Climate Change:
Paths to Global Energy Transitions

Part 1

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Presented at the
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Balsillie School of International Affairs
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- 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

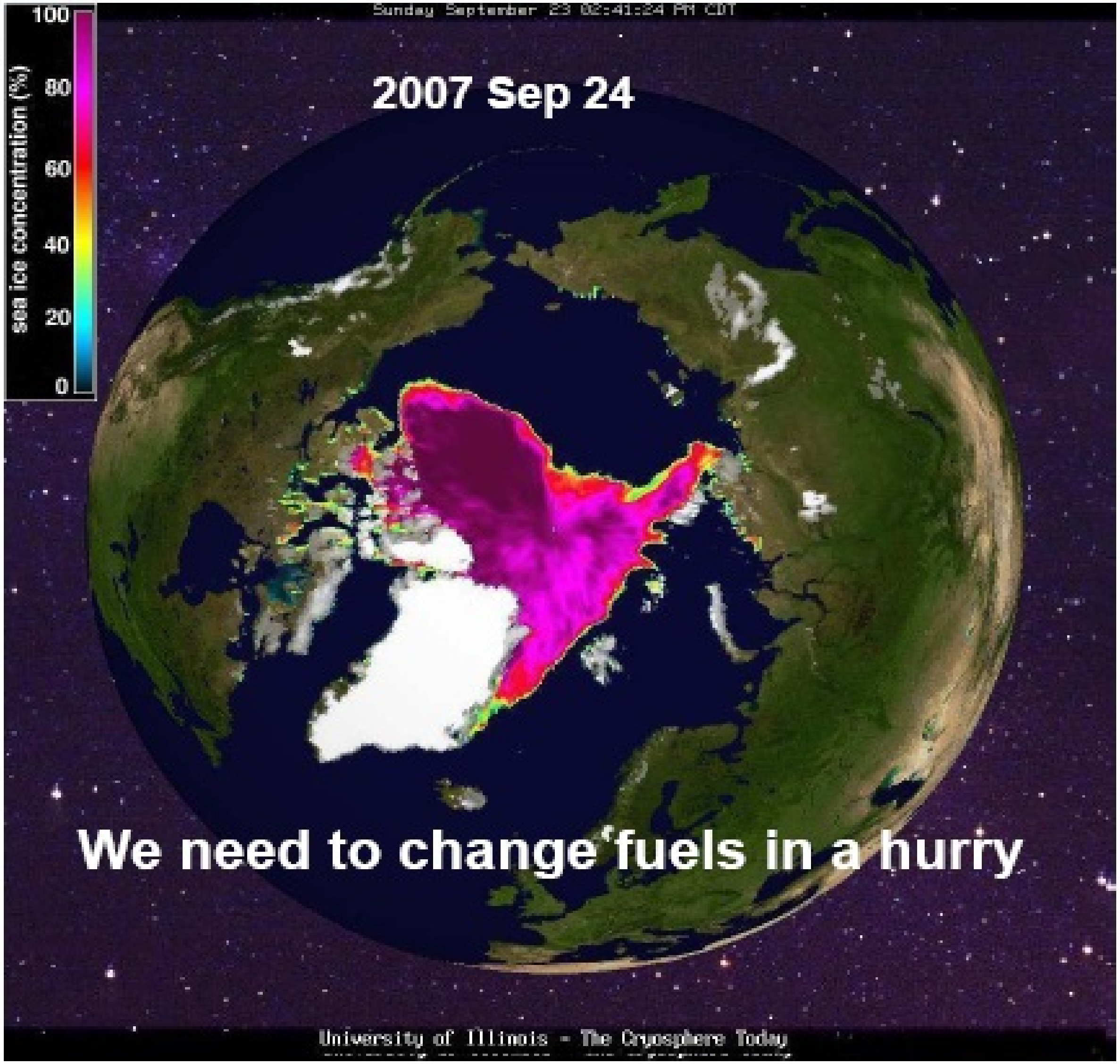
World at Night

~ 60 kWh

240 kWh ~

~ mW

The central global energy challenge: how to de-carbonize



Population Growth: Energy: Income

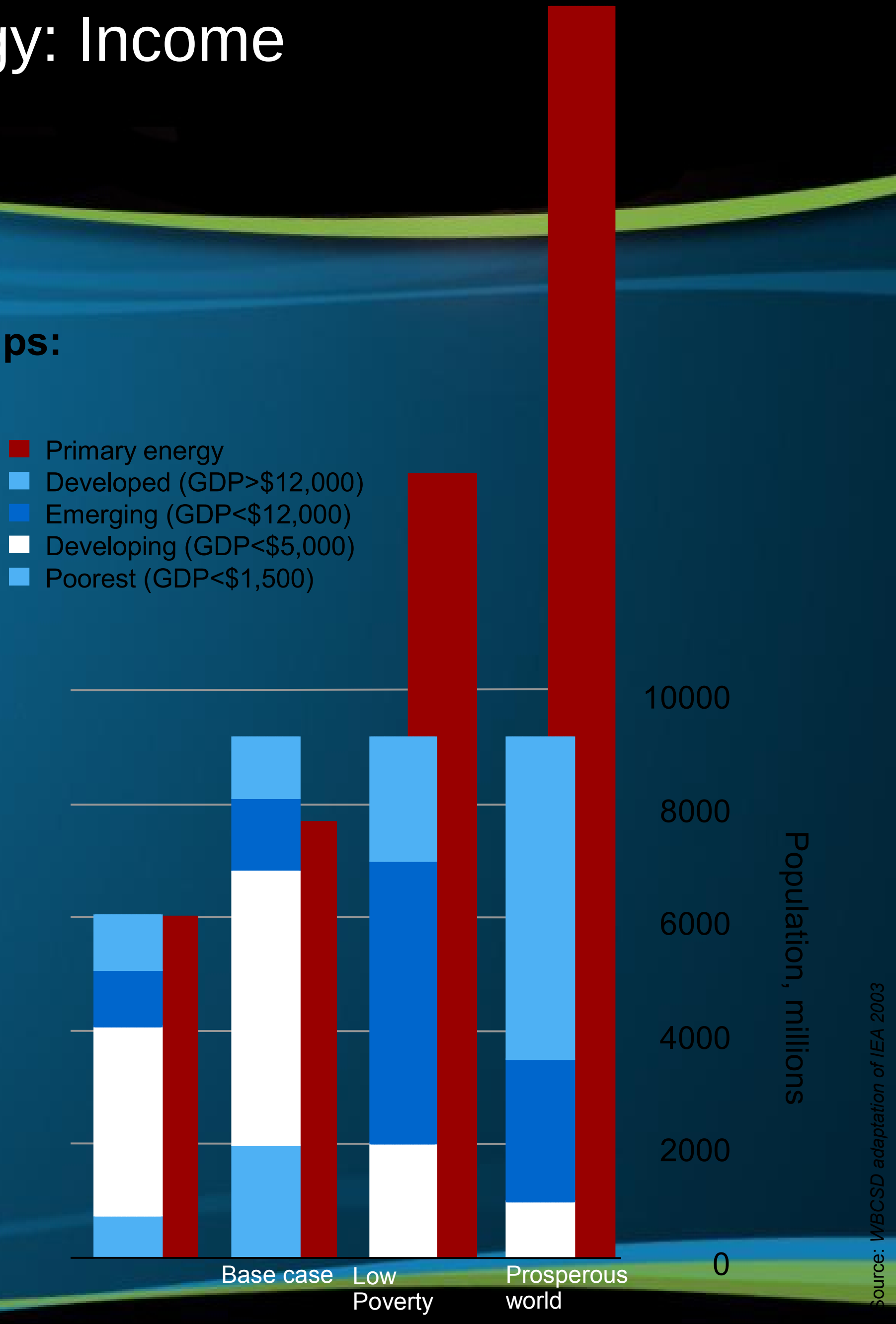
Global population divided into income groups:

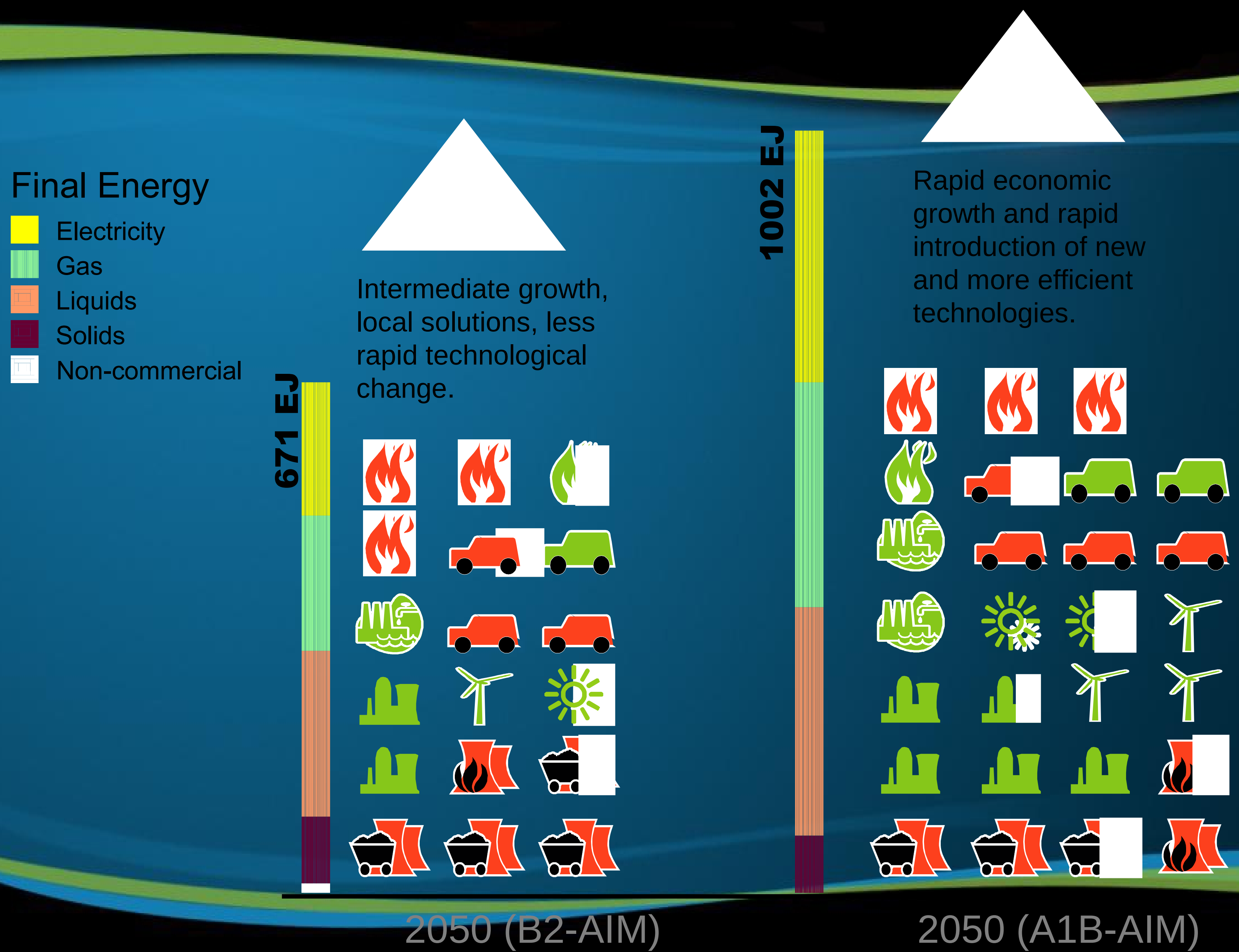
Population rise to 9 billion + by 2050, mainly in poorest and developing countries.

