Equinox Energy 2030:

A technological roadmap for a low carbon electrified future

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Commission for Environmental Co-operation (CEC), NAFTA.
Toronto, ON
April 18, 2012

Today’s Goals

- Challenges
  - A View of Global Energy Transitions

- Innovation
  - Promise of scientific and technology innovation

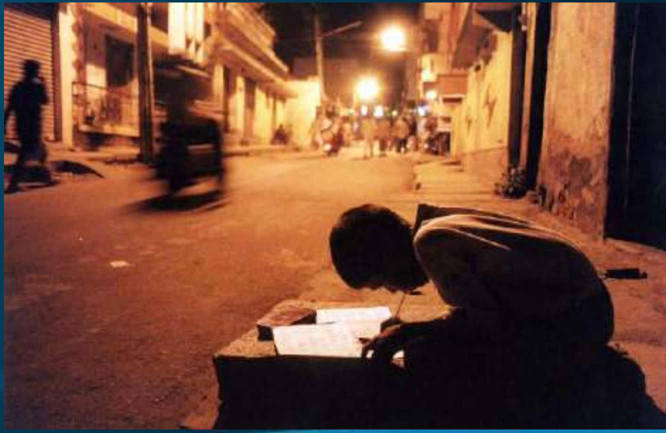
- Bring coherence to a complex problem
  - Offer fresh thinking

World at Night

Lack of Affordable Energy: What does it mean?

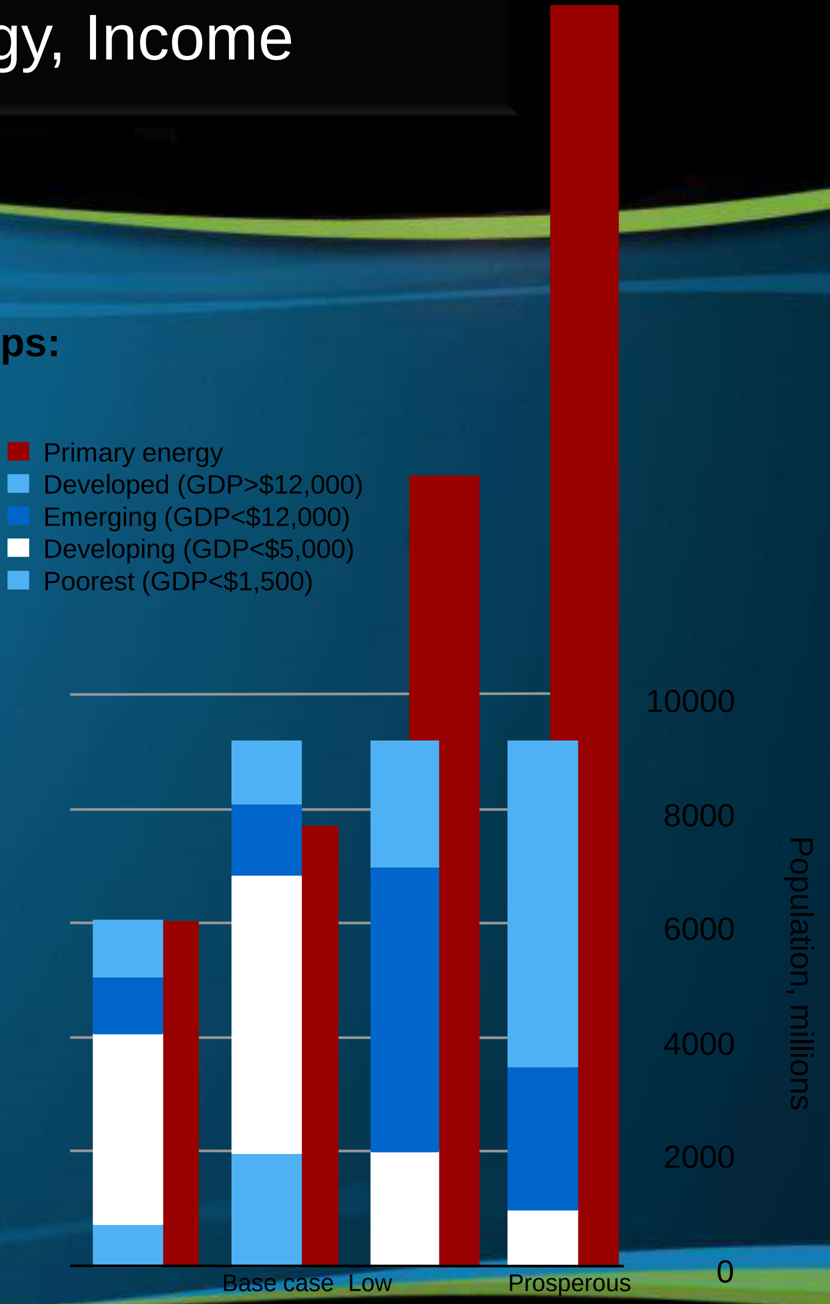
Energy's link to human development

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



Population Growth, Energy, Income

Global population divided into income groups:



Source: WBCSD adaptation of IEA 2003

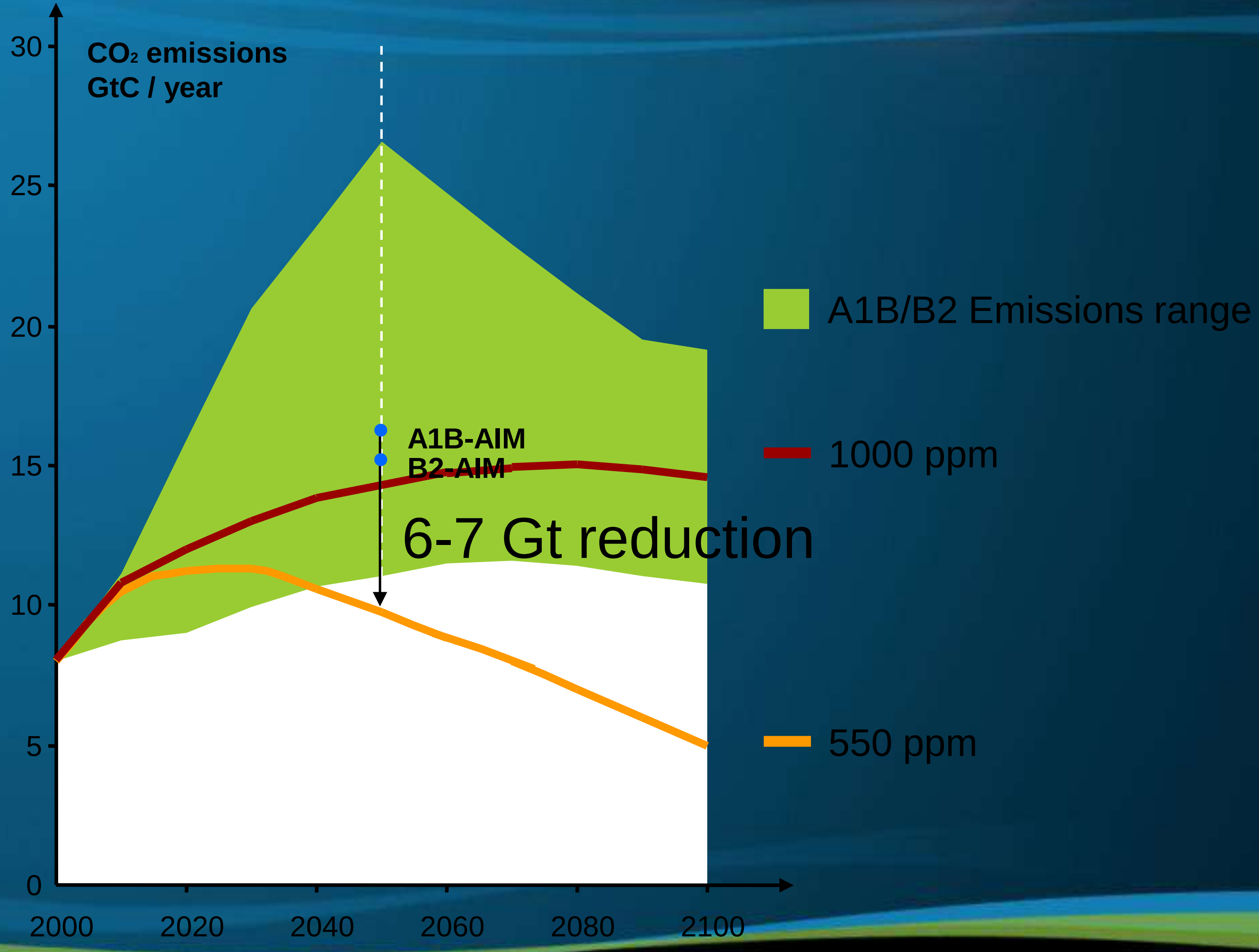
Population rise to 9 billion + by 2050, mainly in poorest and developing countries.

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

rce: WBCSD 2007

Magnitude of change required for CO2 stabilization



Source: WBCSD 2007

Energy Transitions and the Global Challenge

- Today's **Global Energy Consumption: 16.5 TW**
  - of which **2.5 TW** is non-carbon (mainly hydro, nuclear..)

- By 2050: **30 TW**
  - Likely higher (31- 40 TW)

- By 2050: **15 TW** of new non carbon
  - Equal to 6 x today's renewable global capacity

If goal is to stabilize global emissions profile to 550 ppm GHG emissions, approx 50% of Global Energy Demand must be non- carbon forms of energy

