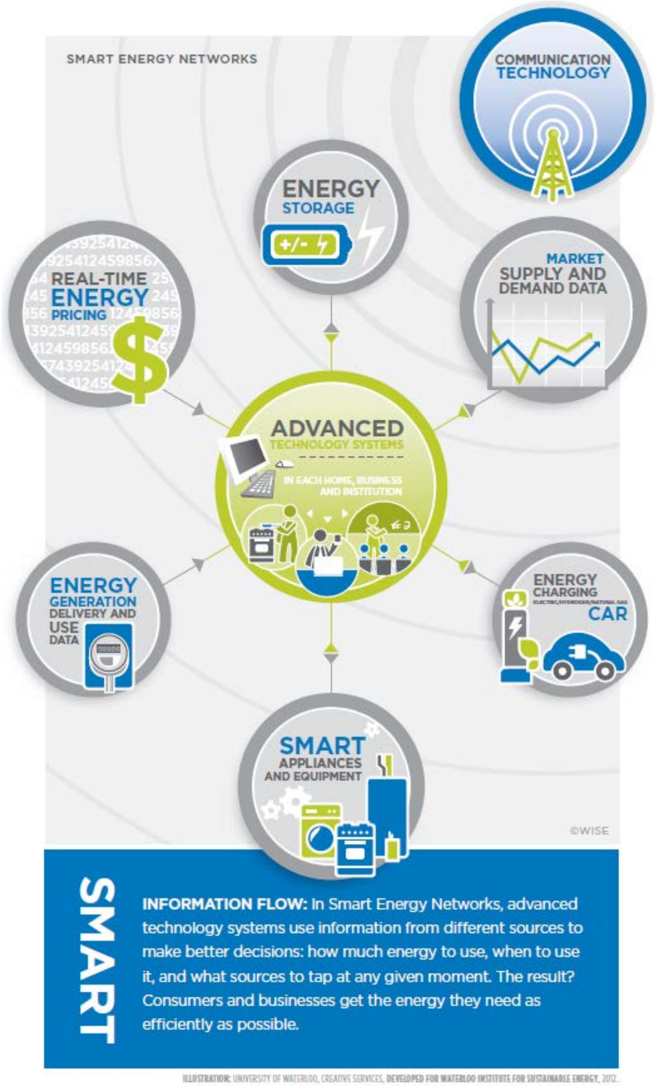
Smart Grids





Existing grid	Smart Grid
Electromechanical	Digital
One-way communication	Two-way communication
Centralised generation	Distributed generation
Hierarchical	Network
Few sensors	Sensors throughout
Blind	Self-monitoring
Manual restoration	Self-healing
Failures and blackouts	Adaptive and islanding
Manual check/test	Remote check/test
Limited control	Pervasive control
Few customer choices	Many customer choices

Smart Energy Networks



INFORMATION FLOW: In Smart Energy Networks, advanced technology systems use information from different sources to make better decisions: how much energy to use, when to use it, and what sources to tap at any given moment. The result? Consumers and businesses get the energy they need as efficiently as possible.

ILLUSTRATION: UNIVERSITY OF WATERLOO, CREATIVE SERVICES, **DEVELOPED FOR WATERLOO INSTITUTE FOR SUSTAINABLE ENERGY**, 2012.

ENERGY FLOW: Smart Energy Networks link different sources of energy, delivery systems and storage systems. As a result, smart homes, businesses and institutions can choose the most efficient way to meet their needs for electricity, heating and cooling and transportation, choosing the best form of energy at any given moment. As new forms of energy and energy technology are developed, they can be integrated into the network.

ILLUSTRATION: UNIVERSITY OF WATERLOO, CREATIVE SERVICES, **DEVELOPED FOR WATERLOO INSTITUTE FOR SUSTAINABLE ENERGY**, 2012.