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

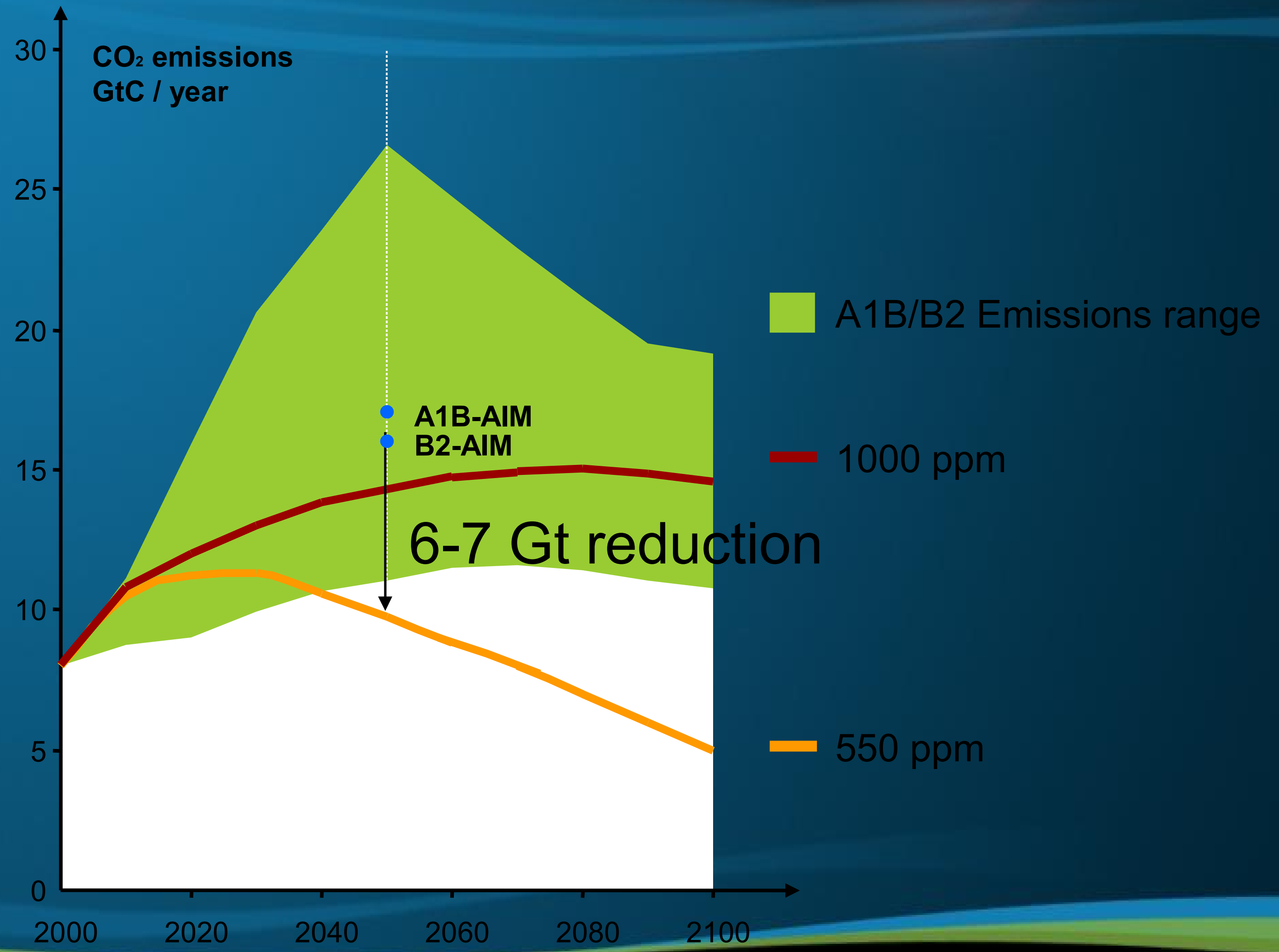
Source: WBCSD 2007



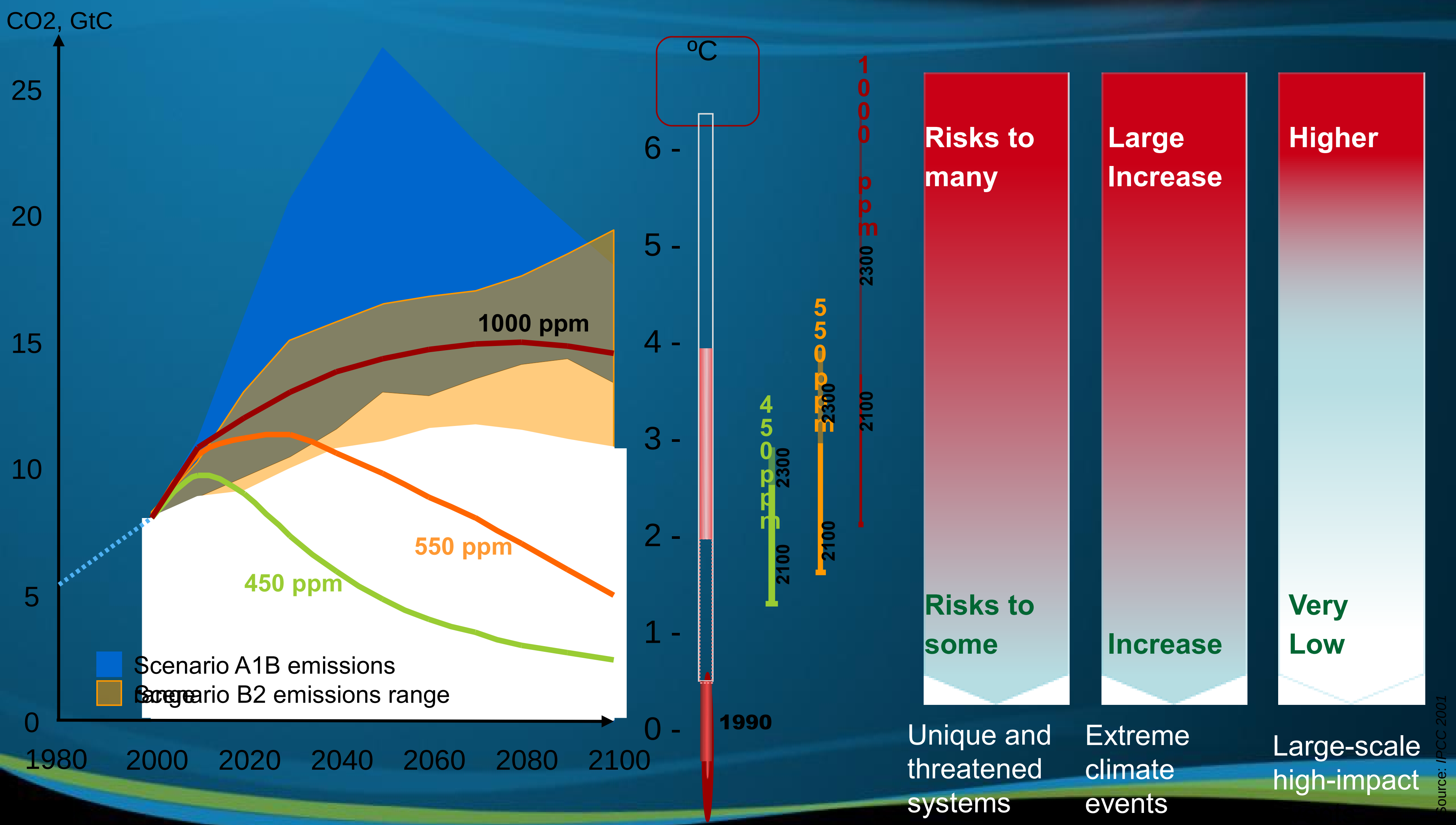


Final Energy
Electricity
Gas
Liquids
Solids
Non-commercial
671 EJ
Intermediate growth, local solutions, less rapid technological change.
1002 EJ
Rapid economic growth and rapid introduction of new and more efficient technologies.
2050 (B2-AIM)
2050 (A1B-AIM)