All new growth to be met by non-carbon sources

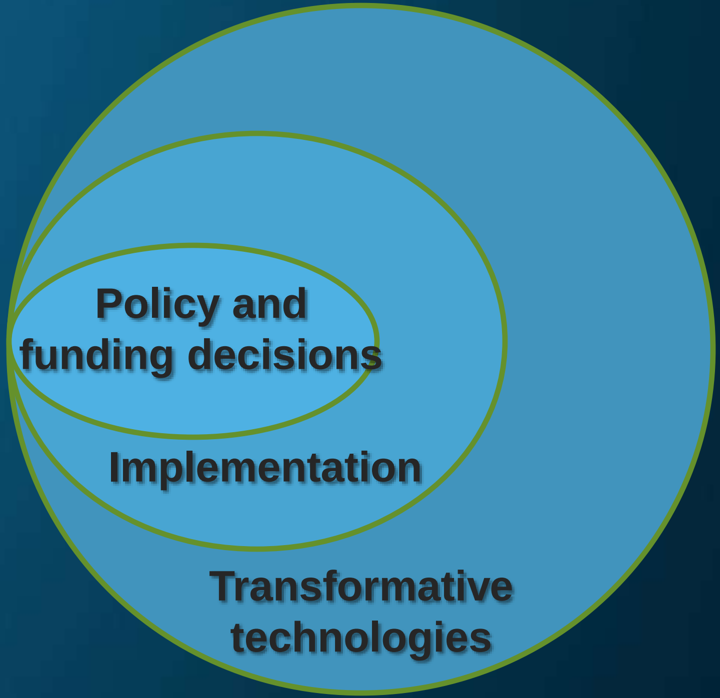
The Equinox Process: Global Thinking

Quorum
scientific experts

Advisors
policy & investment

Forum
future leaders

Blueprint Recommendations



Policy and funding decisions

Implementation

Transformative technologies

Equinox Summit: Energy 2030

Benchmarking

Rebooting Public Dialogue

msnbc

tvo

nature

SCIENTIFIC AMERICAN

The New York Times

ABC
Australian
Broadcasting
Corporation

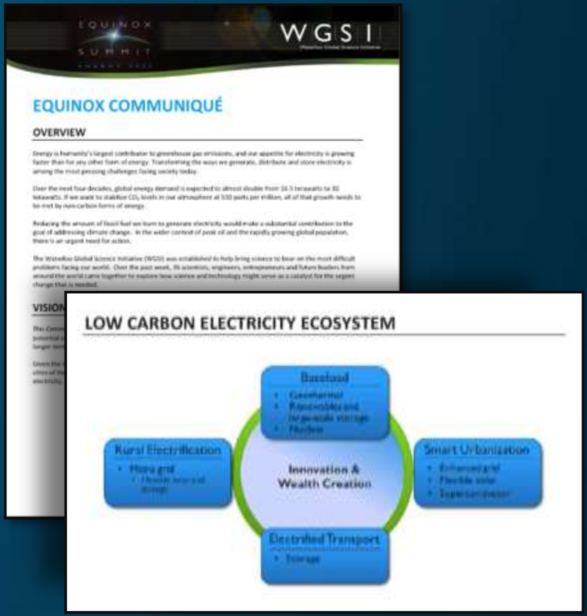
BBC
AFRICA

twitter

THE AGENDA
WITH STEVE PAIKIN

wgsi.org

Communiqué



EQUINOX COMMUNIQUÉ

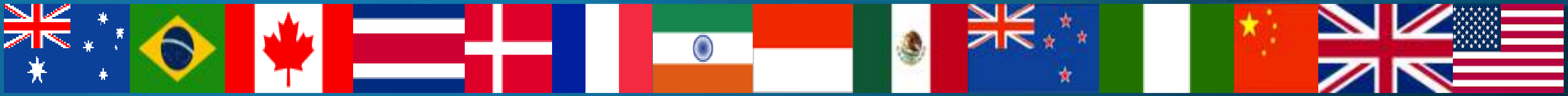
OVERVIEW

VISION

LOW CARBON ELECTRICITY ECOSYSTEM

Young Future Leaders

Global Thinking



Generation

- Solar/ Wind
- Geothermal
- Nuclear

Distribution

- Superconductors
- Smart Grids

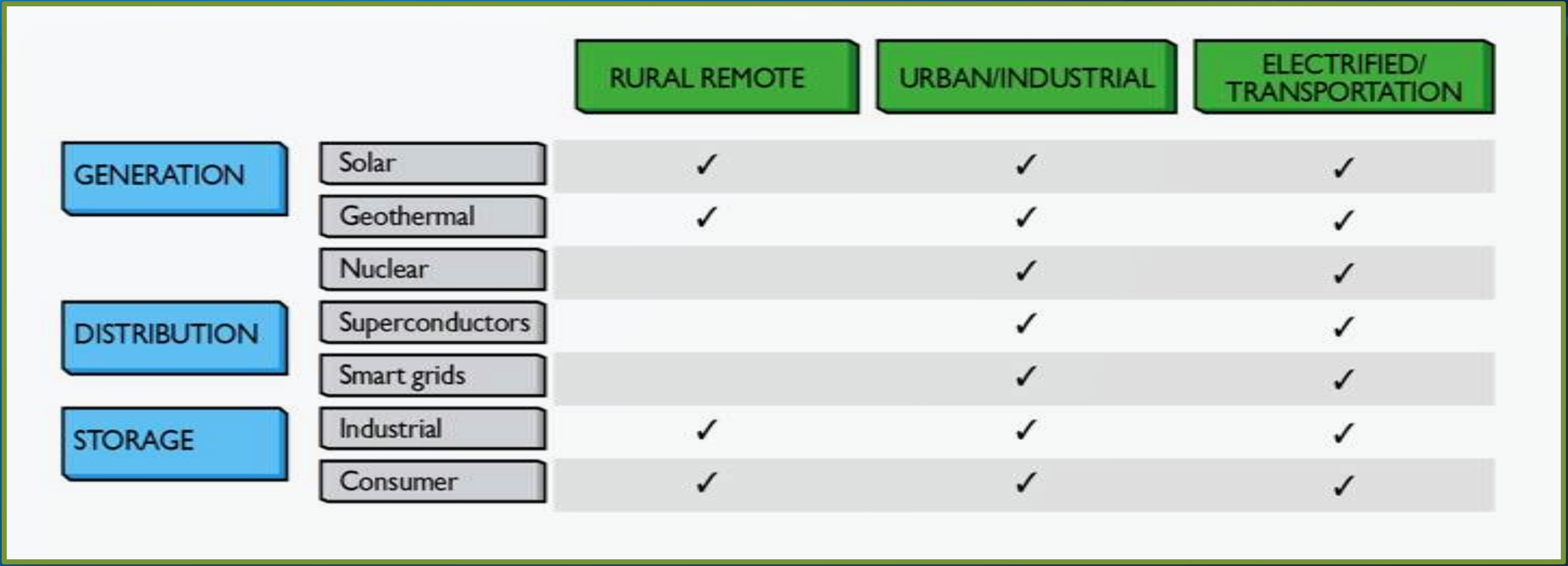
Storage

- Industrial
- Consumer

Societal Needs

- De-carbonization
- Efficiency
- Access
- Security
- Affordability

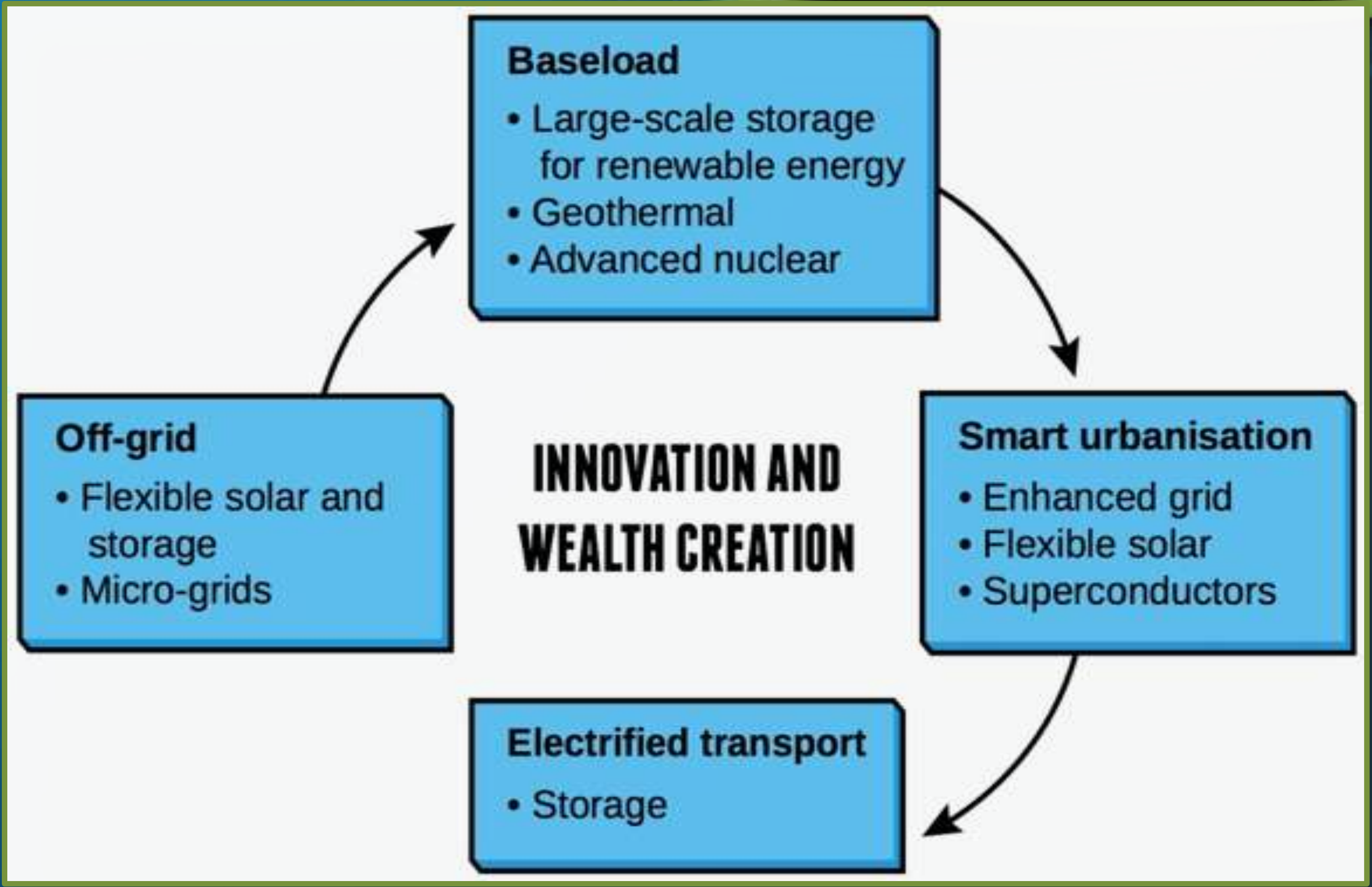
Guiding the discussion: A model of the global electricity landscape



		RURAL REMOTE	URBAN/INDUSTRIAL	ELECTRIFIED/ TRANSPORTATION
GENERATION	Solar	✓	✓	✓
	Geothermal	✓	✓	✓
	Nuclear		✓	✓
DISTRIBUTION	Superconductors		✓	✓
	Smart grids		✓	✓
STORAGE	Industrial	✓	✓	✓
	Consumer	✓	✓	✓

How are transformative technologies integrated into this model?