Transforming Our Energy Future

Our vision is simple: **clean energy, accessible and affordable for all.**

Collaborate

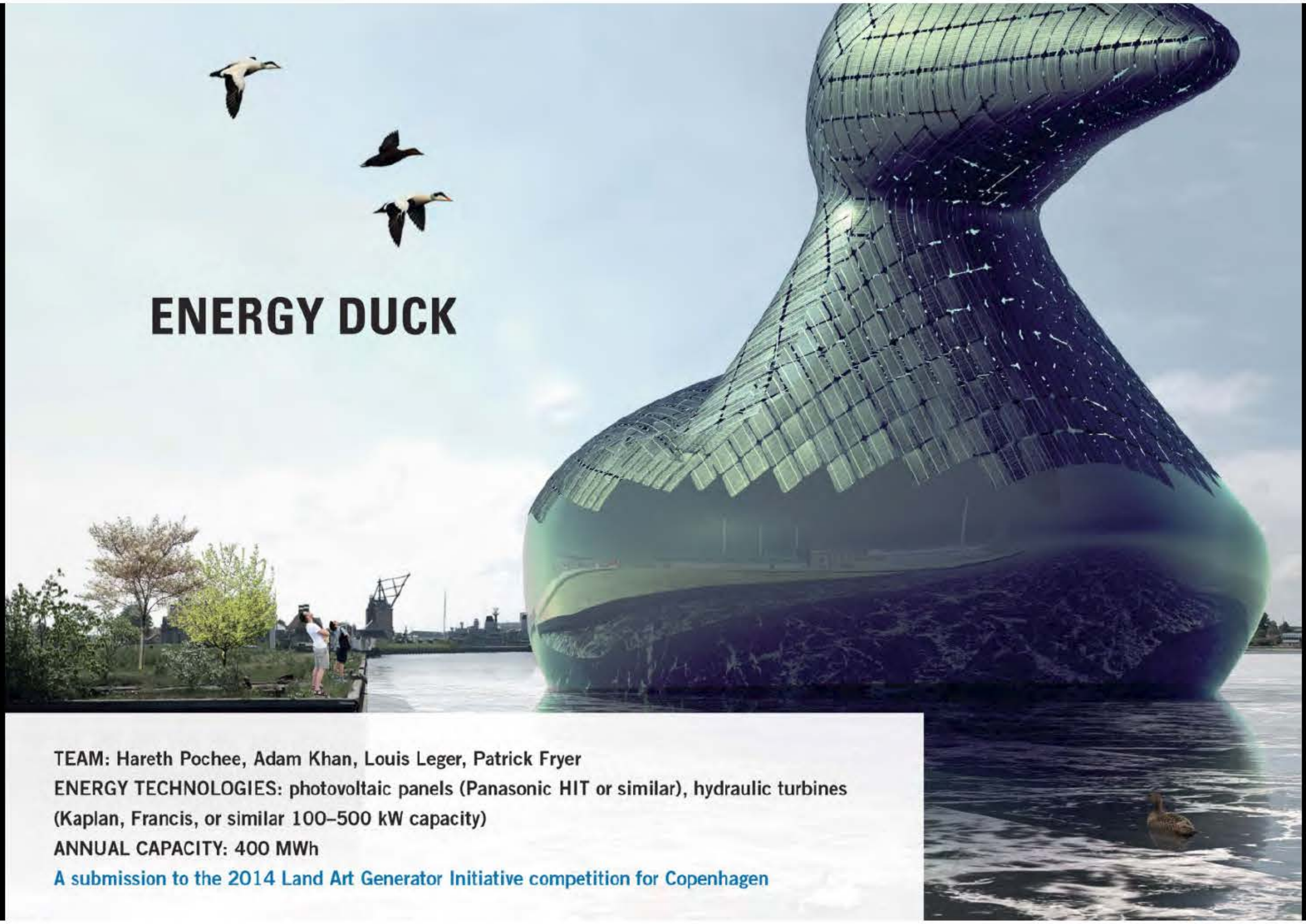
At WISE, we believe the biggest breakthroughs come from uniting leading researchers from dozens of disciplines.

Reach out

Change requires many partners. We're working with industry, government and the non-profit sector to create sustainable energy solutions.