Magnitude of change required for CO2 stabilization

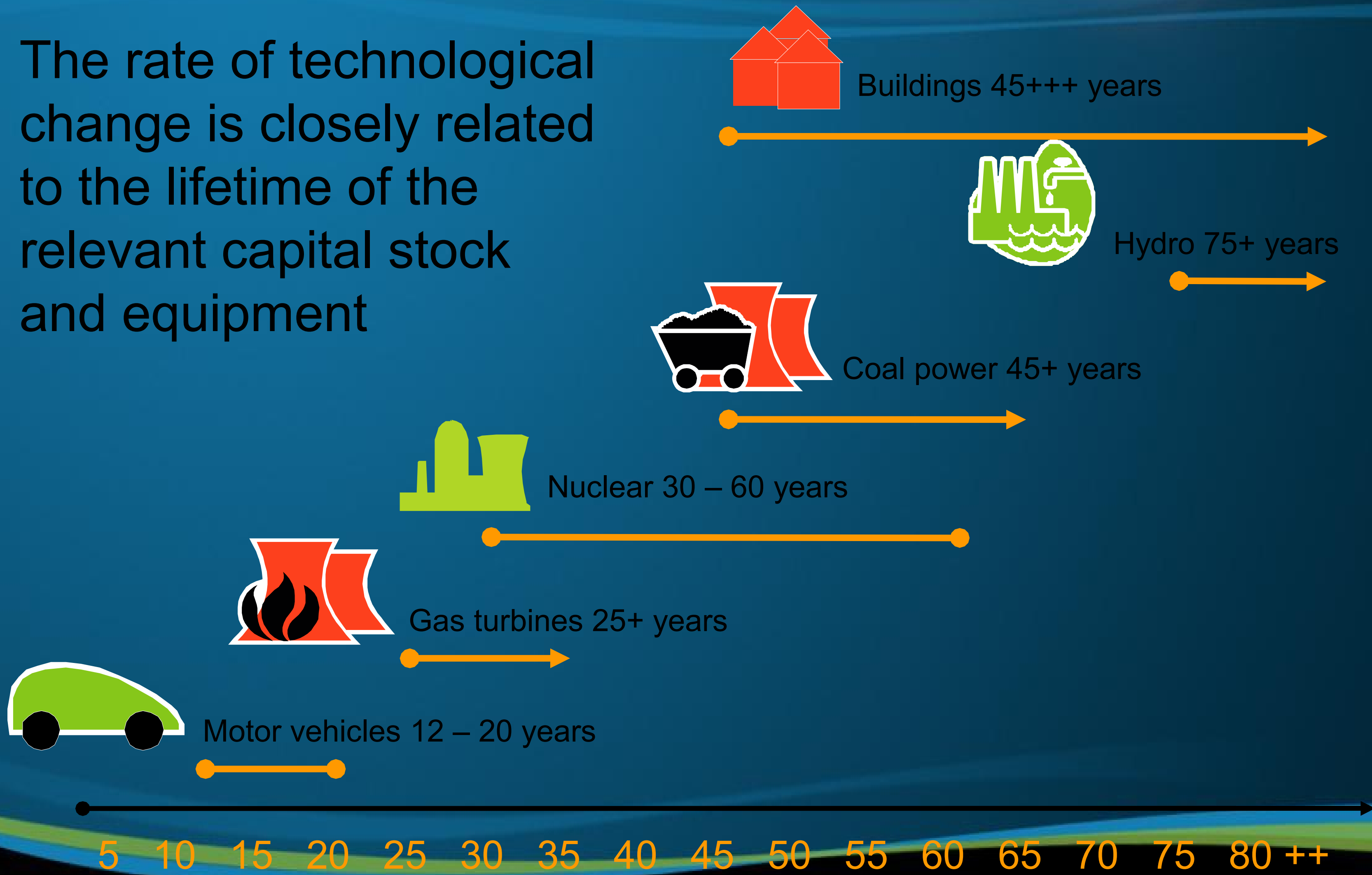


Source: WBCSD 2007

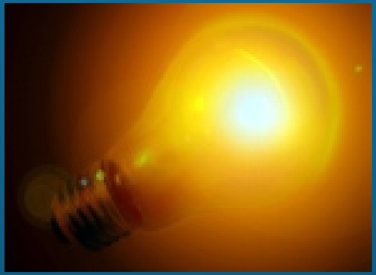

CO2, GtC
25
20
15
10
5
0
1980
2000
2020
2040
2060
2080
2100
1000 ppm
550 ppm
450 ppm
Scenario A1B emissions
Scenario B2 emissions range
°C
6 -
5 -
4 -
3 -
2 -
1 -
0 -
1990
450 ppm
550 ppm
1000 ppm
2100
2300
Risks to many
Risks to some
Unique and threatened systems
Large Increase
Increase
Extreme climate events
Higher
Very Low
Large-scale high-impact
Source: IPCC 2001

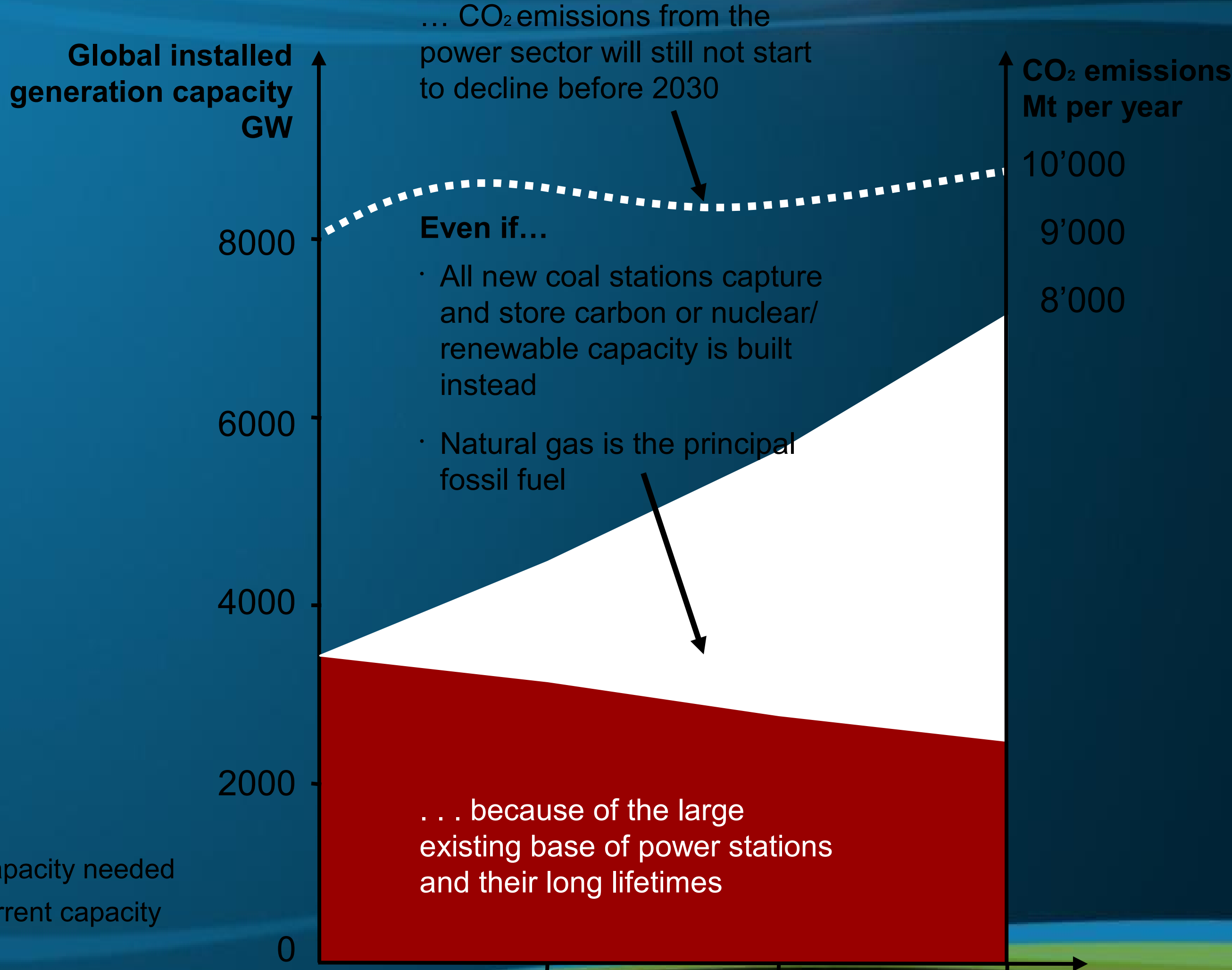
The lifetime of energy infrastructure

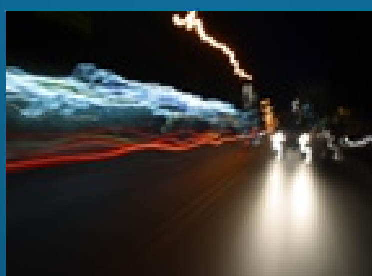
The rate of technological change is closely related to the lifetime of the relevant capital stock and equipment