Low-Carbon Electricity Ecosystem



Baseload

- Large-scale storage for renewable energy
- Geothermal
- Advanced nuclear

Smart urbanisation

- Enhanced grid
- Flexible solar
- Superconductors

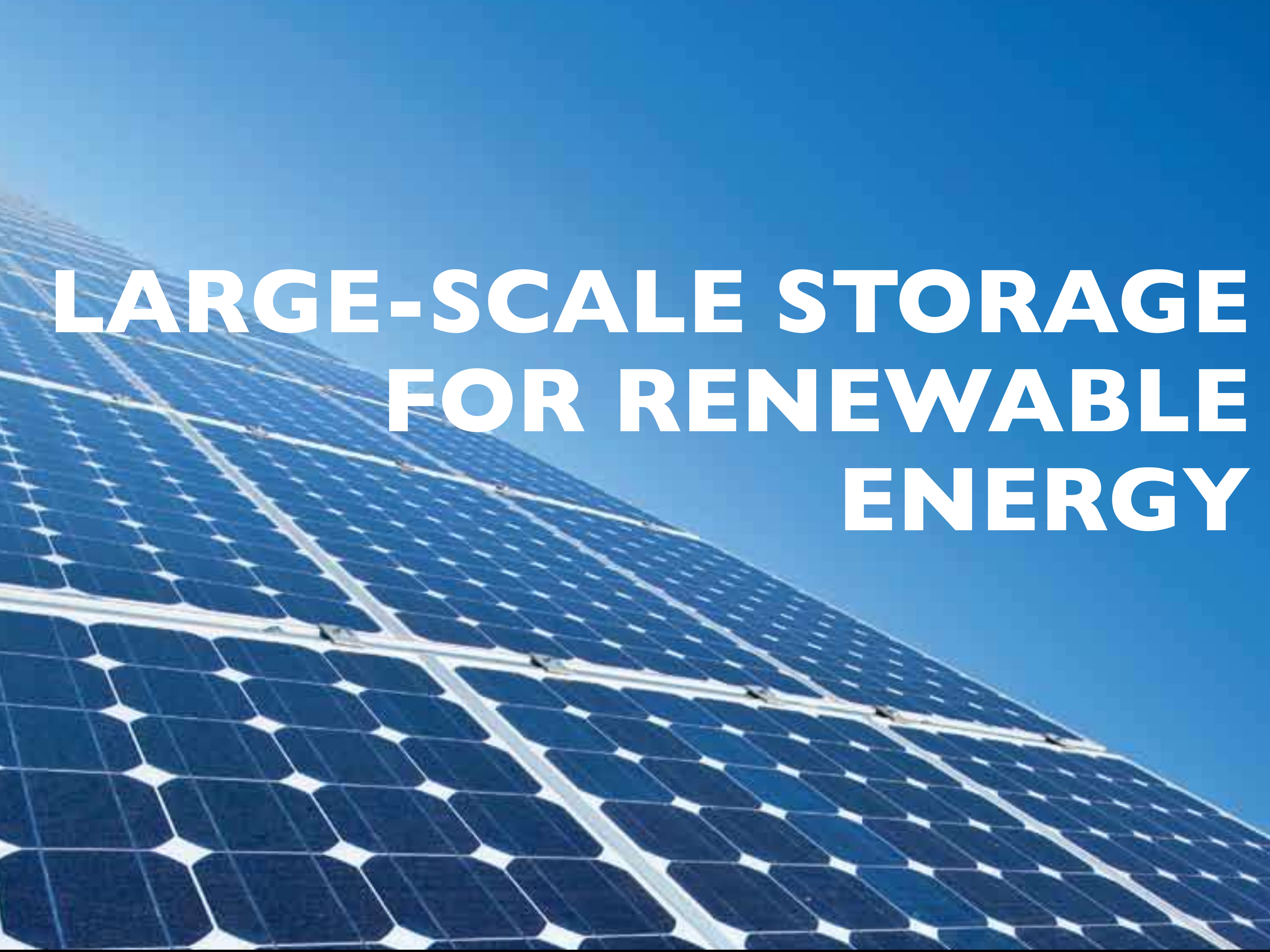
Electrified transport

- Storage

Off-grid

- Flexible solar and storage
- Micro-grids

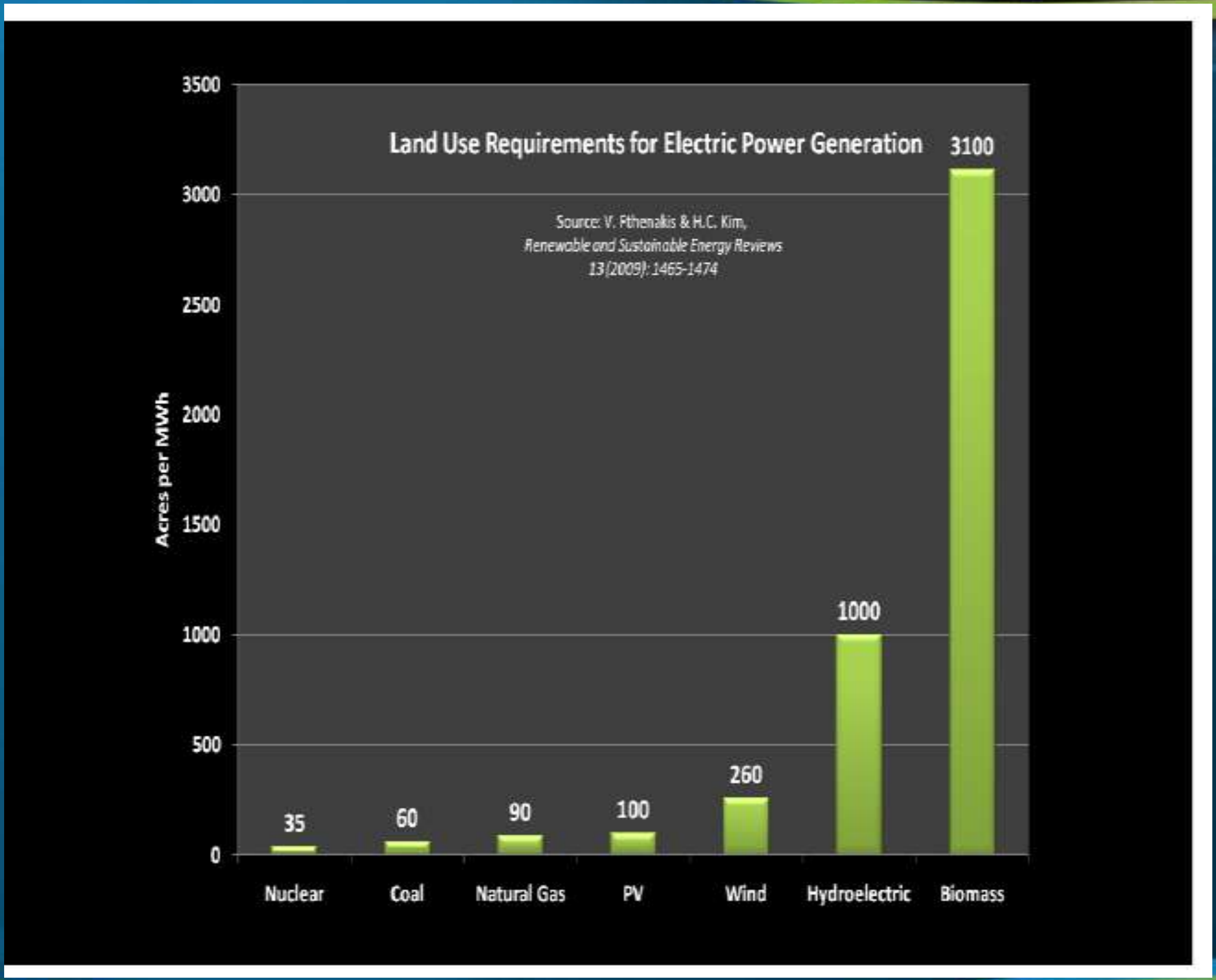
INNOVATION AND WEALTH CREATION



LARGE-SCALE STORAGE FOR RENEWABLE ENERGY

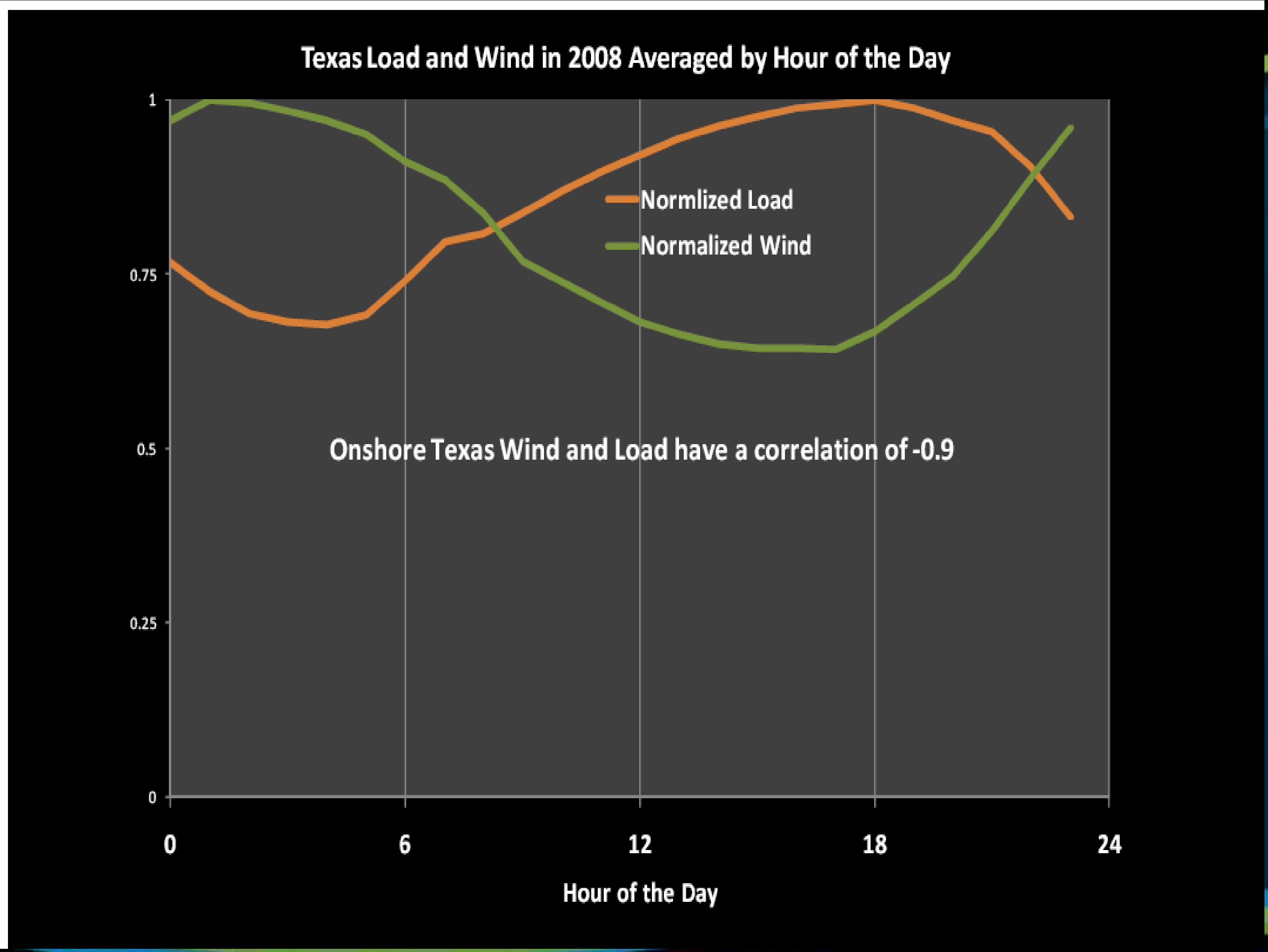
Land use can be benign

Or, Not so Benign



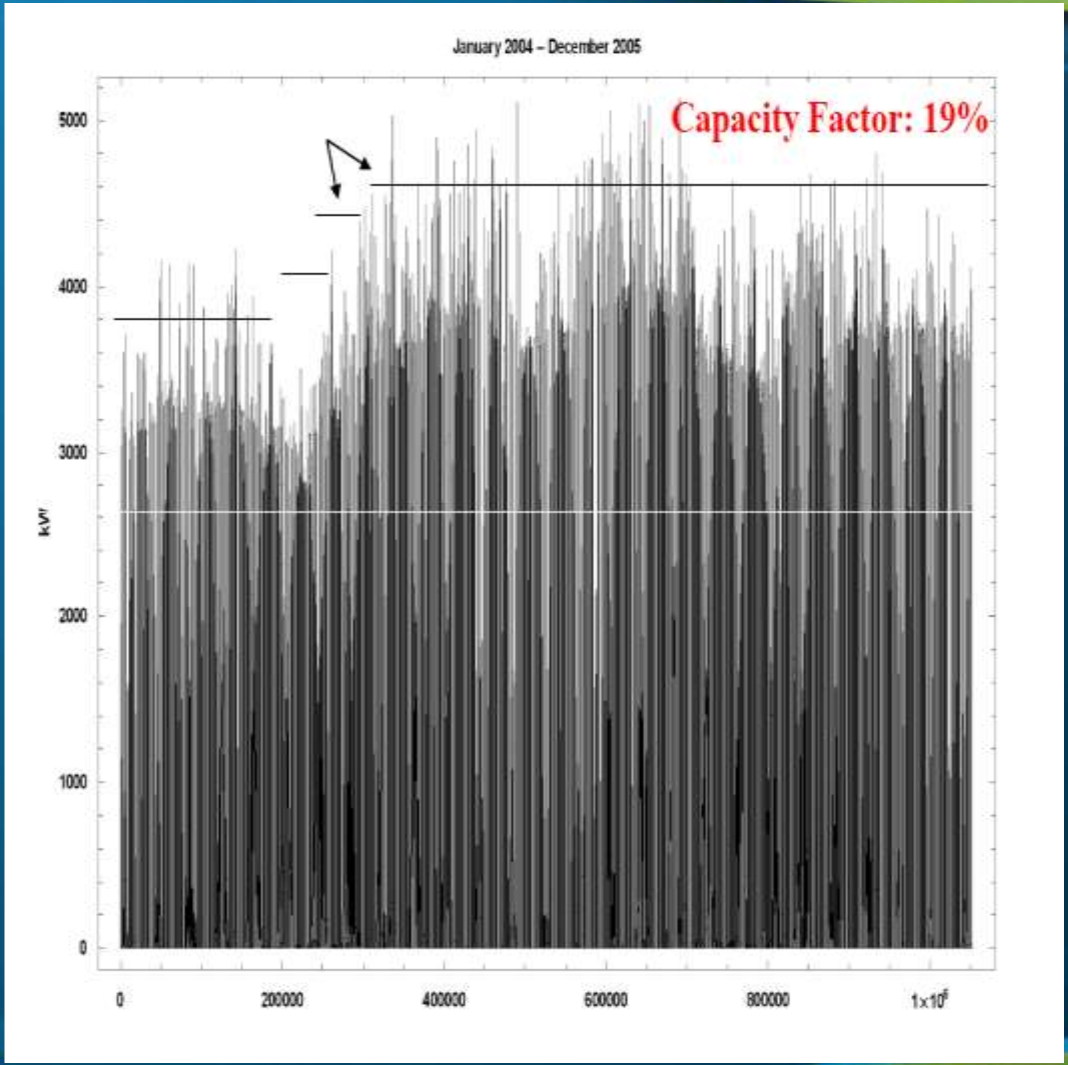
Land Use Requirements for Electric Power Generation

Source: V. Fthenakis & H.C. Kim, *Renewable and Sustainable Energy Reviews* 13(2009): 1465-1474



Texas Load and Wind in 2008 Averaged by Hour of the Day

Onshore Texas Wind and Load have a correlation of -0.9

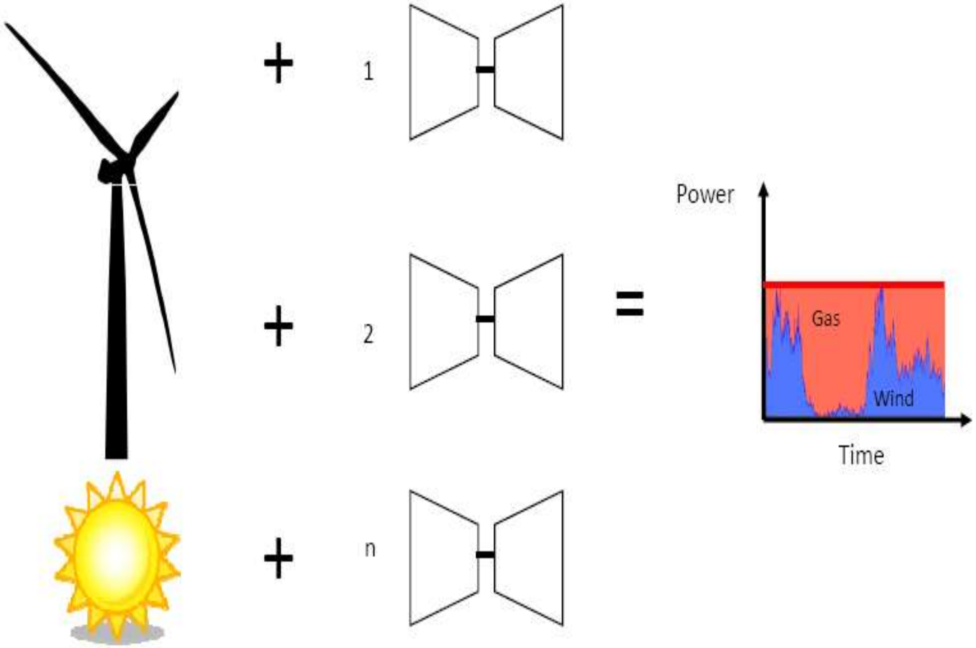

January 2004 – December 2005
Capacity Factor: 19%
kW
5000
4000
3000
2000
1000
0
0
200000
400000
600000
800000
1×10^6

CO_2 and NO_x from natural gas that fills in

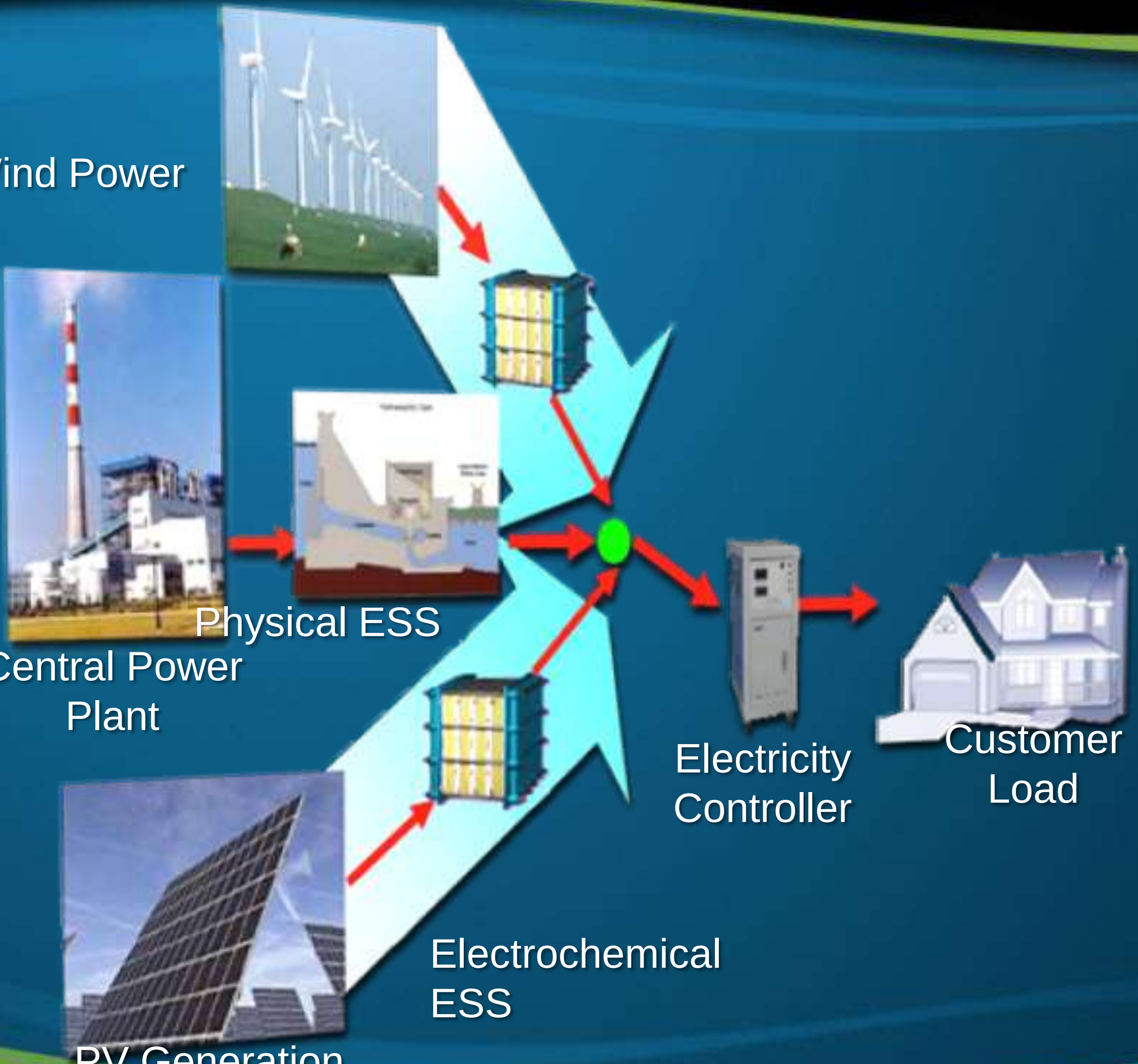
Variable Power

Compensating Power

Firm Power



Energy Storage for the Future Grid



Wind Power

Central Power Plant

Physical ESS

PV Generation

Electrochemical ESS

Electricity Controller

Customer Load

Future Grid

- Reliable and stable output
- Storage critical for increased compatibility of renewable energy to the grid.

Large scale storage for renewable energy

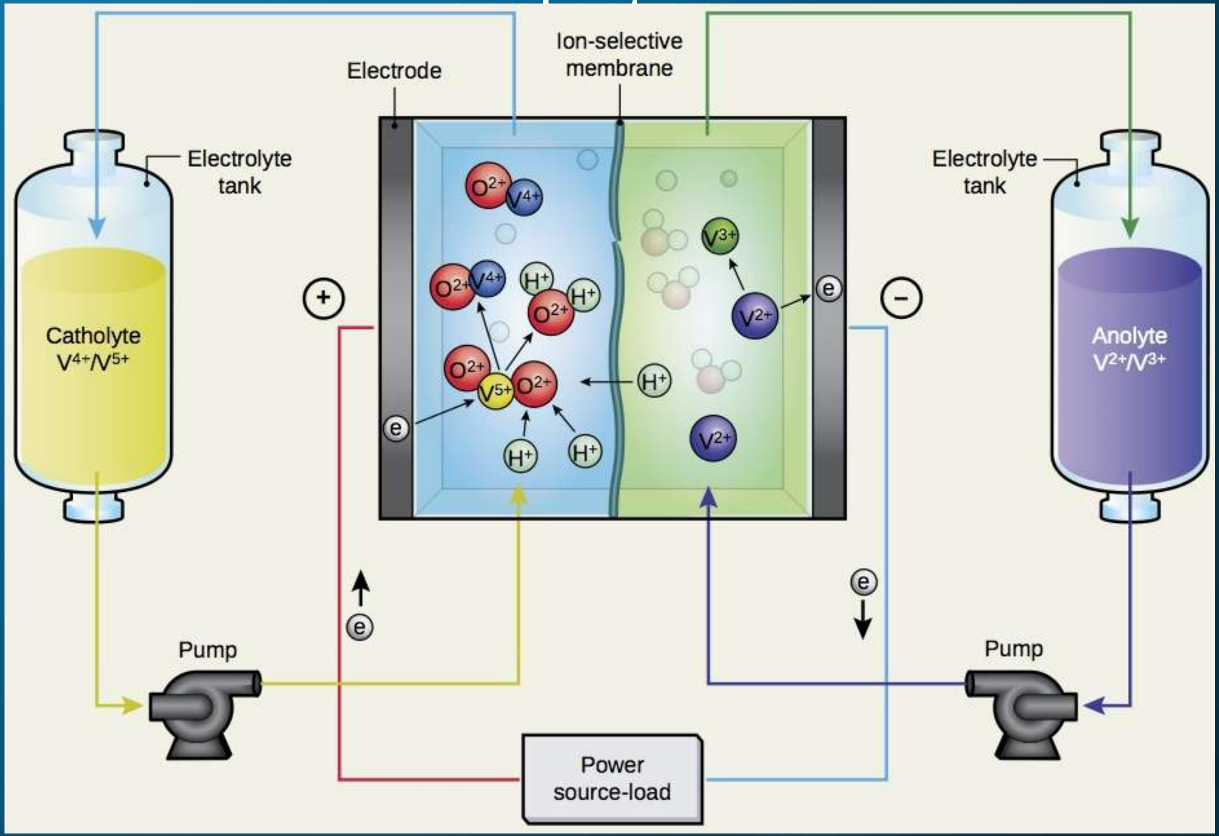
Flow batteries as an illustrative example of electrochemical batteries in grid application

Figure 2: A 1-10 kWh VRB installed by UNSW in a Solar Demonstration House in Thailand in the mid-1990s (top) and 5kWh VRB lab test battery (bottom).

Figure 4: 200 kW/800 kWh VRB installation at the Kashima-Kita Electric Power station in Japan (installed in the mid-1990s).