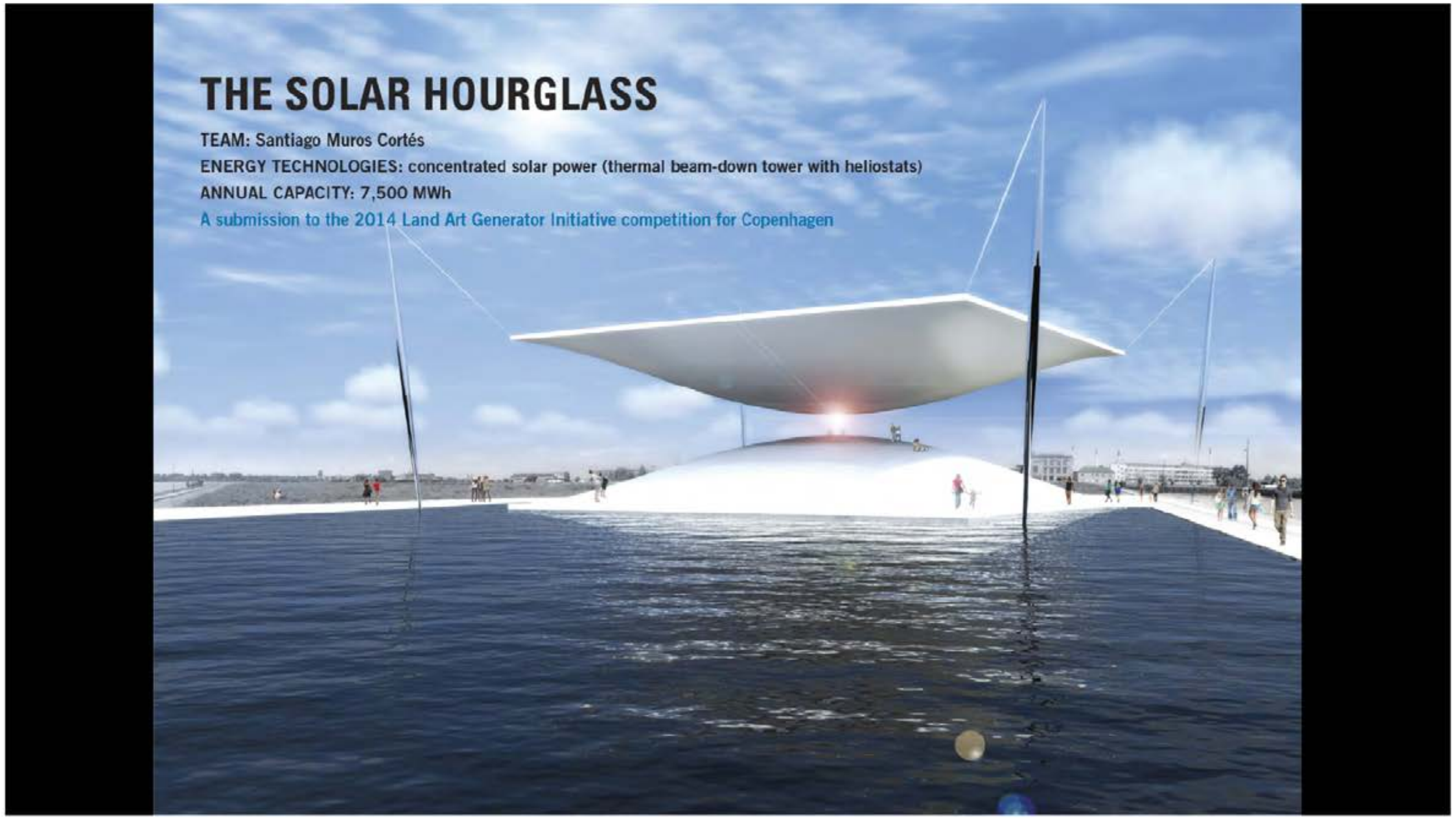
Influence

Our research shapes public attitudes, informs energy policies and improves quality of life at home and around the globe.



ENERGY DUCK

TEAM: Hareth Pochee, Adam Khan, Louis Leger, Patrick Fryer
ENERGY TECHNOLOGIES: photovoltaic panels (Panasonic HIT or similar), hydraulic turbines (Kaplan, Francis, or similar 100–500 kW capacity)
ANNUAL CAPACITY: 400 MWh
A submission to the 2014 Land Art Generator Initiative competition for Copenhagen



THE SOLAR HOURGLASS

TEAM: Santiago Muros Cortés

ENERGY TECHNOLOGIES: concentrated solar power (thermal beam-down tower with heliostats)

ANNUAL CAPACITY: 7,500 MWh

A submission to the 2014 Land Art Generator Initiative competition for Copenhagen

FRESH HILLS

TEAM: Designer: Matthew Rosenberg; Structural Engineering Consultant: Matt Melnyk; Production Assistants: Emmy Maruta, Robbie Eleazer