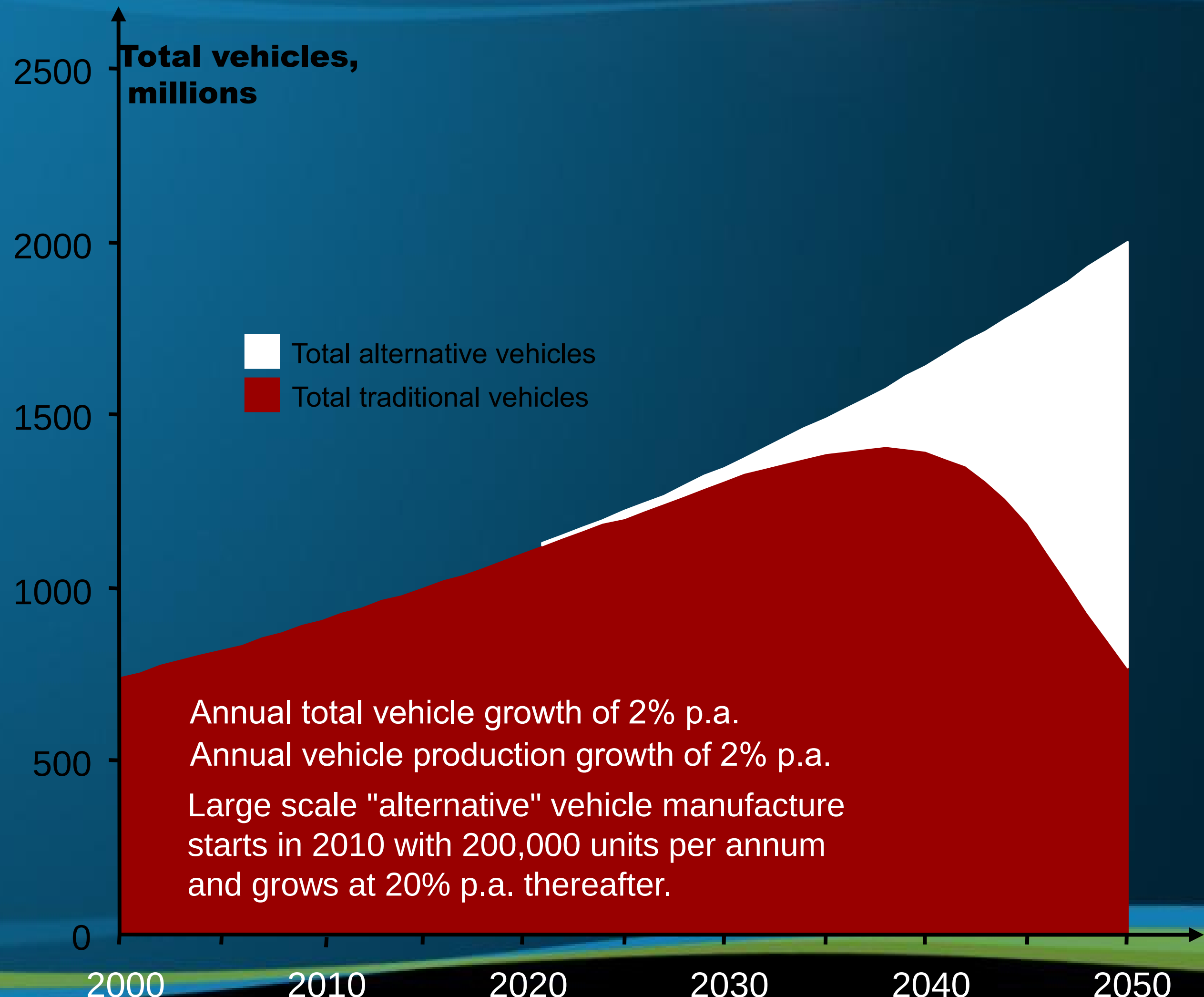


Alternate power generation technologies: Impact on emissions

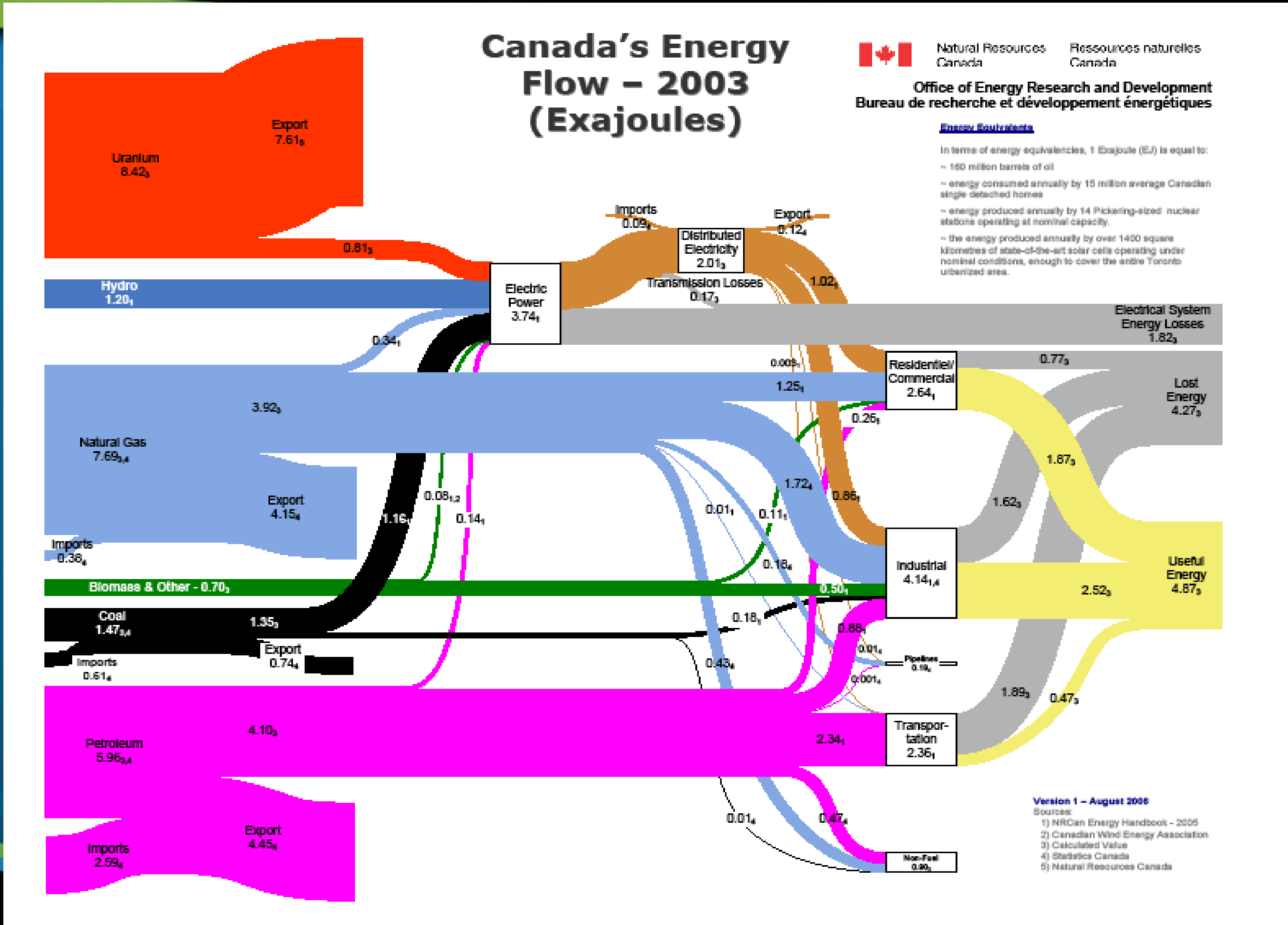







Total vehicles,
millions
2500
2000
1500
1000
500
0
2000
2010
2020
2030
2040
2050
Total alternative vehicles
Total traditional vehicles
Annual total vehicle growth of 2% p.a.
Annual vehicle production growth of 2% p.a.
Large scale "alternative" vehicle manufacture
starts in 2010 with 200,000 units per annum
and grows at 20% p.a. thereafter.

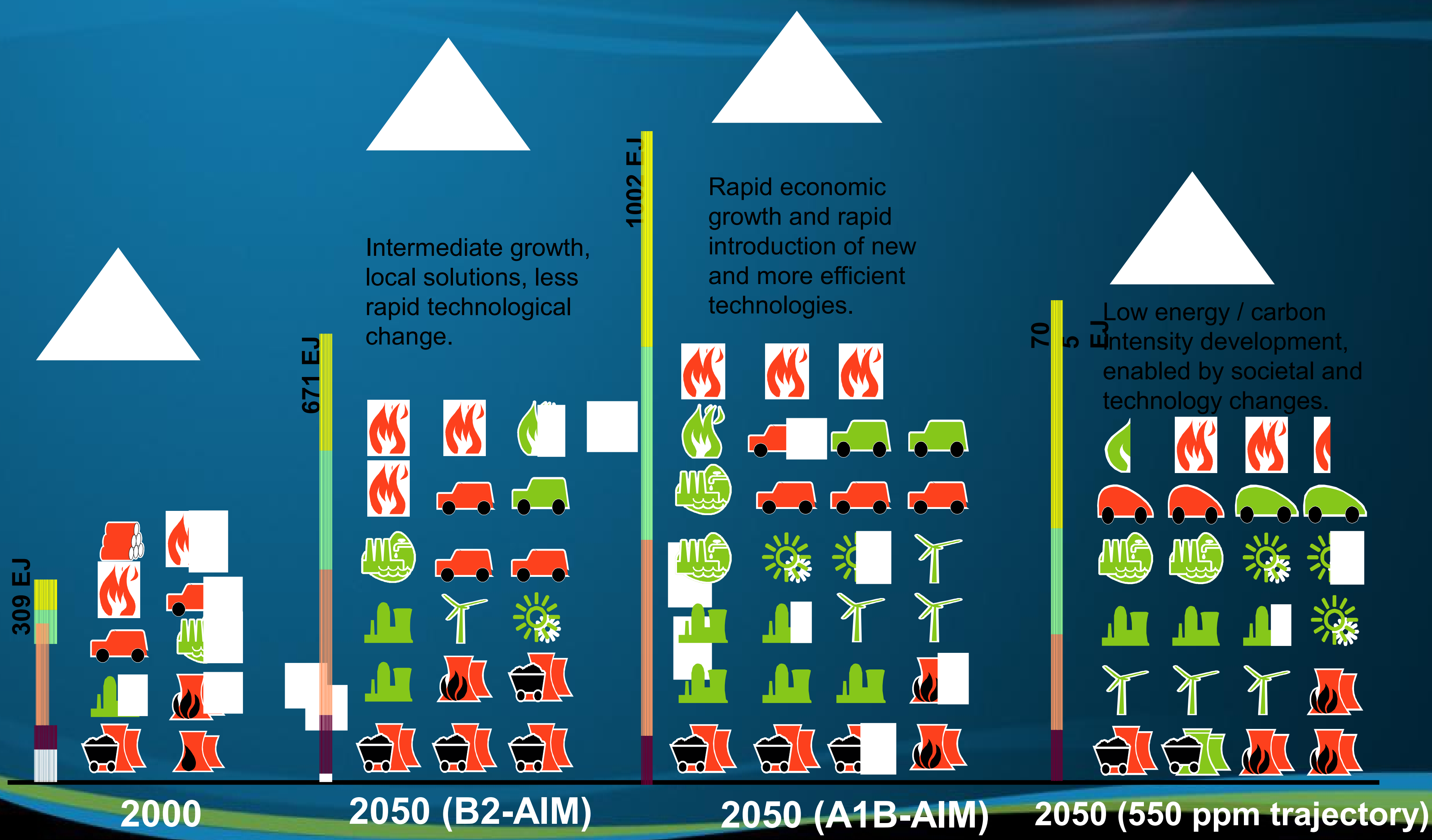
Useful Energy: Efficiency: Waste ???



Useful Energy: Efficiency: Waste ???

- "The Moving Finger writes; and having Writ, Moves on;
Nor all your Piety nor Wit Shall lure it back to cancel half a line, Nor all your tears wash out a word of it."
- The Rubaiyat of Omar Khayam, Edward Fitzgerald

A Balanced Mix of Options



How do we manage the big risks?

Not to focus on regulations for helmets!

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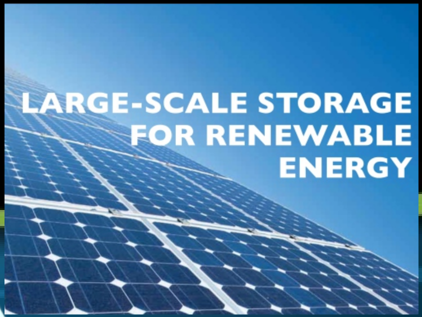
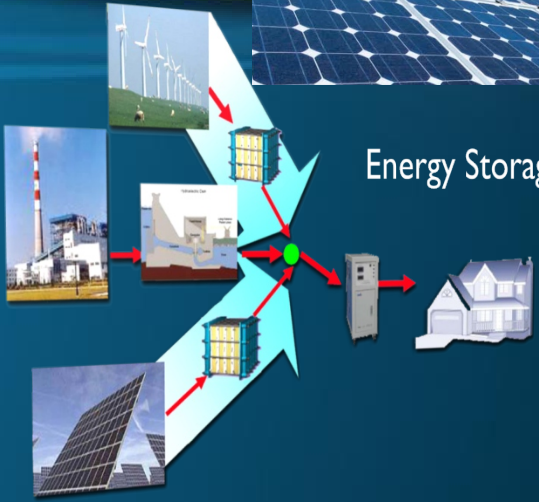
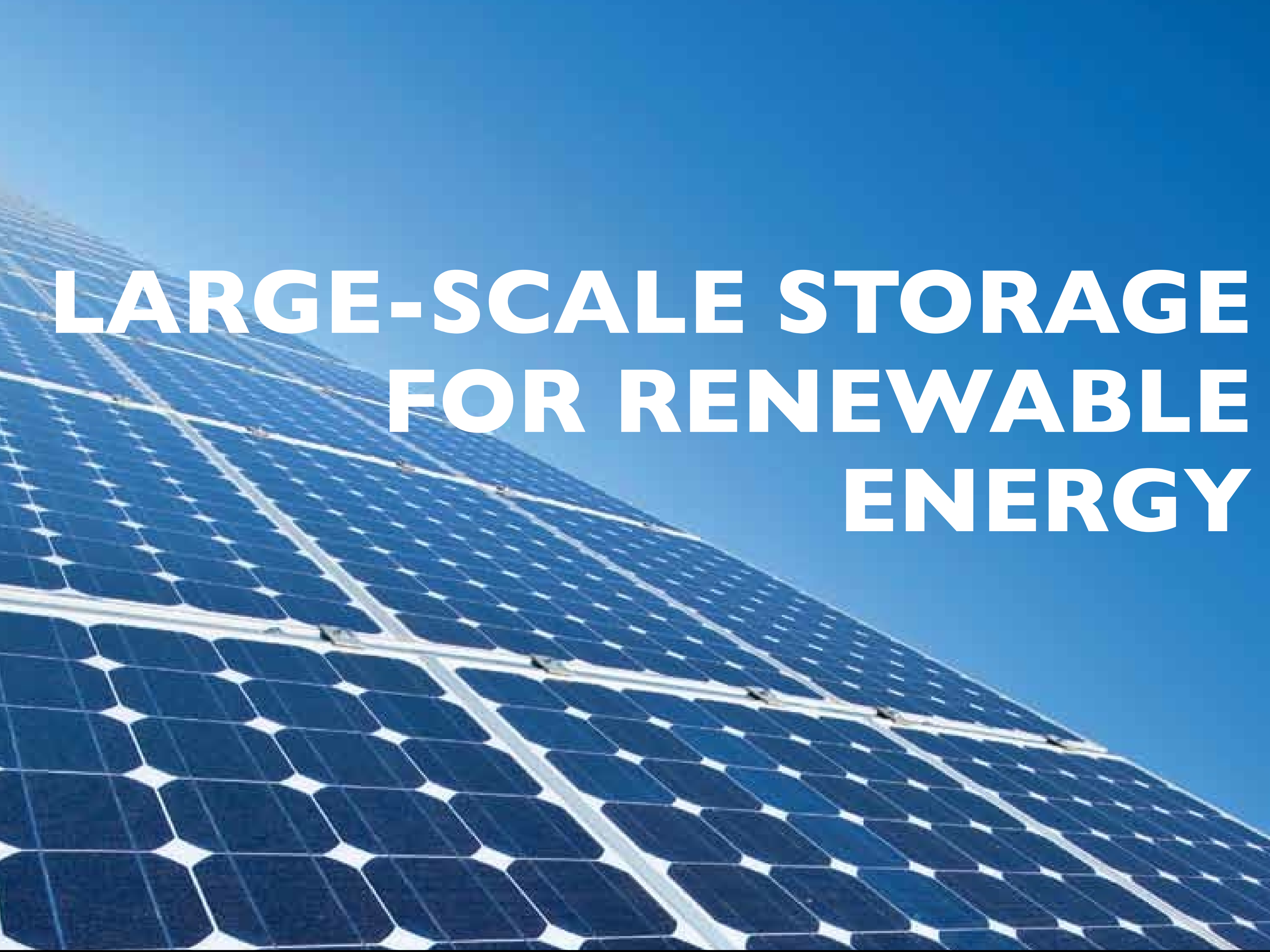