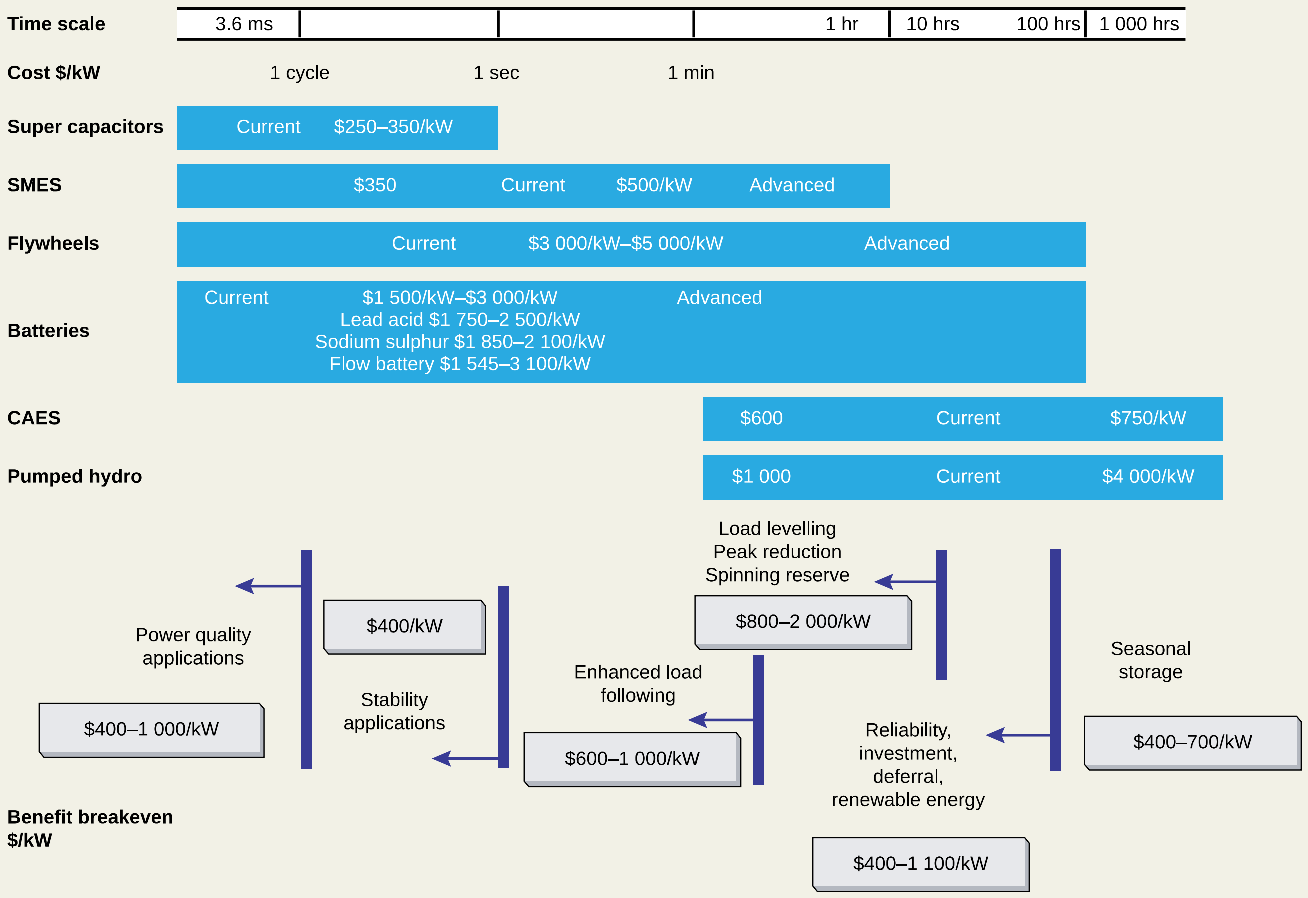
Large scale storage for renewable energy

How flow batteries work: one common electrolyte, simplicity of electrode reaction, and flexibility for stationary energy storage



Large scale storage for renewable energy

Characteristic times for energy storage and cost benefit



Time scale 3.6 ms | | | 1 hr | 10 hrs 100 hrs | 1 000 hrs

Cost $/kW 1 cycle 1 sec 1 min

Super capacitors Current $250–350/kW

SMES $350 Current $500/kW Advanced

Flywheels Current $3 000/kW–$5 000/kW Advanced

Batteries Current $1 500/kW–$3 000/kW Advanced
Lead acid $1 750–2 500/kW
Sodium sulphur $1 850–2 100/kW
Flow battery $1 545–3 100/kW

CAES $600 Current $750/kW

Pumped hydro $1 000 Current $4 000/kW

Power quality applications
$400–1 000/kW

$400/kW
Stability applications

Enhanced load following
$600–1 000/kW

Load levelling
Peak reduction
Spinning reserve
$800–2 000/kW

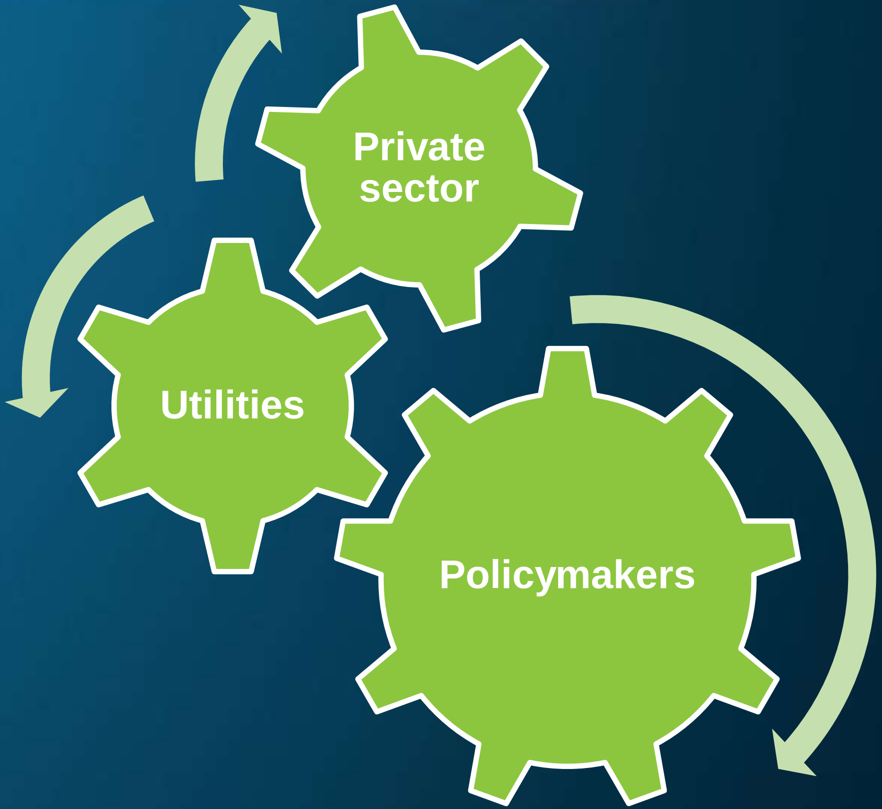
Reliability, investment, deferral, renewable energy
$400–1 100/kW

Seasonal storage
$400–700/kW

Benefit breakeven $/kW

Implementation:
Large scale storage

- Regions with high intermittent renewable energy production
- Policymakers and electrical utilities to coordinate regulatory framework
- Private sector to build energy storage infrastructure



2020-2030

Establish a thriving market in energy storage through deployment on a global scale

ENHANCED GEOTHERMAL POWER

The Krafla geothermal power plant in Iceland produces 60 MW of energy. Iceland's five major geothermal power plants produced approximately 26.2% of the nation's energy in 2010.

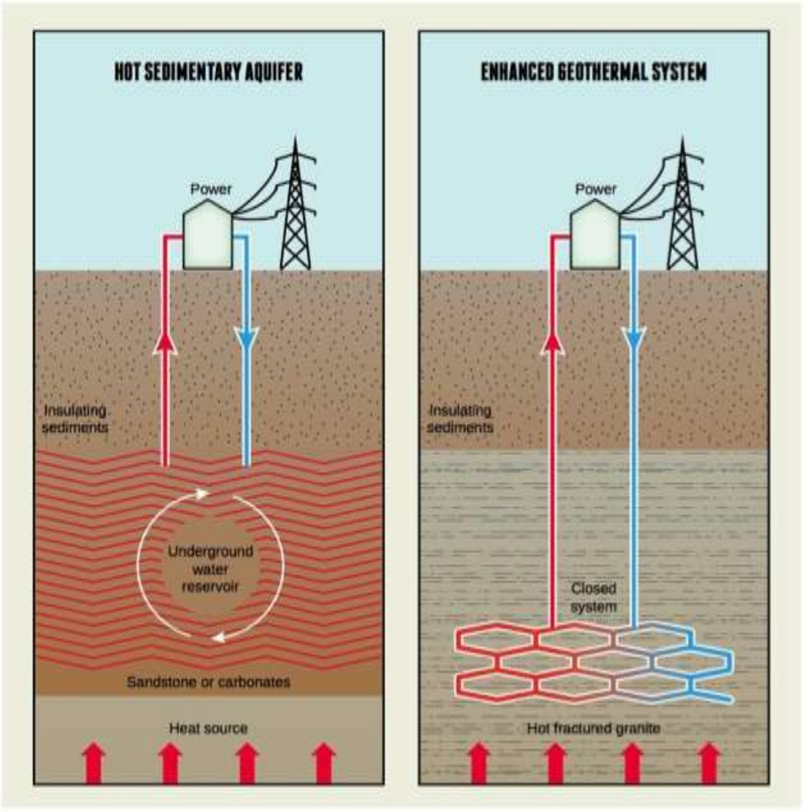
Low Emission Baseload Power

GEOPOWER

Enhanced Geothermal Power

Geothermal technologies

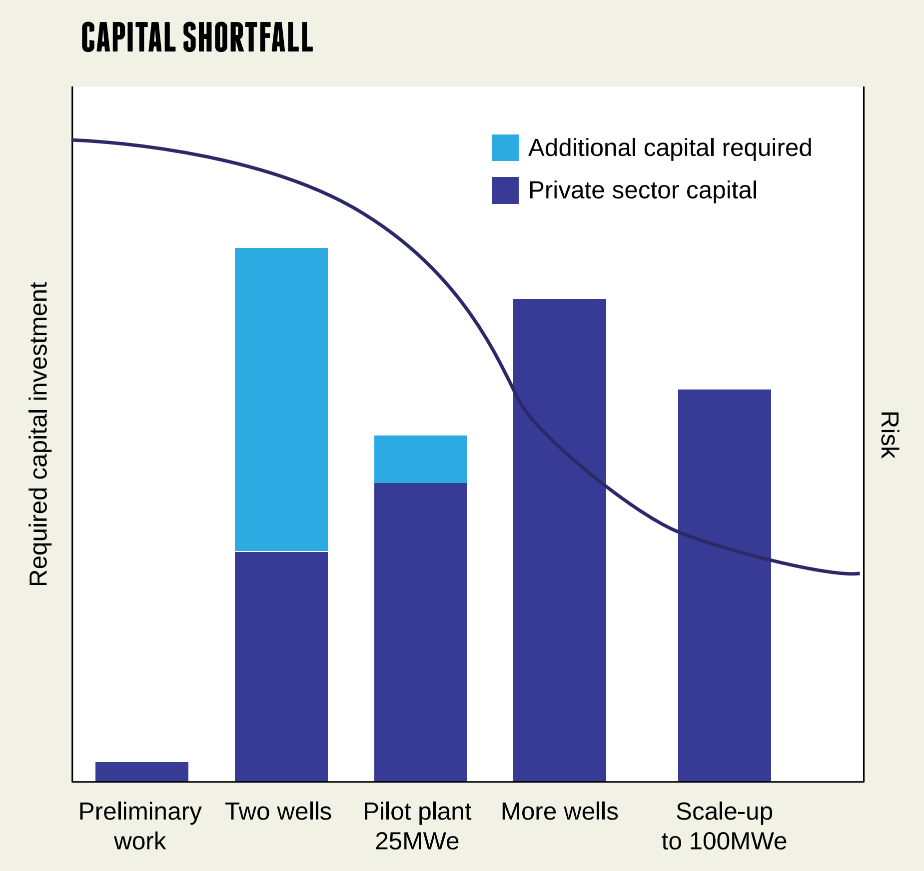
- Enhanced Geothermal Systems (EGS)
- Co-produced systems
- Advanced binary-cycle plants



Enhanced Geothermal Power

Challenges for EGS

- Large upfront capital cost for drilling projects
- Lack of access to private sector capital to undertake high-risk capital intensive projects
- Lack of long-term investment incentives such as a price on carbon
- Lack of proof of resource for many geothermal prospects
- Lack of technically and commercially proven projects



Geothermal Power Potential

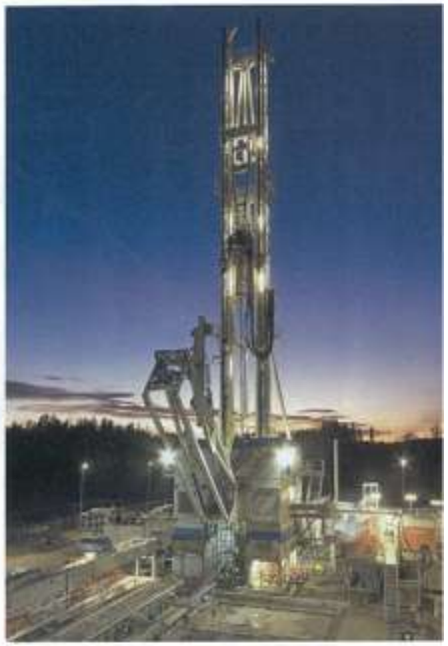
- Currently 10 GW, potential is 10% baseload by 2030
- A number of working projects globally, advancing different technologies (HAS, EGS, Co-produced, Hydrothermal)
- Several large demo projects to <u>deliver certainty and confidence</u>
- Canada can take a leadership role in advancing geopower to the terawatt scale

Energy from the Earth

Clean Power from the Deep

Practically endless energy potential lies in the depths of the Earth: heat, stored within the rock. Drilling technology from Germany makes geothermal energy economically feasible

By Rainer Stumpf



First you leave the *autobahn*, drive a few kilometres down a country road and turn sharp right at the small sign with the blue GFZ logo. The journey then continues down a bumpy dirt track for almost 400 metres, past the trucks at the gravel pit, and finally the white top of the drilling derrick becomes visible over the tops of the trees. On 19 February, more than 100 geologists, engineers and energy experts from all over Europe took this route from Munich to the tiny village of Dürrnhaar in order to gain nothing less than an exclusive insight into the future of geothermal energy. It bears the somewhat unwieldy name of InnovaRig, is nearly 52 metres tall and, with a 2,700-horsepower drive unit, is powerful enough to drill up to 5,000 metres into the ground. The operators do not aim to extract oil or gas, but are instead raising a very special treasure: hot water. From the end of 2008 this natural resource should be driving a five megawatt power plant that will simultaneously generate both electricity and heat – around the clock and independently of the wind and the sun. The drilling installation in Dürrnhaar is unique. In collaboration with the Herrenknecht tunnel-drilling specialists, the German Research Centre for Geosciences (GFZ) in Potsdam has developed a deep drilling system packed full of innovations. On this sunny February day the guests stand crowded together in the Bavarian countryside stretching their heads in the direction of the derrick. Yet there is no sound and no smell. That is precisely what makes InnovaRig so unique, says Martin Herrenknecht, CEO of the business of the same name: "The installation operates waste-free and so silently that it can even be used in populated areas." That is an important advantage for geothermal energy, because its use is only economically viable where there is sufficient demand in the immediate vicinity. The assembly of the drills is carried out fully automatically, various drilling techniques can be used – as required – and this "technological masterpiece", as Herrenknecht puts it, can drill up to 100 metres a day. The expert onlookers nod appreciatively and busily take notes. By the summer, 150 litres of water per second will be flowing to the surface at a temperature of 140 degrees Celsius.