ENERGY TECHNOLOGY: WindTamer™, Carbon Dioxide Scrubber, SmartWrap™

ANNUAL CAPACITY: 238 MWh

A submission to the 2012 LAGI competition for New York City

Source: Tesla
https://www.tesla.com/en_CA/models

THANK YOU

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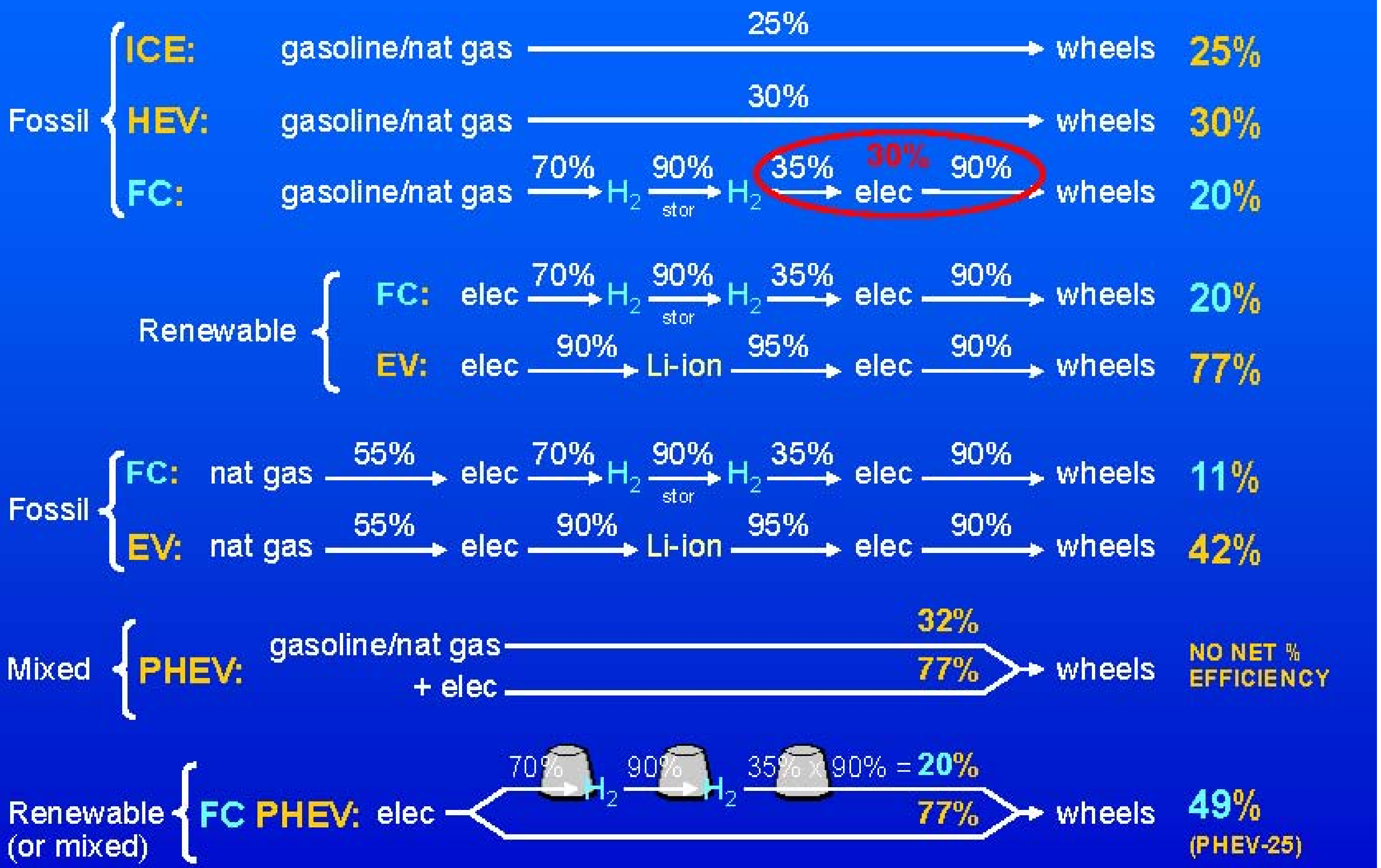
Fuel-to-Wheels Efficiency



Fossil

ICE: gasoline/nat gas $\xrightarrow{25\%}$ wheels **25%**

HEV: gasoline/nat gas $\xrightarrow{30\%}$ wheels **30%**

FC: gasoline/nat gas $\xrightarrow{70\%}$ H_2 $\xrightarrow[\text{stor}]{90\%}$ H_2 $\xrightarrow{35\%}$ elec $\xrightarrow{90\%}$ wheels **20%**

30%

Renewable

FC: elec $\xrightarrow{70\%}$ H_2 $\xrightarrow[\text{stor}]{90\%}$ H_2 $\xrightarrow{35\%}$ elec $\xrightarrow{90\%}$ wheels **20%**

EV: elec $\xrightarrow{90\%}$ Li-ion $\xrightarrow{95\%}$ elec $\xrightarrow{90\%}$ wheels **77%**

Fossil

FC: nat gas $\xrightarrow{55\%}$ elec $\xrightarrow{70\%}$ H_2 $\xrightarrow[\text{stor}]{90\%}$ H_2 $\xrightarrow{35\%}$ elec $\xrightarrow{90\%}$ wheels **11%**

EV: nat gas $\xrightarrow{55\%}$ elec $\xrightarrow{90\%}$ Li-ion $\xrightarrow{95\%}$ elec $\xrightarrow{90\%}$ wheels **42%**

Mixed

PHEV: gasoline/nat gas $\xrightarrow{32\%}$ + elec $\xrightarrow{77\%}$ wheels **NO NET % EFFICIENCY**

Renewable
(or mixed)

FC PHEV: elec: 70% H_2 90% H_2 35% x 90% = 20% ; 77% → wheels **49%** (PHEV-25)