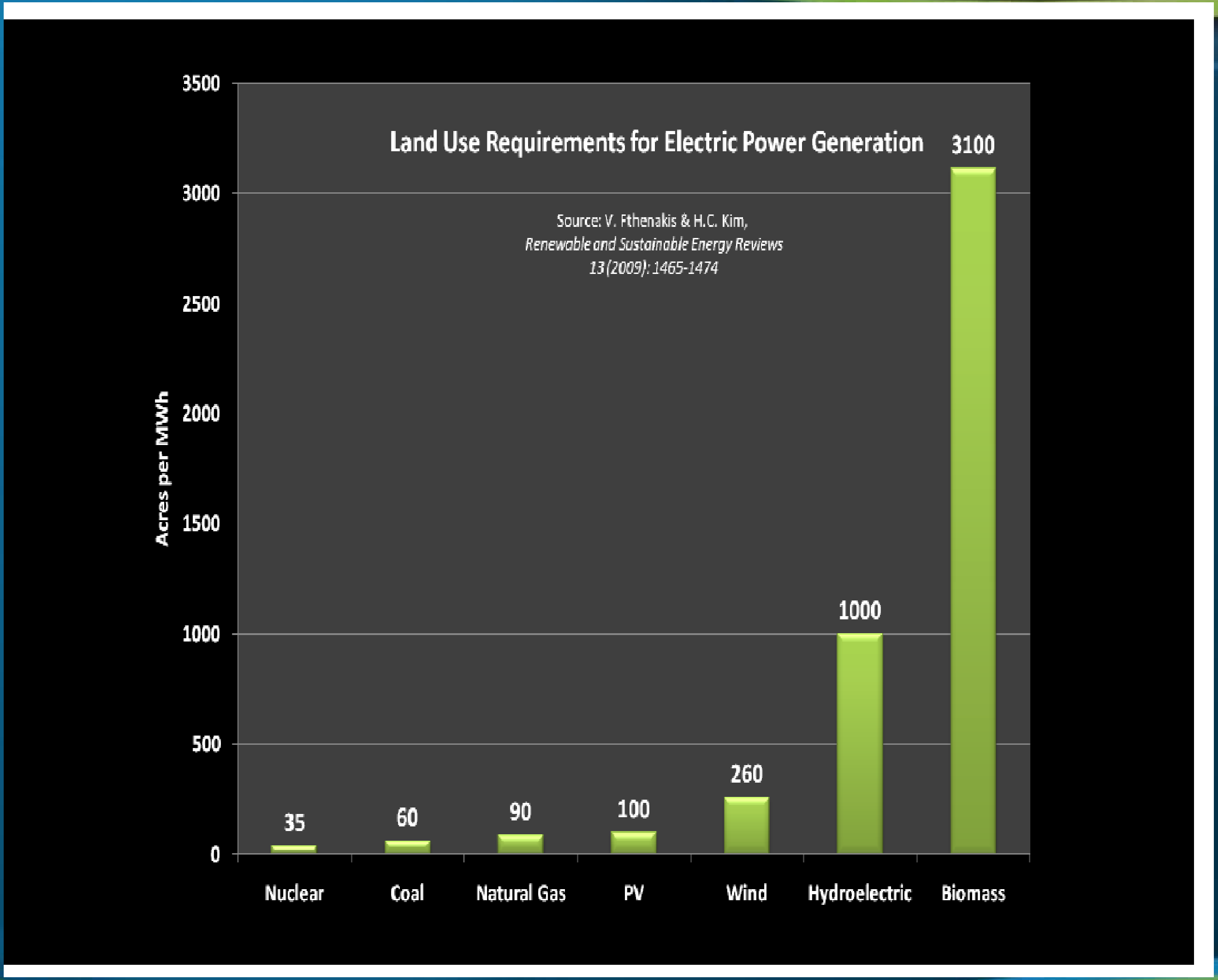
Energy Storage for the Future Grid

LARGE-SCALE STORAGE FOR RENEWABLE ENERGY

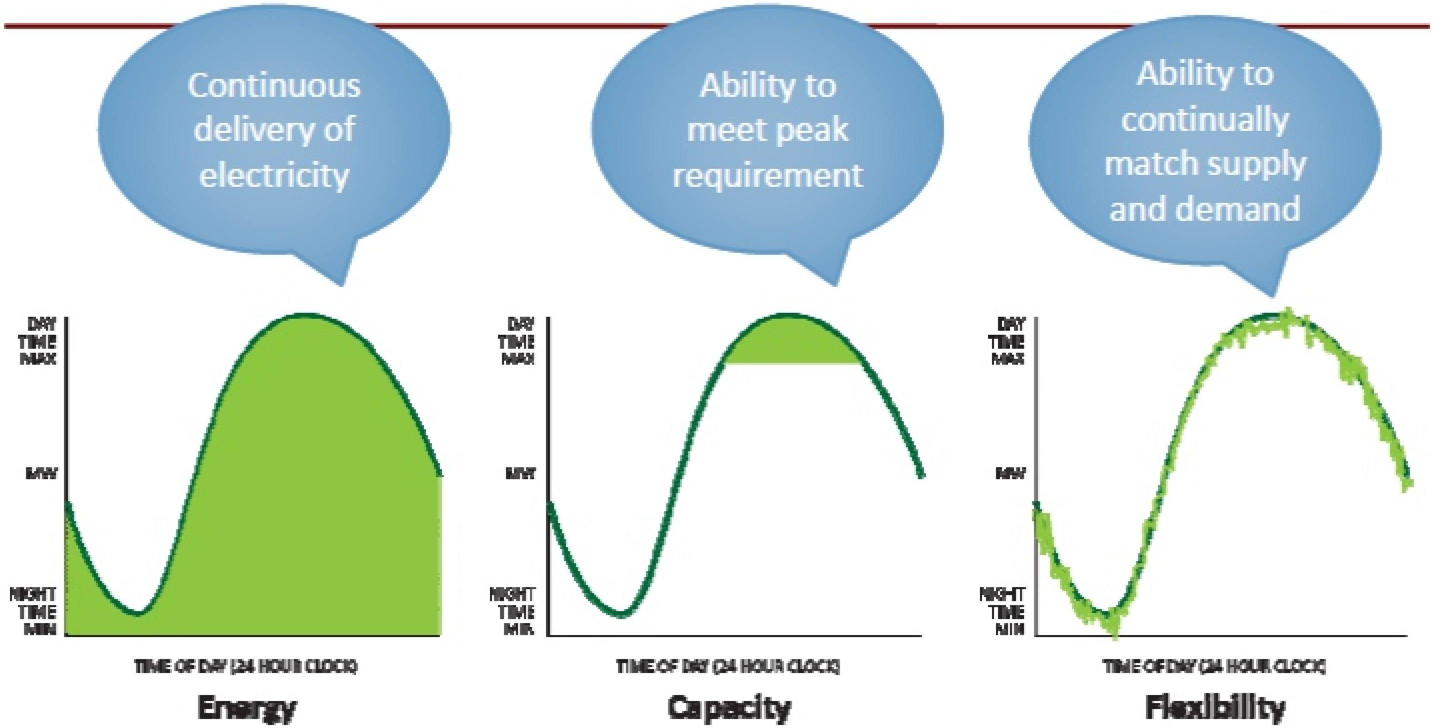


Land use can be benign

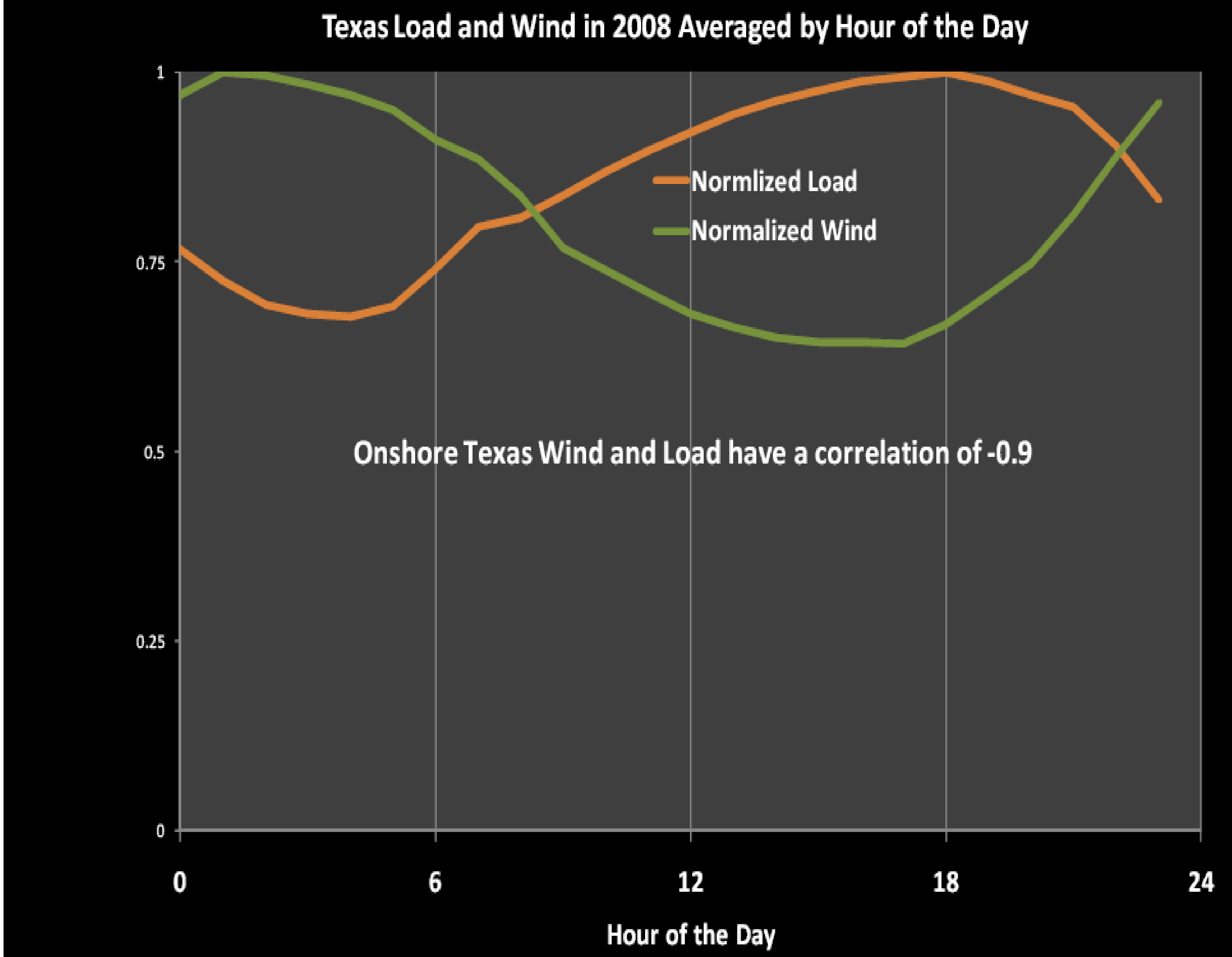
Or, Not so Benign


Land Use Requirements for Electric Power Generation
Source: V. Fthenakis & H.C. Kim,
Renewable and Sustainable Energy Reviews
13(2009): 1465-1474
Acres per MWh
3500
3000
2500
2000
1500
1000
500
0
35
60
90
100
260
1000
3100
Nuclear
Coal
Natural Gas
PV
Wind
Hydroelectric
Biomass