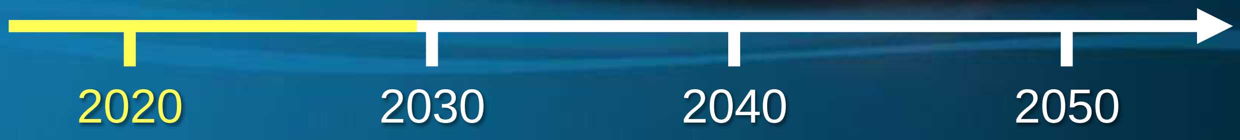
The CEO saves the best until last: "When we reach the water, we will realign the system six metres to drill a second hole." Enthusiastic applause. After all, that's never been done before either. Extracting geothermal energy always requires the drilling of two holes: the hot water is pumped out of one hole, the heat is used to produce energy and the cooled water is pumped back into the hot rock formation through a second hole. This used to be an expensive business because the drill had to be dismantled and reassembled at another position – not any more. Using the mobile

Implementation:
Enhanced Geothermal Technologies

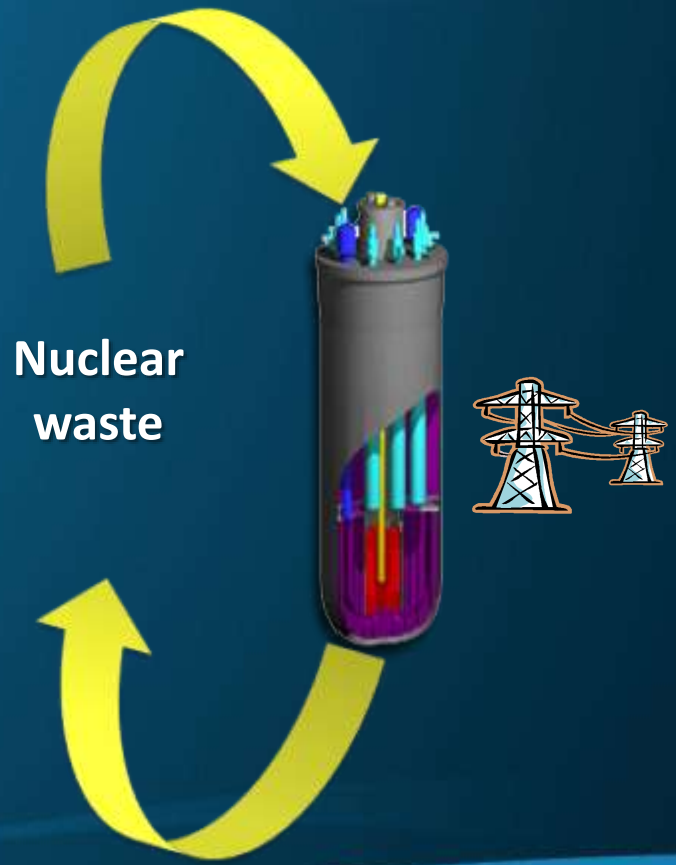
- Convene International stakeholders
  - Information sharing;
  - assess opportunities;
  - de-risk industry
- "Ten Enhanced Geothermal Projects' is timely and relevant.
  - Initial funding and global working structure
  - Develop program strategy moving forward

ADVANCED NUCLEAR POWER

Challenging your assumptions about nuclear



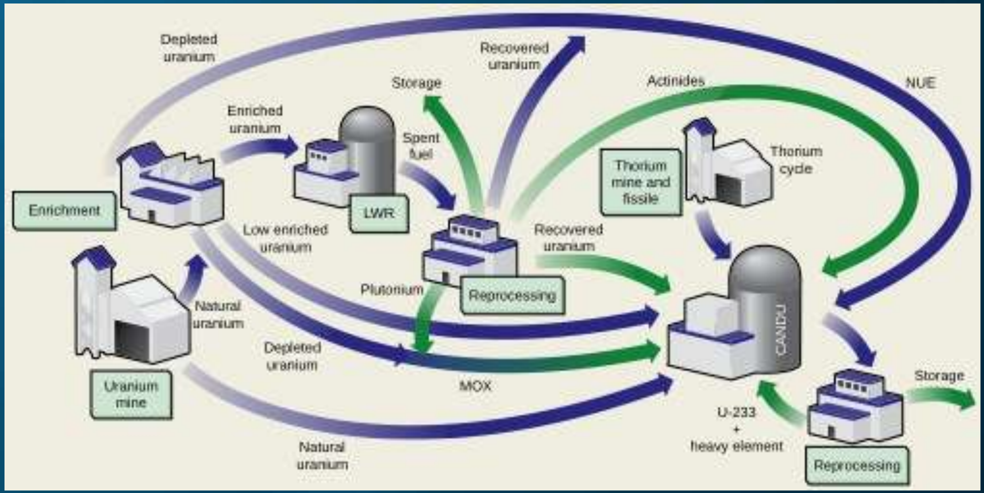
- Nuclear waste is fuel
  - Avoids long-term storage
- Closing the fuel cycle
  - Inexhaustible supply
- Inherent safety
  - Public acceptance
- Decarbonizes base load
  - Eliminates coal



Advanced Nuclear Power

Why nuclear?

- Proven capacity to deliver on a large scale
- Build on existing technological base
- Closing the fuel cycle: eliminate waste, improved safety, near inexhaustible resource
- Transition from fossil fuels without Advanced Nuclear Technologies?



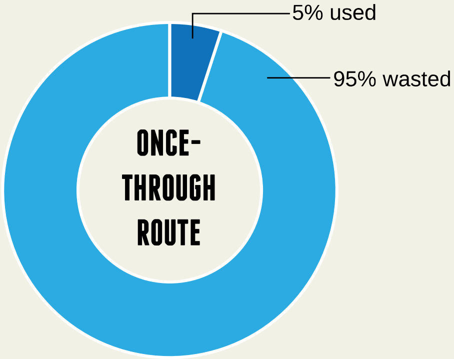
Advanced nuclear fuel cycle concepts

Advanced Nuclear Power

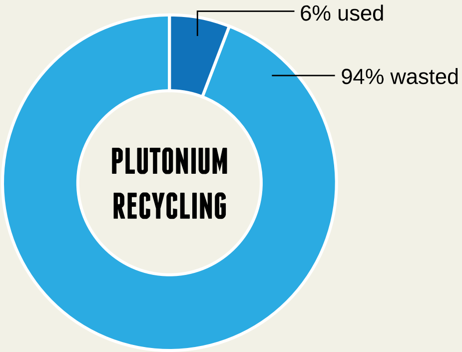
Comparing three nuclear fuel cycles

Three major approaches to burning nuclear fuel and handling its wastes can be employed; some of their features are noted below.

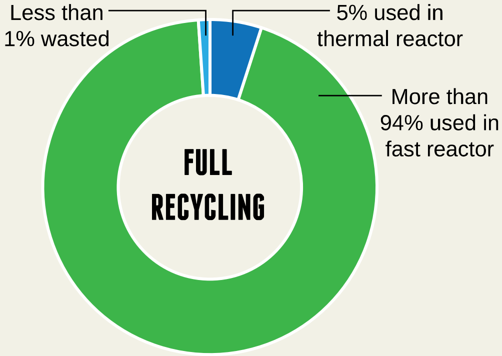
Fuel is burned in thermal reactors and is not reprocessed; occurs in the U.S.



Fuel is burned in thermal reactors, after which plutonium is extracted using what is called PUREX processing; occurs in other developed nations



Recycled fuel prepared by pyrometallurgical processing would be burned in advanced fast-neutron reactors; prototype technology



Fuel utilisation

Uses about 5% of energy in thermal-reactor fuel and less than 1% of energy in uranium ore (the original source of fuel)

Cannot burn depleted uranium (that part removed when the ore is enriched) or uranium in spent fuel

Uses about 6% of energy in original reactor fuel and less than 1% of energy in uranium ore

Cannot burn depleted uranium or uranium in spent fuel

Can recover more than 99% of energy in spent thermal-reactor fuel

After spent thermal-reactor fuel runs out, can burn depleted uranium to recover more than 99% of the rest of the energy in uranium ore

CANDU High Fuel Efficiency & Flexibility

CANDU Fuel-Capability Uniqueness:

- **Lowest uranium consumption/unit of energy supplied**
- **CANDU can utilize:**
    - ➢ **Natural uranium**
    - ➢ **Enriched uranium**
    - ➢ **Recovered uranium**
    - ➢ **Mixed oxides**
    - ➢ **Thorium**
    - ➢ **Actinide waste**

Advanced Nuclear Power

Next generation designs

- Integral Fast Reactors:
  - allow the nuclear fuel cycle to be closed
  - ‘burn’ most the nuclear fuel waste
  - turn waste liability into an asset

- Thorium Accelerator-Driven System:
  - sub-critical fission through the constant introduction of fast neutrons into the reactor core

Advanced Nuclear Power

Challenges for implementation

- Proliferation and safety
- Skepticism
- Difficulty to assess the trade-offs between benefits and risks
- Industry inertia
- Political stalemate: but China and India are plowing ahead

🟩 Countries with operational reactors that have announced no safety reviews or policy changes

▨ Countries that are reviewing their existing reactors

🟩 Countries conducting wider appraisals of reactors and nuclear safety standards

🟦 Countries that are ending their nuclear power programs

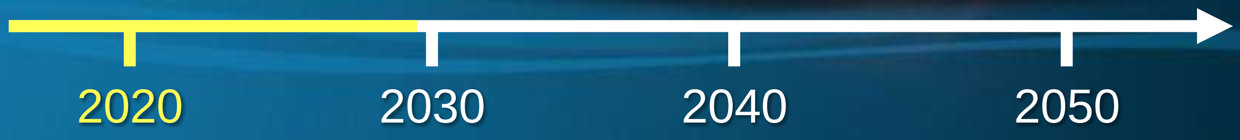
🟪 Countries with their first reactors in planning or proposal stages; some of these countries have not yet declared whether they'll follow through with their nuclear plans

🟦 2 Reactors in use

🟨 2 Reactors under construction

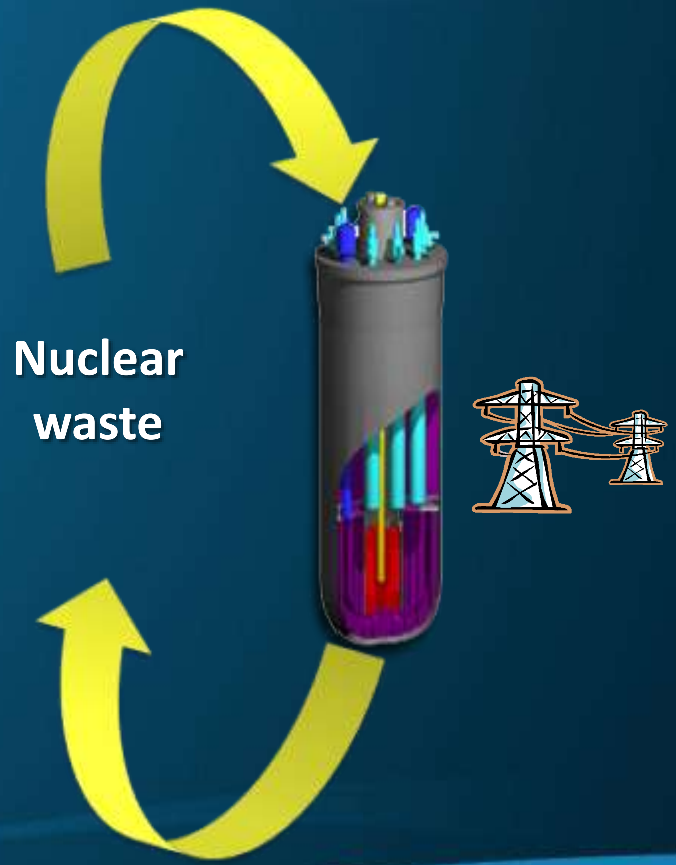
🟩 2 Reactors planned/proposed

The path towards sustainability



2020 2030 2040 2050

- 400 – 800 GWe
  - Business as usual, open fuel cycle
- 1200 GWe by 2030 / 7000 GWe by 2050
  - Accelerated alternative scenario
  - Only made possible by closing fuel cycle
- Commercial demos
  - IFR by 2020 & Th-ADS by 2030
  - Multilateral initiative scale of ITER



Nuclear waste

OFF-GRID ELECTRICITY ACCESS

Electricity Access for All

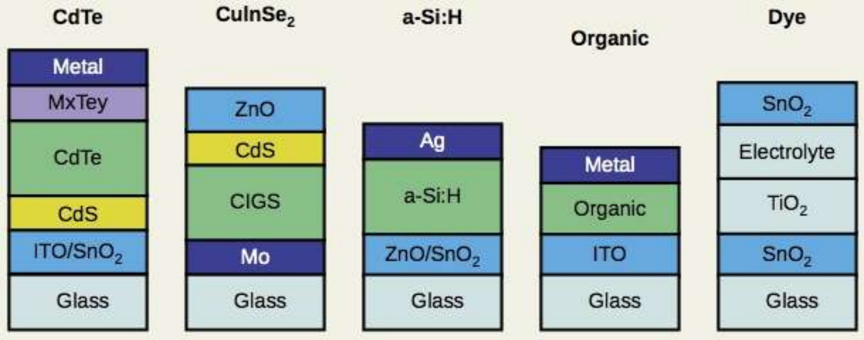
2.5 billion energy-poor people

Plastic Organic PV with Magnesium batteries

Off-Grid Electricity Access

Organic Photovoltaics (OPV) as an illustrative example

- PV technologies in development form an ecosystem from silicon-based photovoltaics to thin films and emerging next-generation nanotechnology concepts
- They in turn are a part of a larger system with the potential to be integrated within smart micro-grids, along other local renewable resources



The thin film family: amorphous silicon, copper indium gallium diselenide (CIGS), cadmium telluride (CdTe), organic thin films and dye-sensitised integrated photovoltaic