Power Systems Need Flexibility as well as Energy & Capacity



CPC: Demand Side Management Working Group

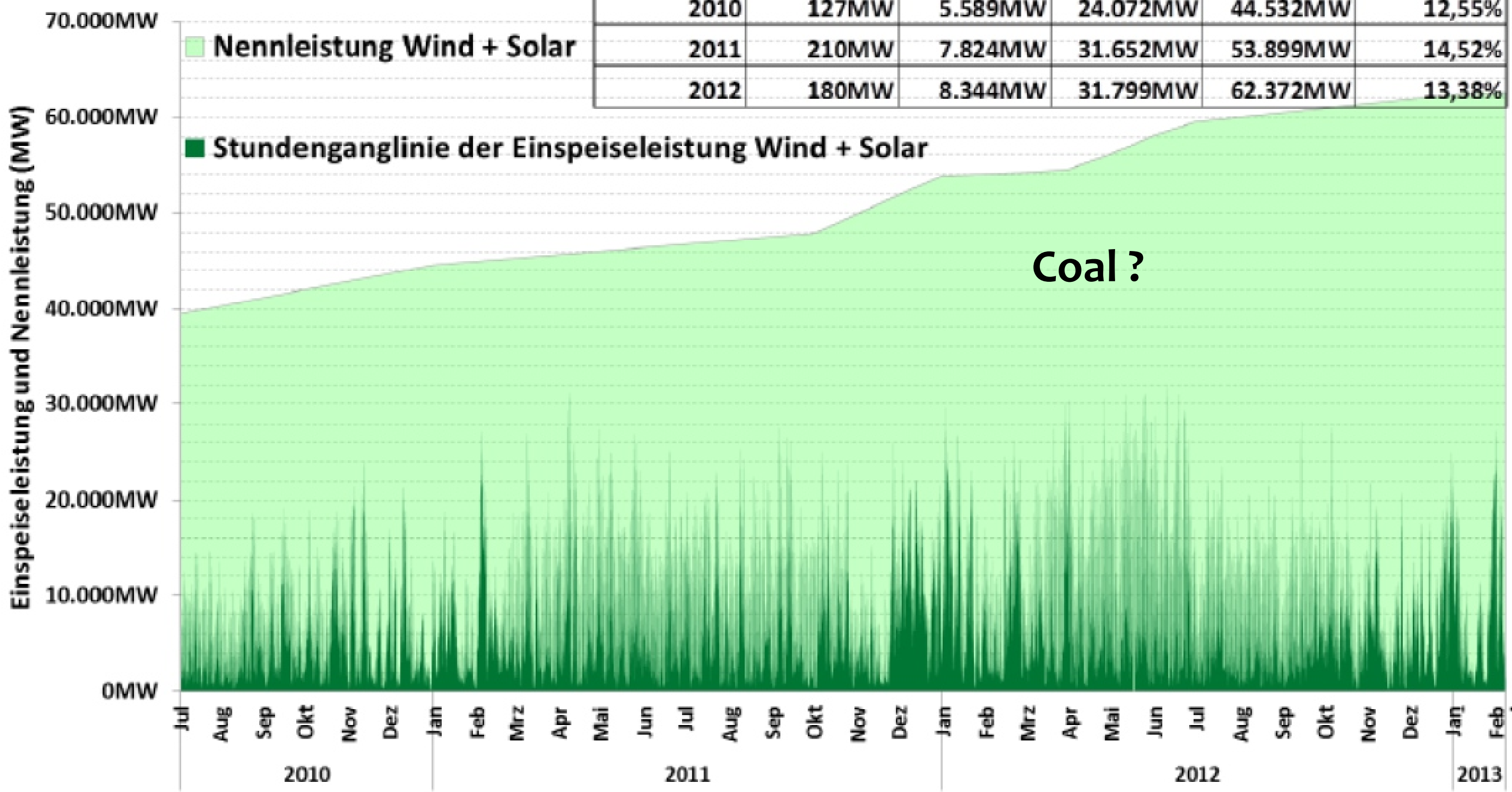

Texas Load and Wind in 2008 Averaged by Hour of the Day
1
0.75
0.5
0.25
0
0
6
12
18
24
Hour of the Day
Normlized Load
Normalized Wind
Onshore Texas Wind and Load have a correlation of -0.9

EEX: Wind & PV Energy in Germany (01/2010-02/2013)

Karlsruhe Institute of Technology

EEX Wind + Solarenergie

Wind + Solar Jahr	minimale Einspeisung	Mittelwert	maximale Einspeisung	installierte Leistung Jahresende	Mittelwert / Leistung
2010	127MW	5.589MW	24.072MW	44.532MW	12,55%
2011	210MW	7.824MW	31.652MW	53.899MW	14,52%
2012	180MW	8.344MW	31.799MW	62.372MW	13,38%