Off-Grid Electricity Access

OPV

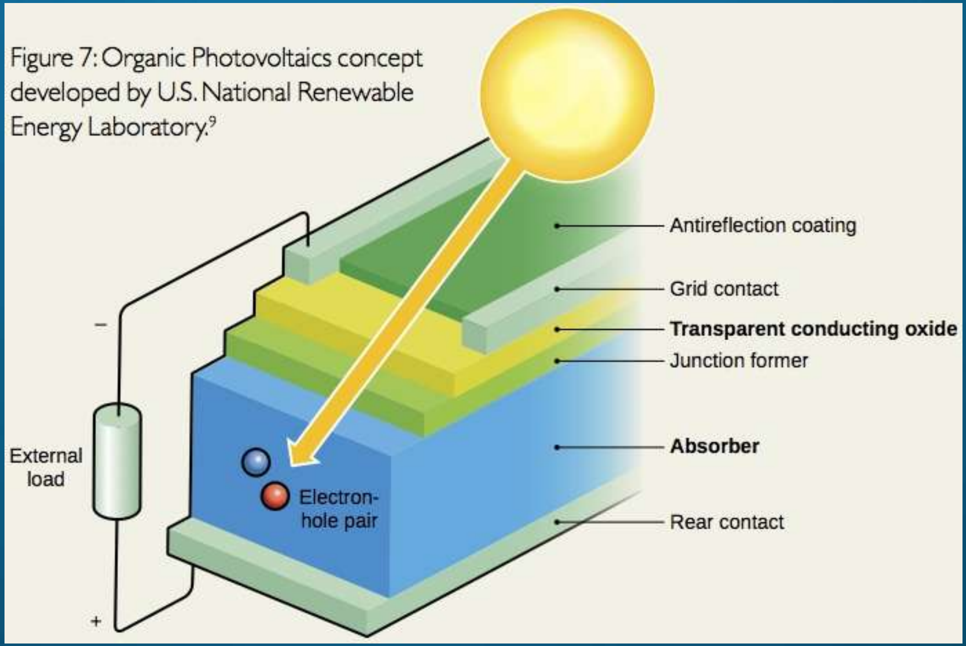
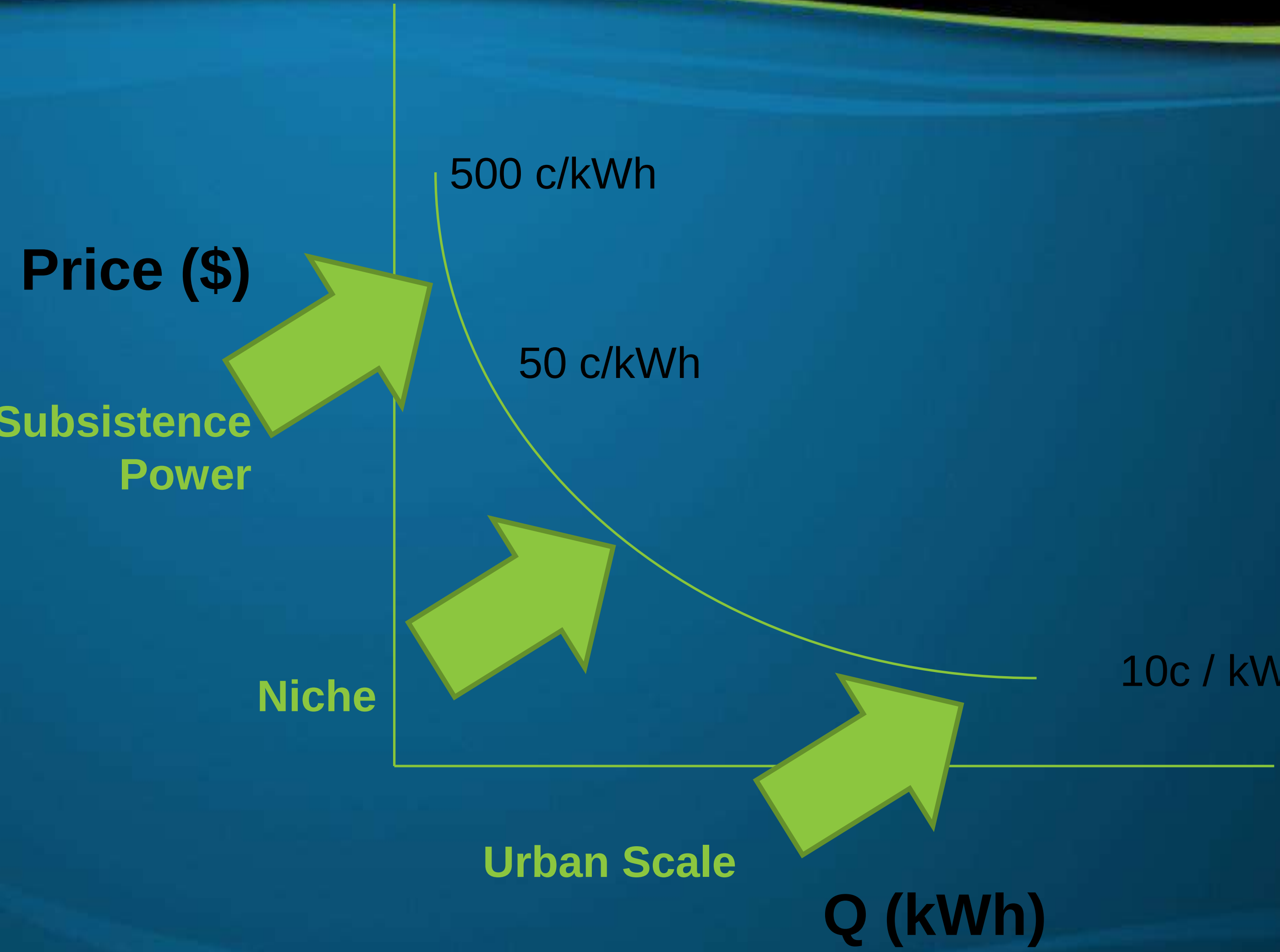


Figure 7: Organic Photovoltaics concept developed by U.S. National Renewable Energy Laboratory.[9]

OPV has the potential to become one of the lowest- cost thin-film alternatives to the currently dominant silicon photovoltaic technology, due to their potential for low-cost, high-speed processing

The context



Price ($)

500 c/kWh

50 c/kWh

Subsistence Power

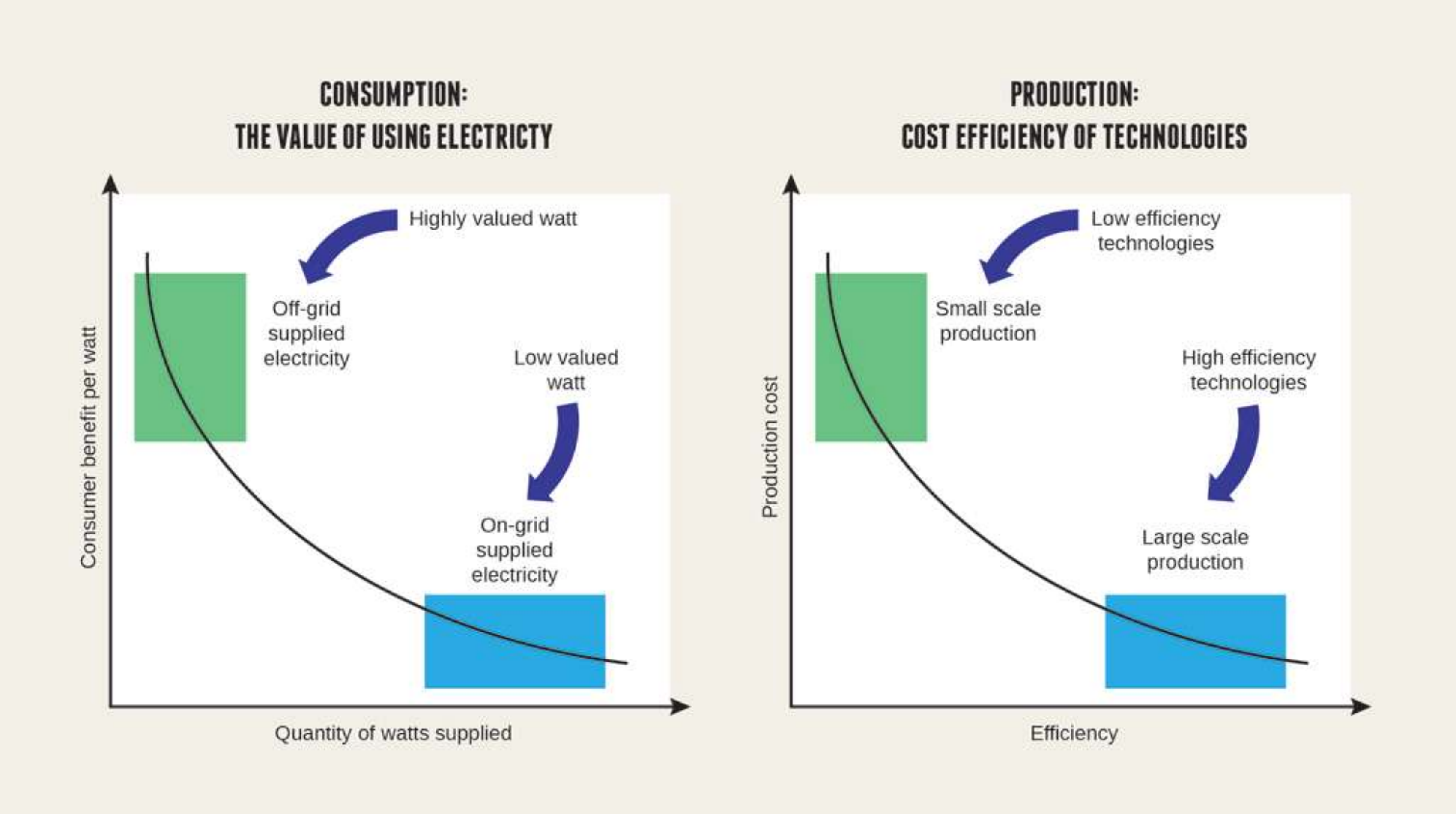
Niche

10c / kWh

Urban Scale

Q (kWh)

Low WTP : High kWh use
High WTP : Low kWh use



High WTP, Low kWh

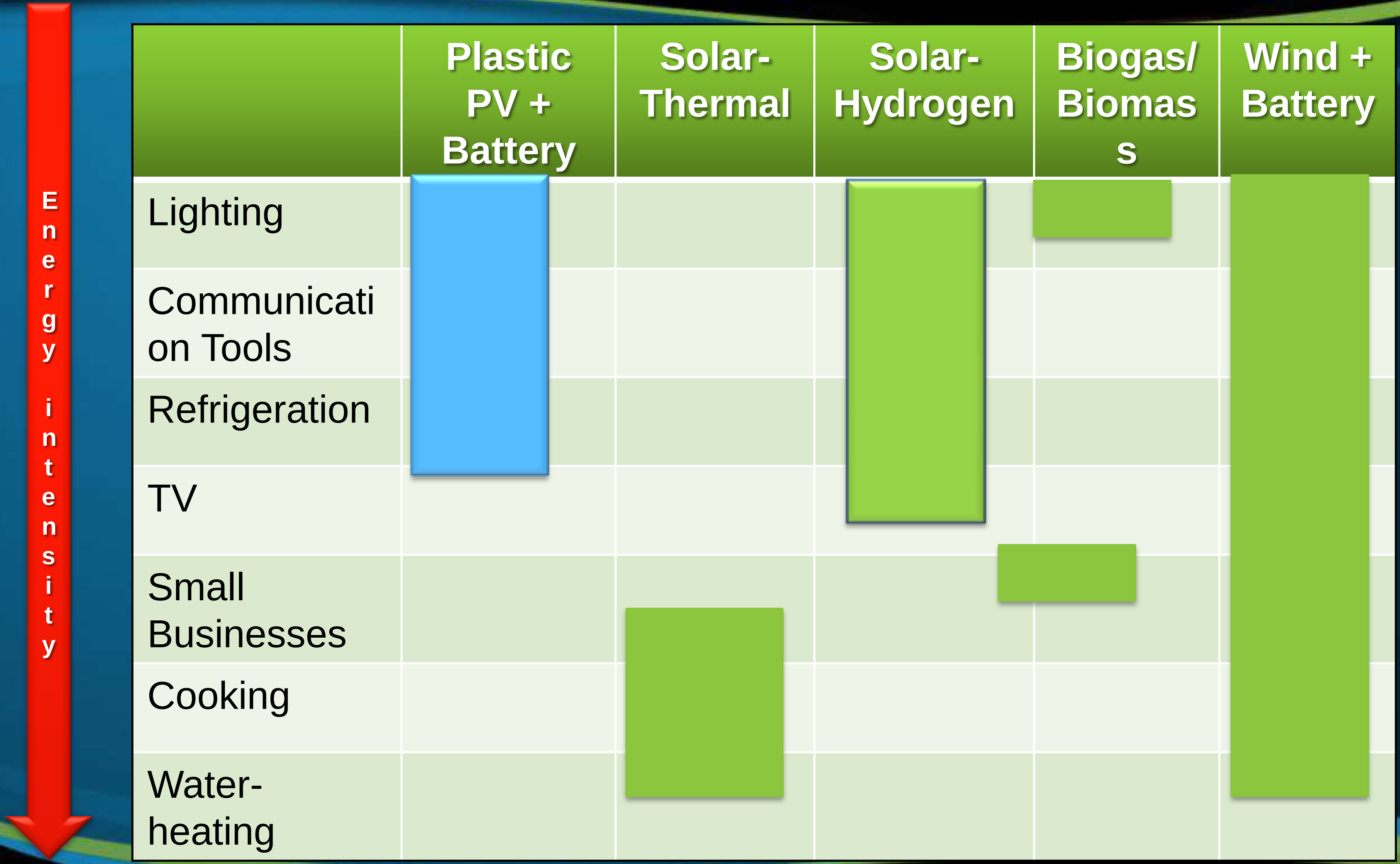
- 2.5 billion people without electricity (500 million households)
- @$200/system, $100B
    - Cost of systems being purchased now in Haiti

Low Cost Innovations:
Critical Pathways for Human Development Goals

Flexible, Portable, Light-weight and Resilient.

Attractive Price.

Solutions

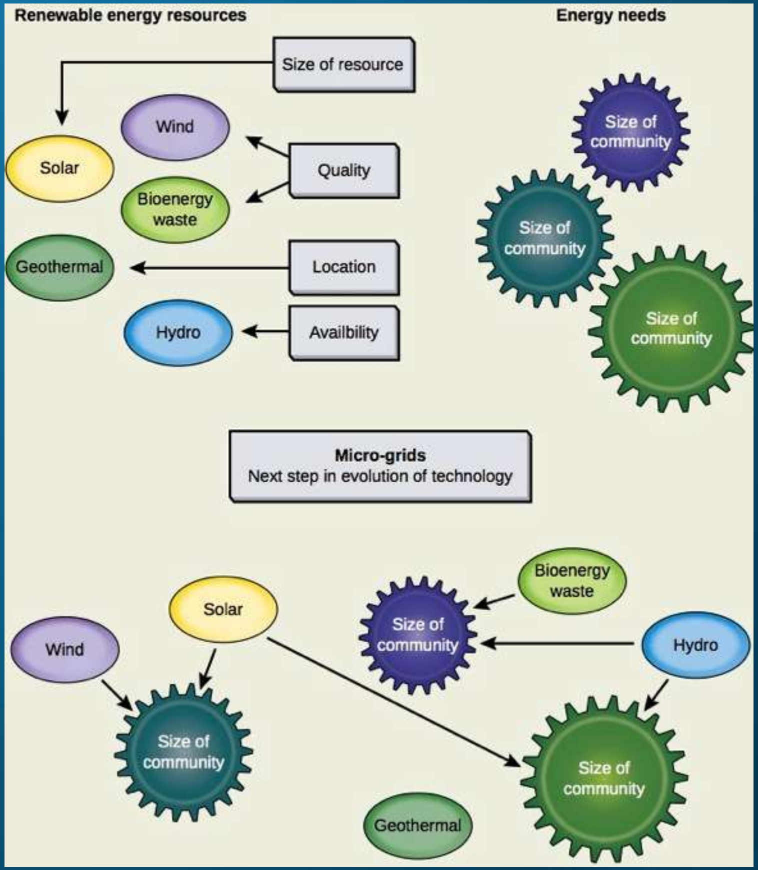


Energy intensity

	Plastic PV + Battery	Solar-Thermal	Solar-Hydrogen	Biogas/ Biomass	Wind + Battery
Lighting	🟦		🟩	🟩	🟩
Communication Tools	🟦		🟩		🟩
Refrigeration	🟦		🟩		🟩
TV			🟩		🟩
Small Businesses		🟩		🟩	🟩
Cooking		🟩			🟩
Water-heating		🟩			🟩

Off-Grid Electricity Access

Beyond OPV: Micro-grids



2030 → 500,000,000 households

Medium WTP, Medium kWh

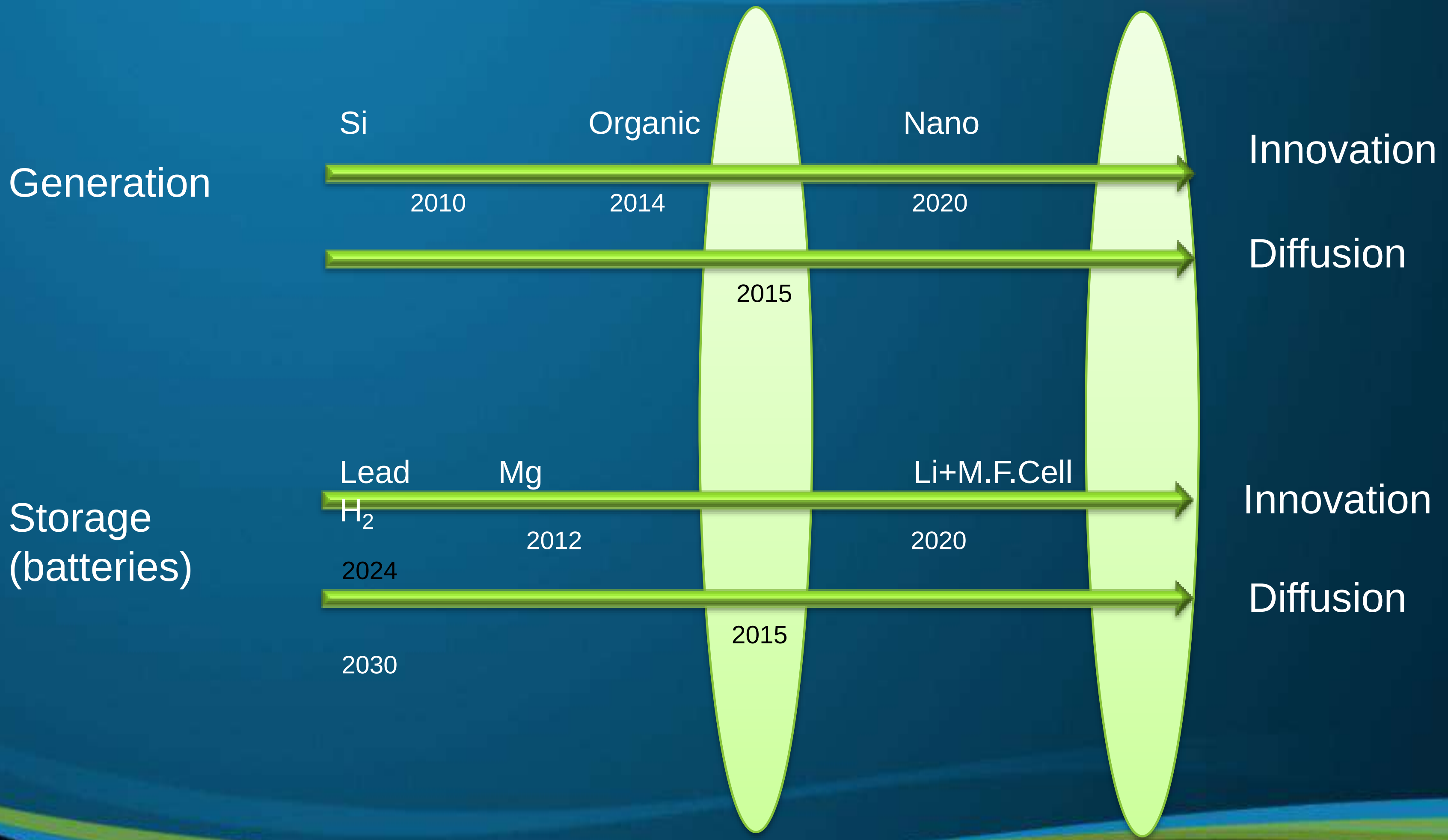
Replace Si based PV in applications such as:

- Water pumps
- Refugee camps
- Military forward bases ($ > 100+/gallon delivered diesel)
- Distributed sensors (rugged for deployment)

Realistic Partnership Potential

Business/ Industry	**Civil Society**	**Government**	**International Organizations**
			UNFCCC (NAMAs) UNHCR Red Cross/Crescent Development Banks
Digicel			

Timelines



Generation

Si

Organic

Nano

2010

2014

2020

Innovation

Diffusion

2015

Storage (batteries)

Lead

Mg

Li+M.F.Cell

H_2

2012

2020

2024

Innovation

Diffusion

2015

2030

Implementation:
Off-Grid Electricity Access

Near-term

- Identify partners, align finances
- R&D, efficiency increases in Organic Photovoltaics

Within 5 Years

- Finances in place/business models developed
- Policy framework and incentives in place
- Societal acceptance and scale-up of production

Within 20 years

- Expansion of market
- next-generation Organic Photovoltaics

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

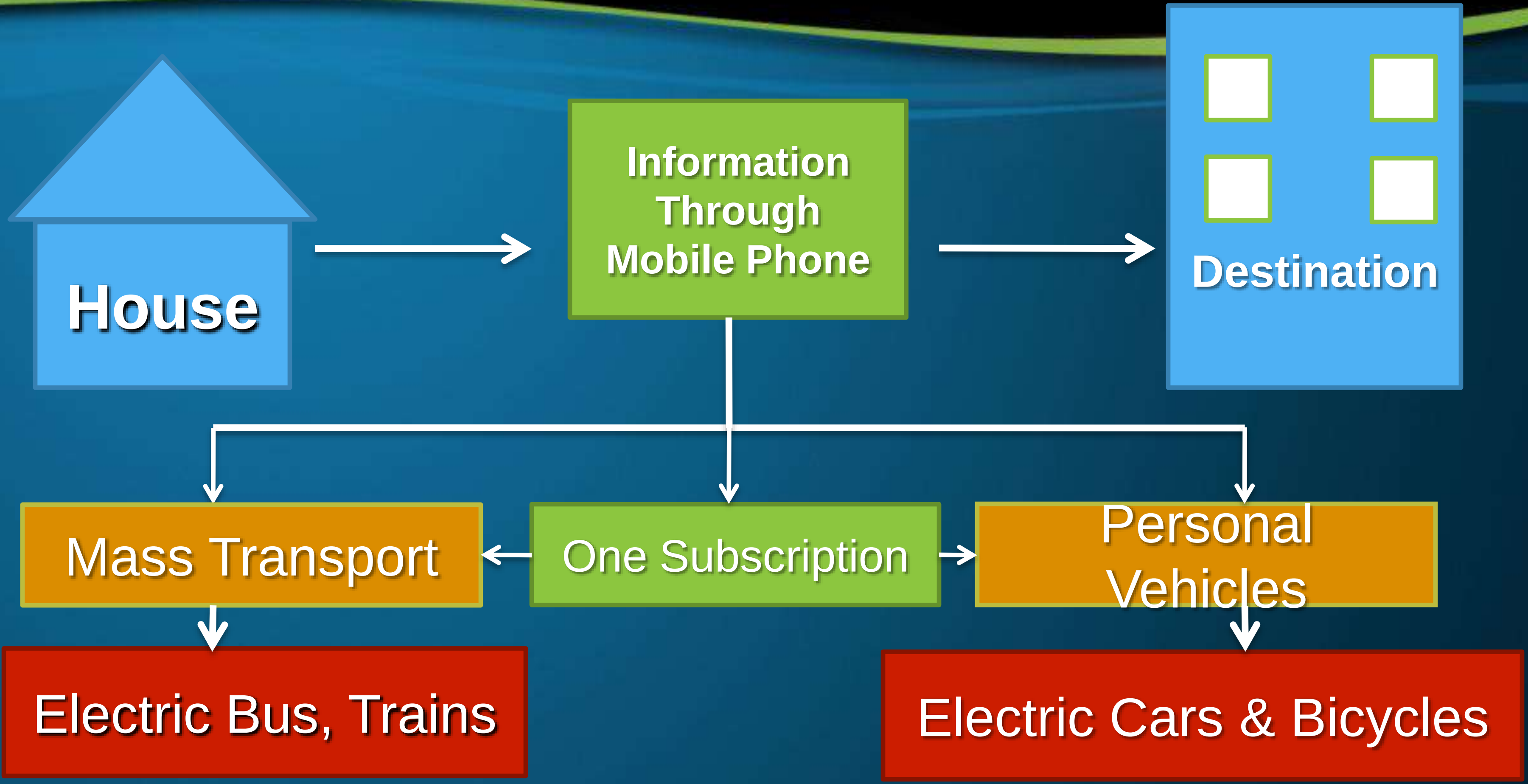
GHG Emission

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’

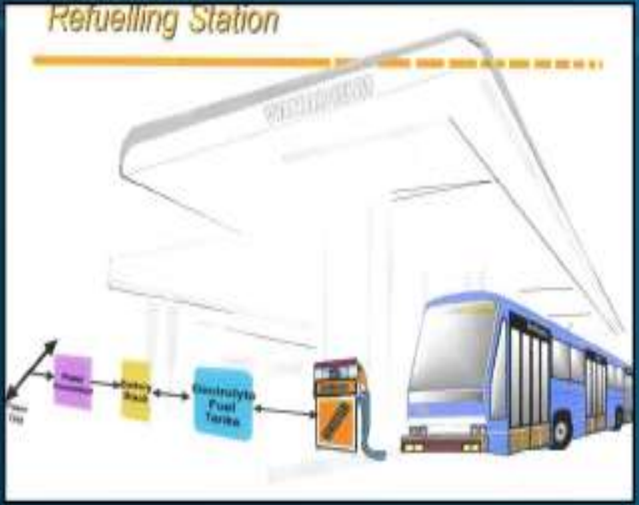
Enabling Technology

Advanced Lithium Ion → Cars, Bicycles

Flow Battery → Bus, Fleets

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

Refuelable Electric Buses



- Redox Flow Batteries are only batteries that allow BOTH electrical recharge and “instant” recharge by mechanical refueling
- Spent solutions can be recharged overnight with off-peak power
- Eliminates need for new power stations to meet increased load from electric cars

Buildings

- 6 Billion people in urban centres by 2025

- Buildings emit 7.5 Gt CO2 or equivalent 1.5 billion cars

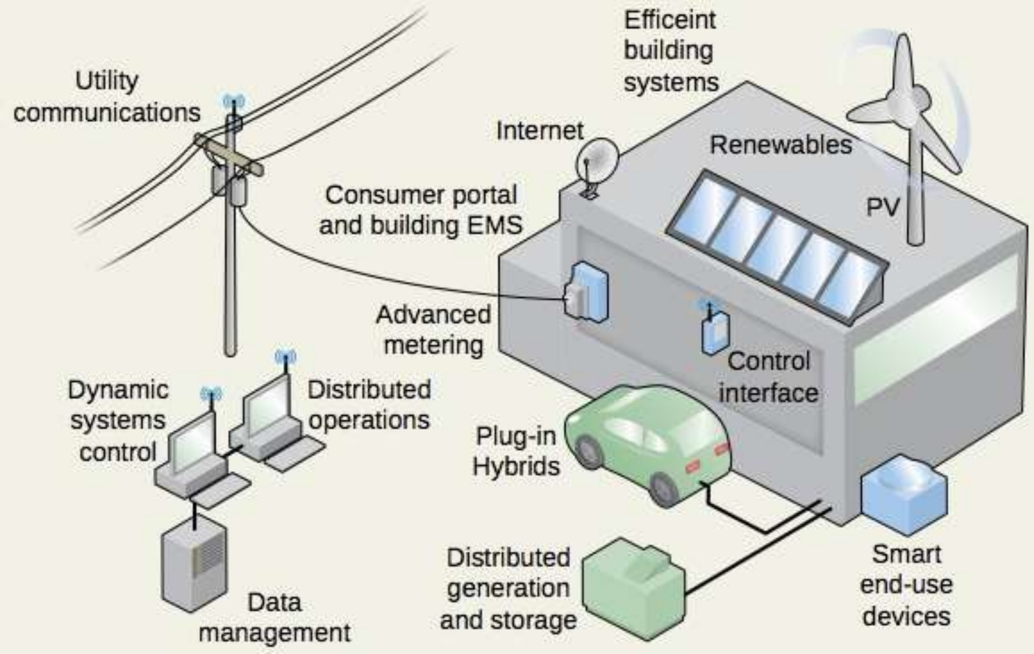
Smart Urbanization

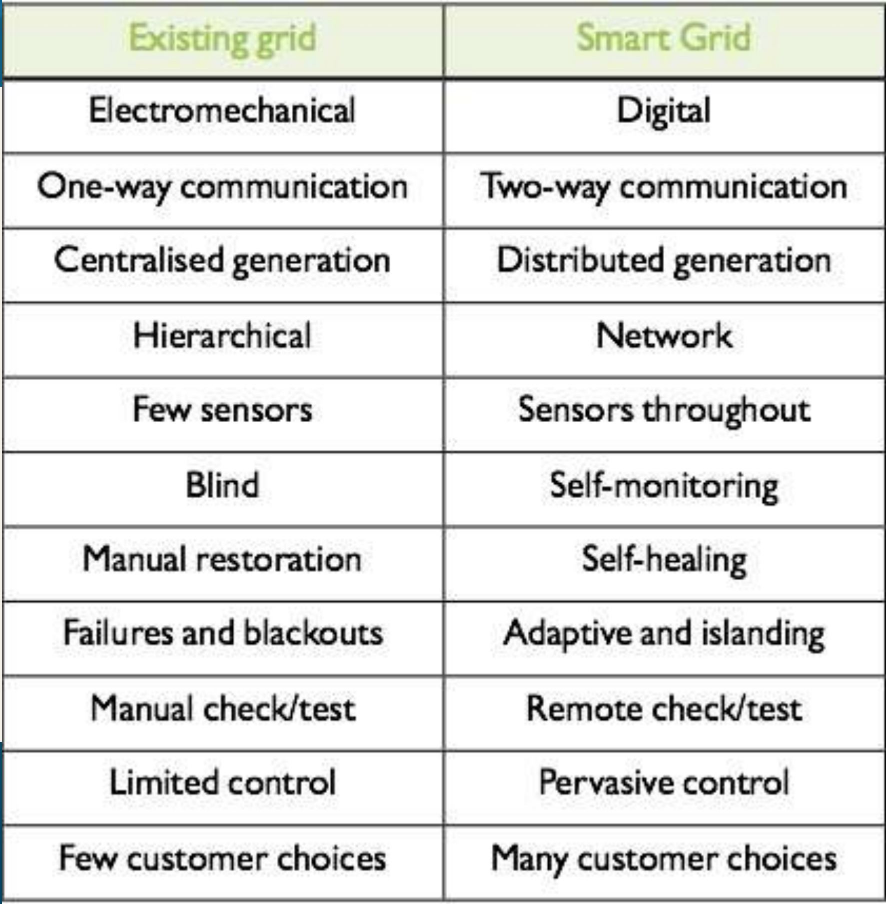
- Need an intelligent infrastructure that can accommodate renewable energy solutions:
  - Matching load with renewable energy availability
  - Electrification of transportation

- Knowledge is literally power
  - Ability to influence future construction & design
  - Ability to influence behaviour now