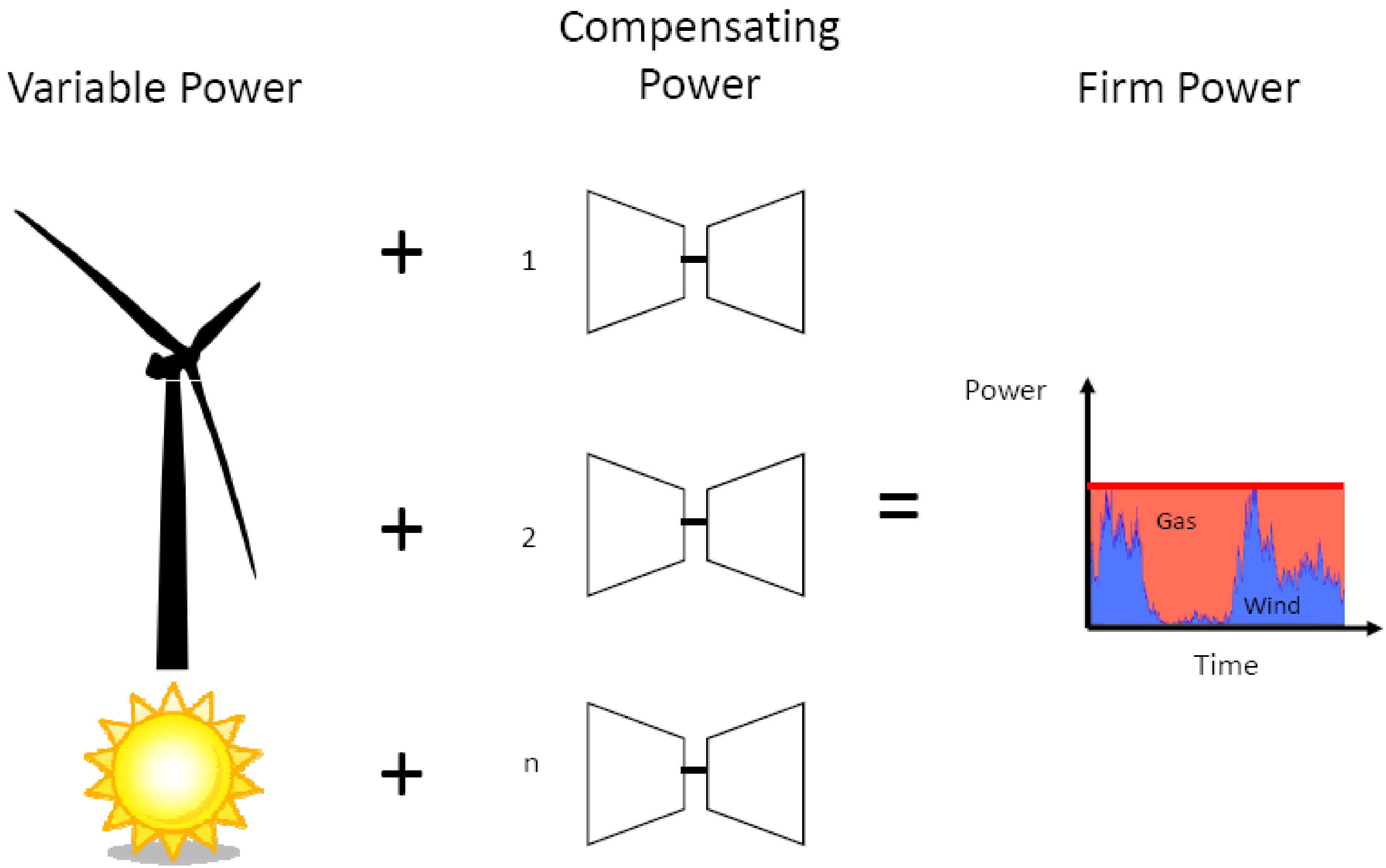
Datenquelle : Leipziger Strombörse EEX

Auflösung: Stundenwerte

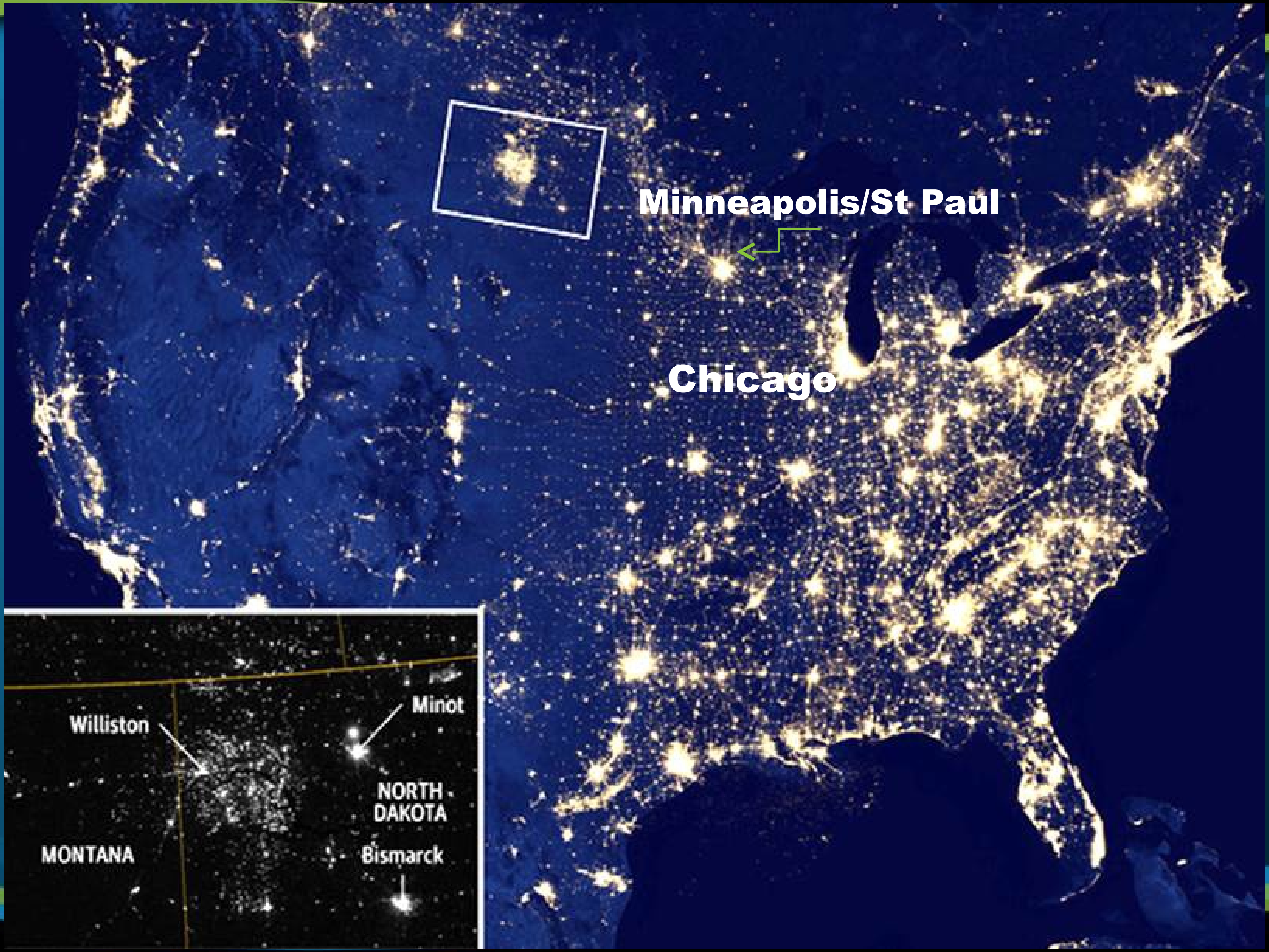
Darstellung: Rolf Schuster

Quelle: Leipzig Electricity Stock Exchange EEX; Karl Linnenfelser

CO_2 and NO_x from natural gas that fills in

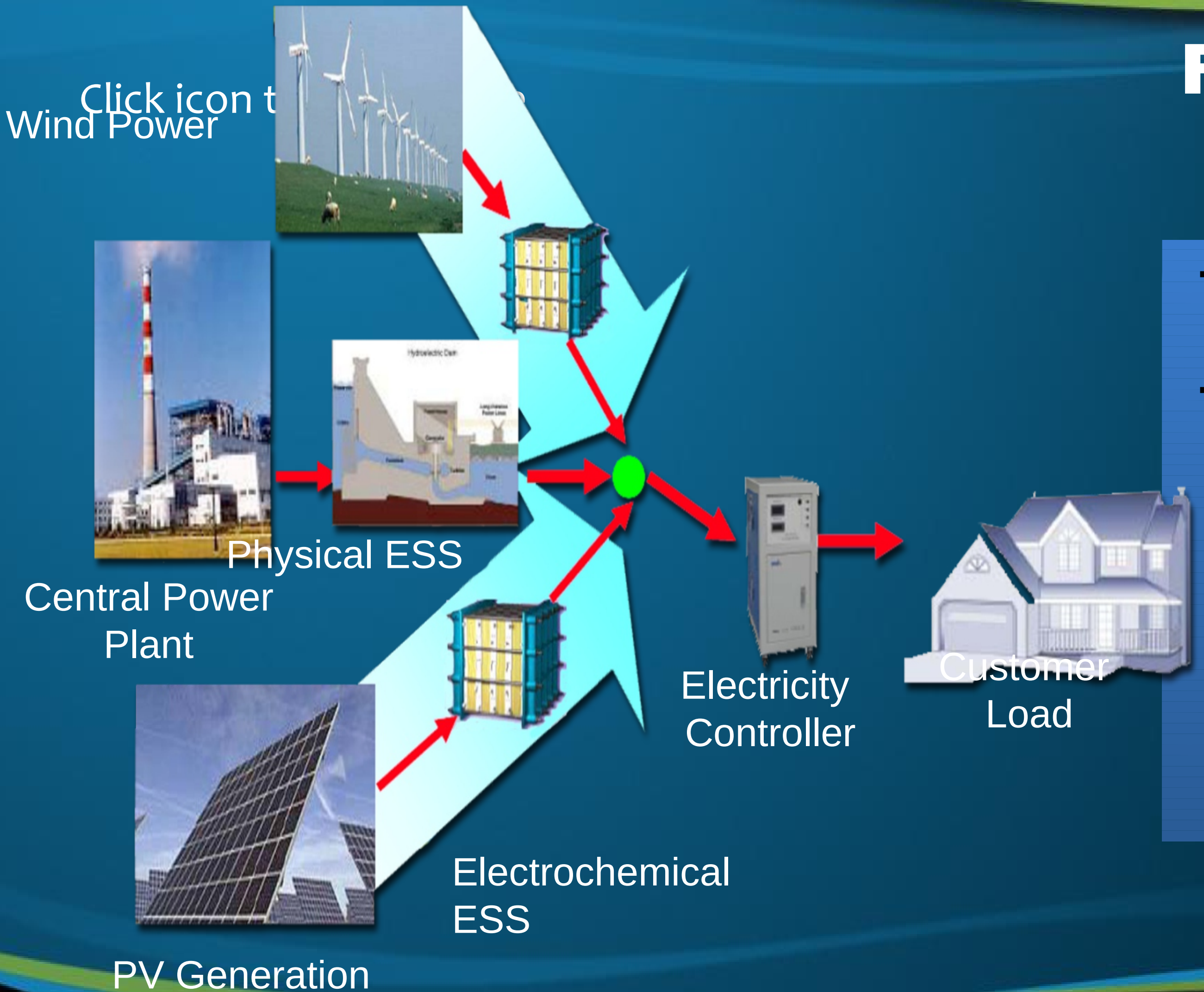


A New Metropolis on the North American Continent ?



Energy Storage for the Future Grid

Future Grid



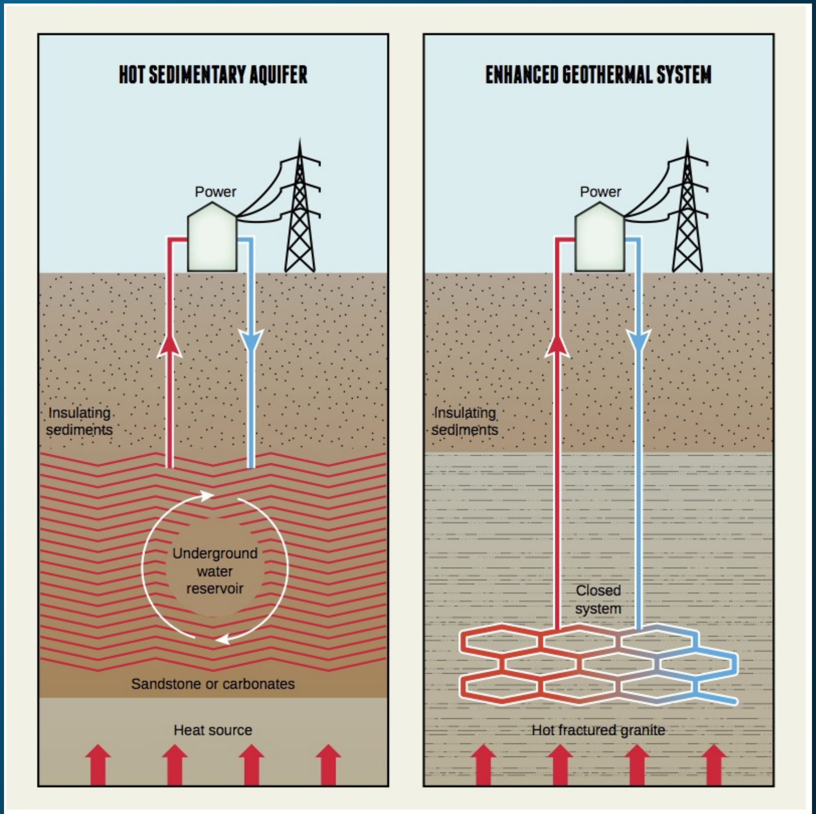
- *Reliable and stable output*
- *Storage critical for increased compatibility of renewable energy to the grid.*

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.