Smart Urbanization

Smart Grids

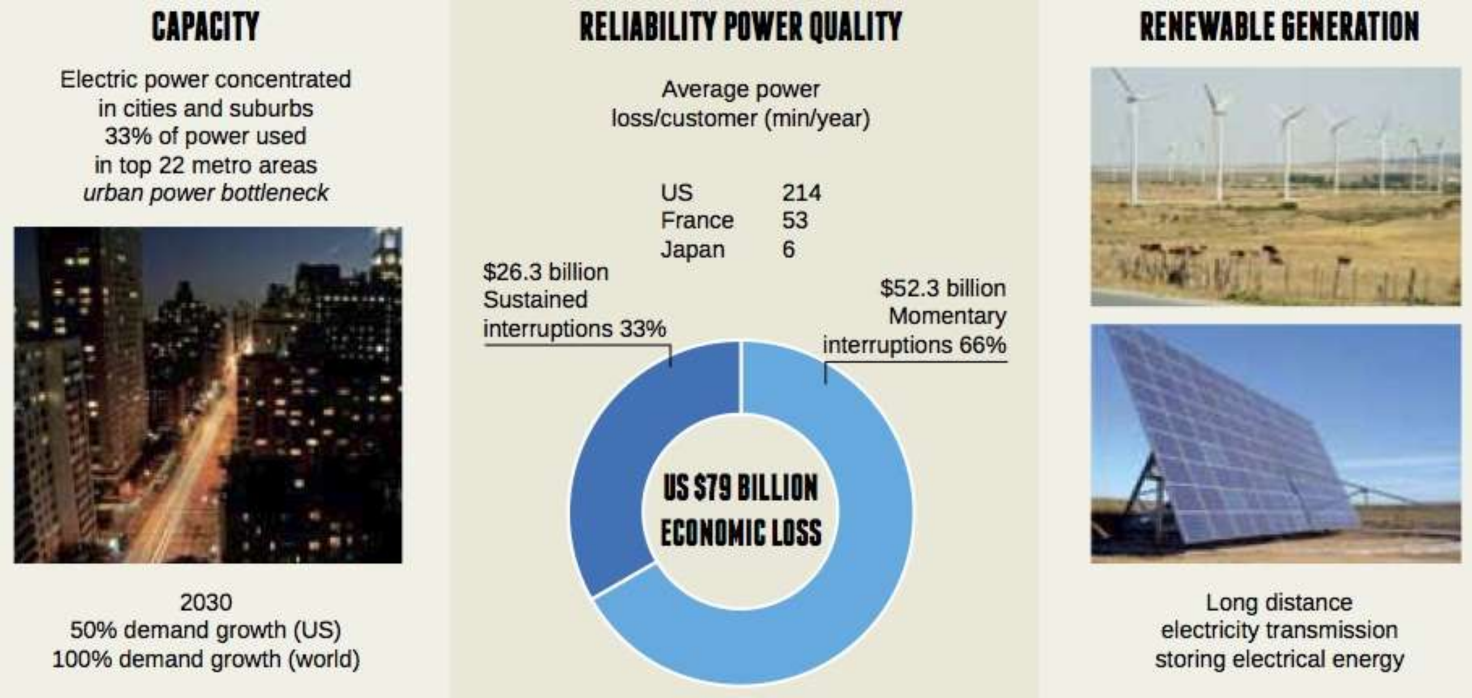




Existing grid	Smart Grid
Electromechanical	Digital
One-way communication	Two-way communication
Centralised generation	Distributed generation
Hierarchical	Network
Few sensors	Sensors throughout
Blind	Self-monitoring
Manual restoration	Self-healing
Failures and blackouts	Adaptive and islanding
Manual check/test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

Smart Urbanization

The growth of the electrification of transportation and the expansion of ICT will add stresses on the existing electricity distribution and supply infrastructure



CAPACITY

Electric power concentrated
in cities and suburbs
33% of power used
in top 22 metro areas
urban power bottleneck

2030
50% demand growth (US)
100% demand growth (world)

RELIABILITY POWER QUALITY

Average power
loss/customer (min/year)

US	214
France	53
Japan	6

$26.3 billion
Sustained
interruptions 33%

$52.3 billion
Momentary
interruptions 66%

US $79 BILLION ECONOMIC LOSS

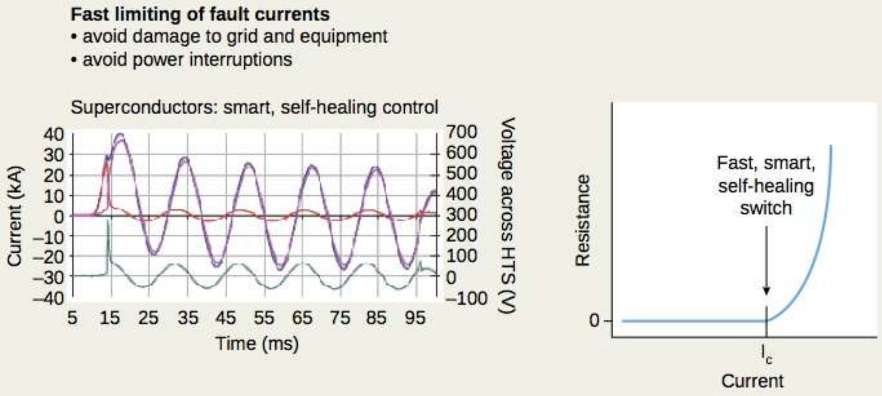
RENEWABLE GENERATION

Long distance
electricity transmission
storing electrical energy

Set of challenges in electricity transmission and distribution

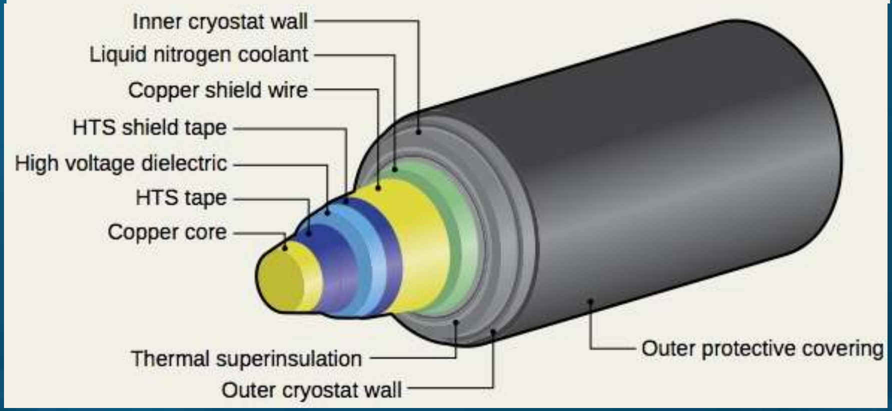
Smart Urbanization

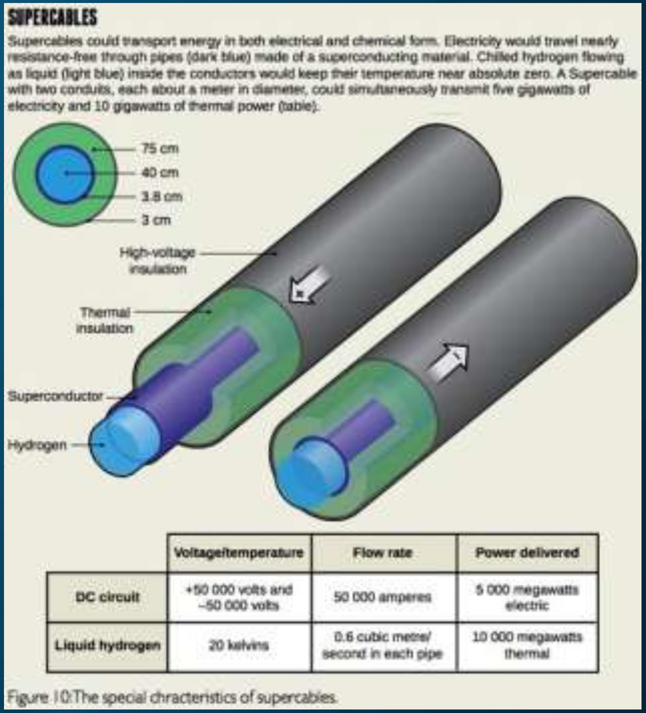
Superconductors offer opportunities to dramatically increase the capacity and efficiency of power transmission with a much lower physical foot



Fast limiting of fault currents

- avoid damage to grid and equipment
- avoid power interruptions





SUPERCABLES

Supercables could transport energy in both electrical and chemical form. Electricity would travel nearly resistance-free through pipes (dark blue) made of a superconducting material. Chilled hydrogen flowing as liquid (light blue) inside the conductors would keep their temperature near absolute zero. A Supercable with two conduits, each about a meter in diameter, could simultaneously transmit five gigawatts of electricity and 10 gigawatts of thermal power (table).

	Voltage/temperature	Flow rate	Power delivered
DC circuit	+50 000 volts and −50 000 volts	50 000 amperes	5 000 megawatts electric
Liquid hydrogen	20 kelvins	0.6 cubic metre/ second in each pipe	10 000 megawatts thermal

Figure 10:The special chracteristics of supercables.

Smart Urbanization: Conclusions

Smart Urbanization will require planning supported by:

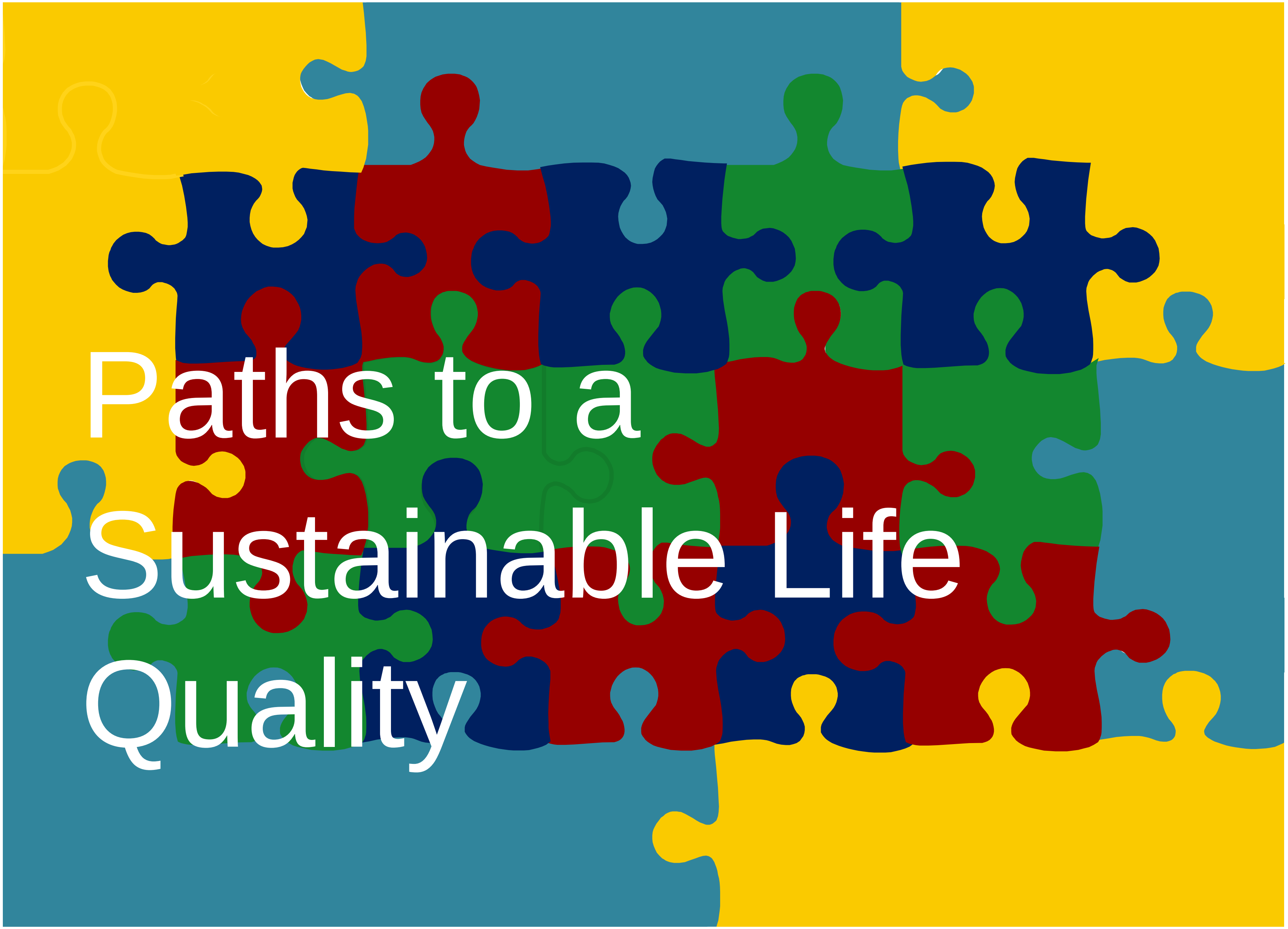
- Smart Grid technologies integrated through ICT
- Electrification of Transport
- ICT to enable mobility in dense urban environments
- Superconducting technologies for reliable transmission in dense urban cores

Equinox Energy 2030: Summary

- An energy ‘ecosystem’ view to approaching possible, low carbon technologies

- Potential pathways identified to help research, development and implementation of long-term solutions

- Technical details help convey the complexities, challenges and opportunities posed by a few transitional technological systems.

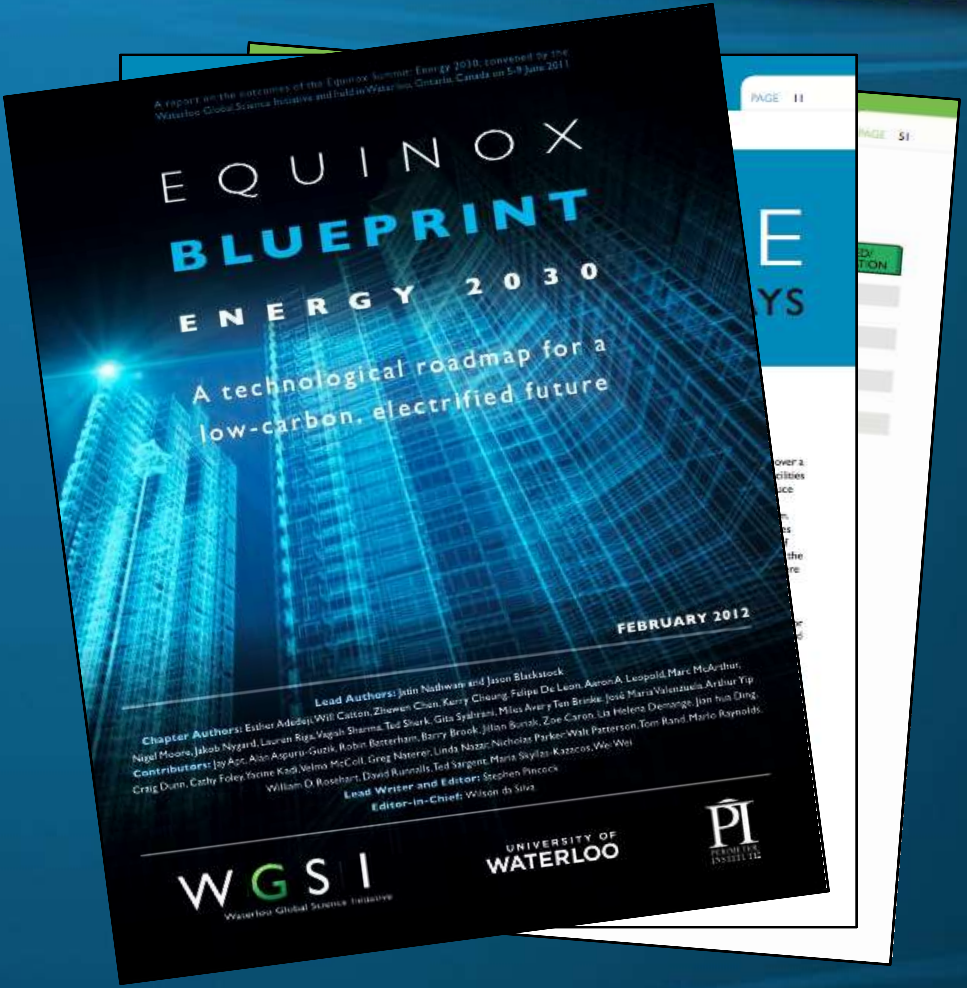


Paths to a Sustainable Life Quality

How do we manage the big risks?

Not to focus on regulations for helmets!

© Victor Lucas 2006



A report on the outcomes of the Equinox Summit: Energy 2030, convened by the Waterloo Global Science Initiative and held in Waterloo, Ontario, Canada on 5-9 June 2011

EQUINOX BLUEPRINT
ENERGY 2030

A technological roadmap for a low-carbon, electrified future

FEBRUARY 2012

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