ENHANCED GEOTHERMAL POWER

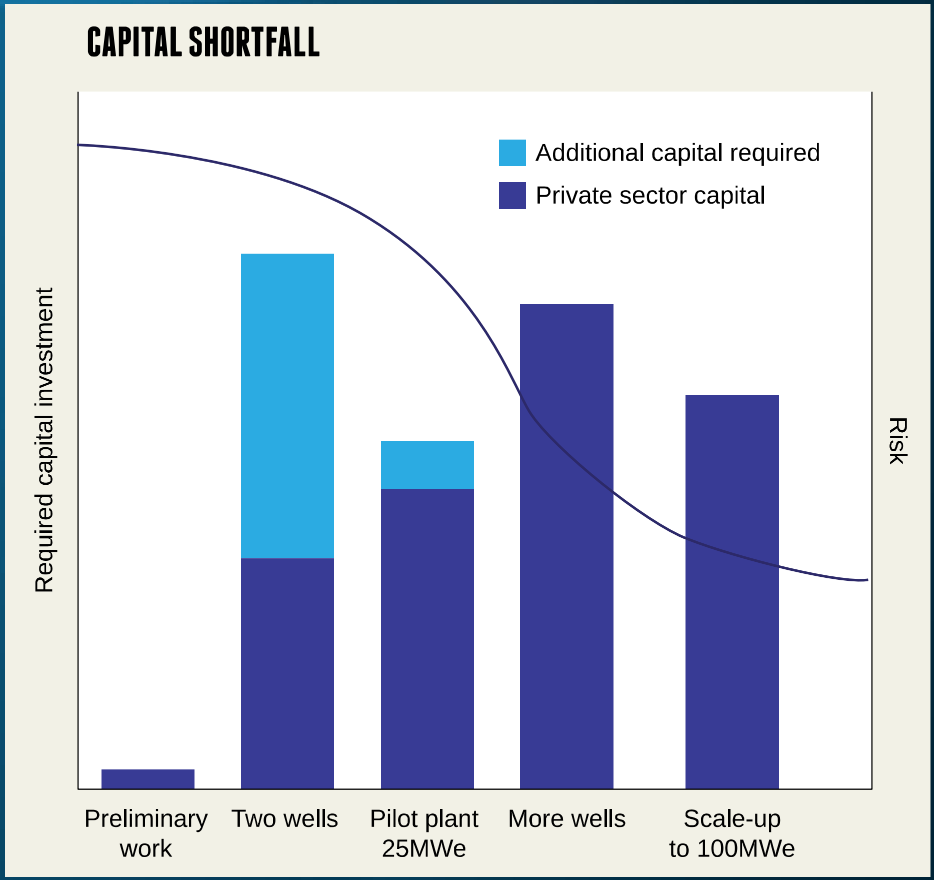
Geothermal technologies

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



Challenges for EGS

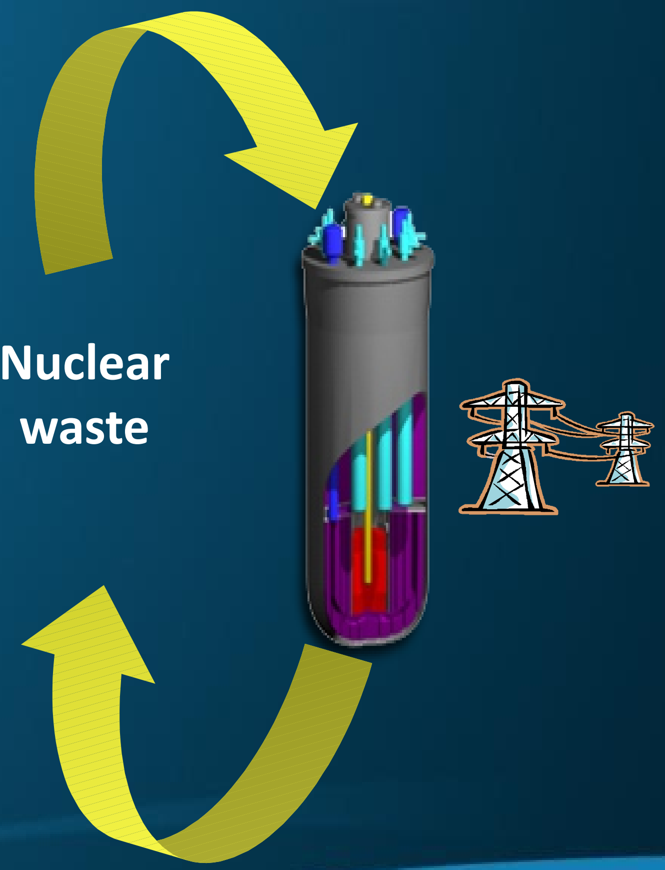
- Large upfront capital cost for drilling projects
- Lack of access to private sector capital to undertake high-risk capital intensive projects
- Lack of long-term investment incentives such as a price on carbon
- Lack of proof of resource for many geothermal prospects
- Lack of technically and commercially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



ADVANCED NUCLEAR POWER

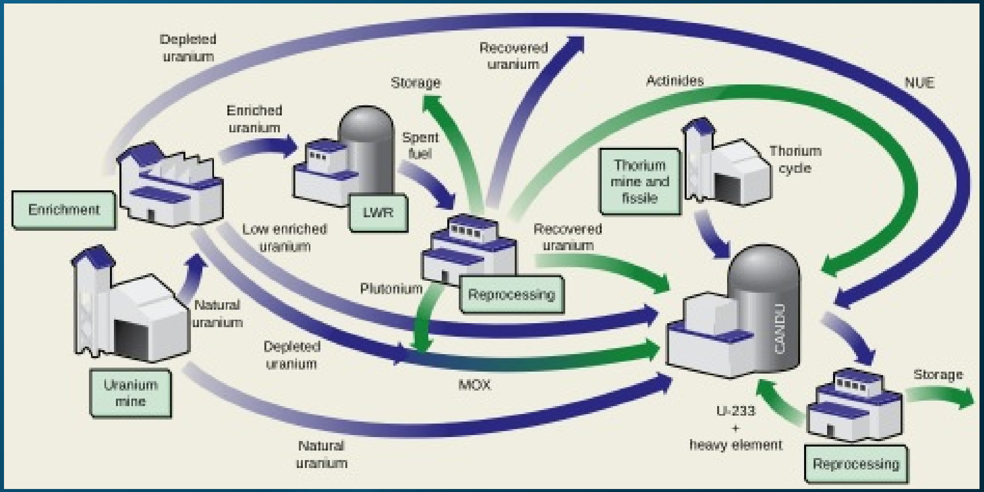
2020 2030 2040 2050

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



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?

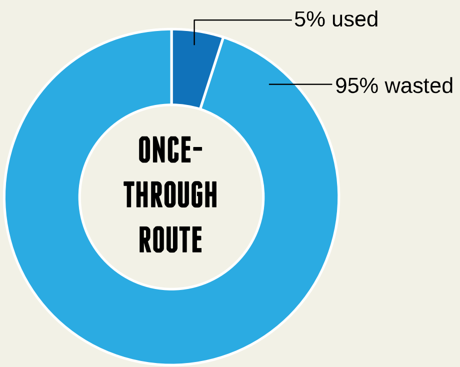


Advanced nuclear fuel cycle concepts

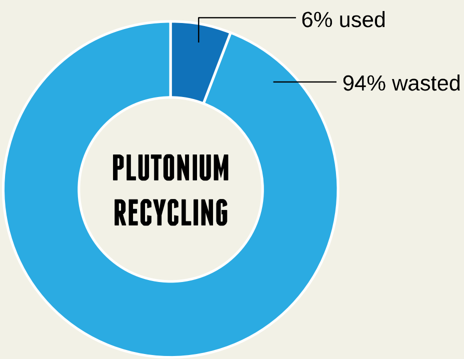
Comparing three nuclear fuel cycles

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

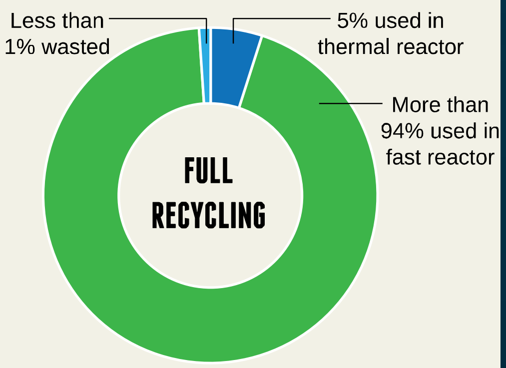
Fuel is burned in thermal reactors and is not reprocessed; occurs in the U.S.



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

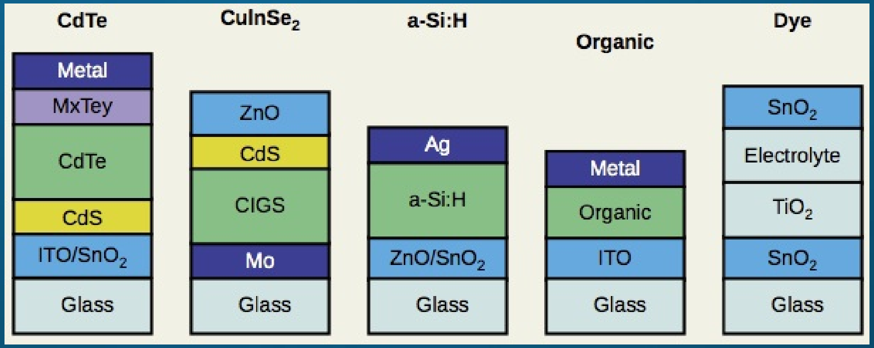

OFF-GRID
ELECTRICITY ACCESS

2.5 billion energy-poor people

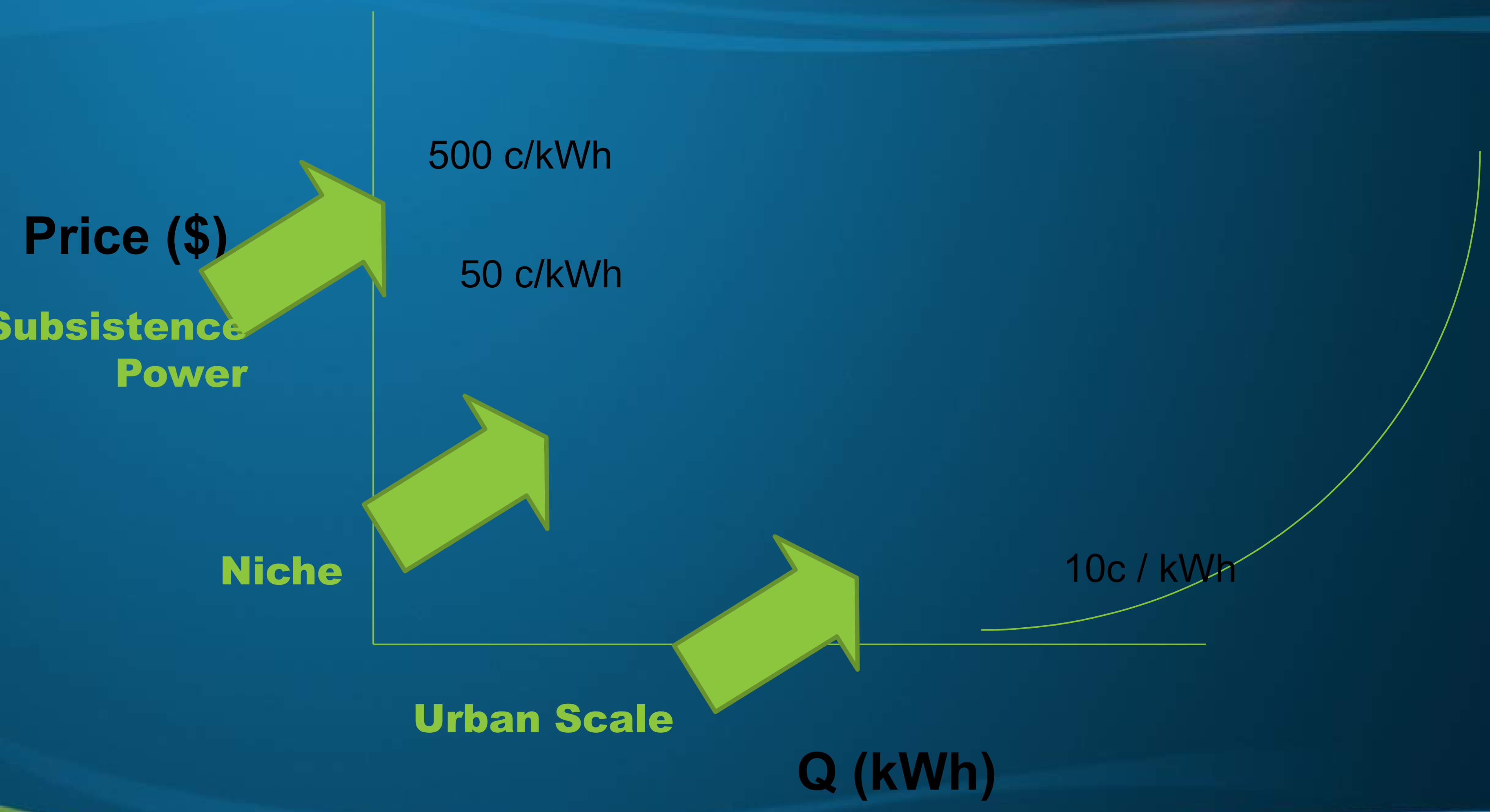

©James Fontanella-Khan

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

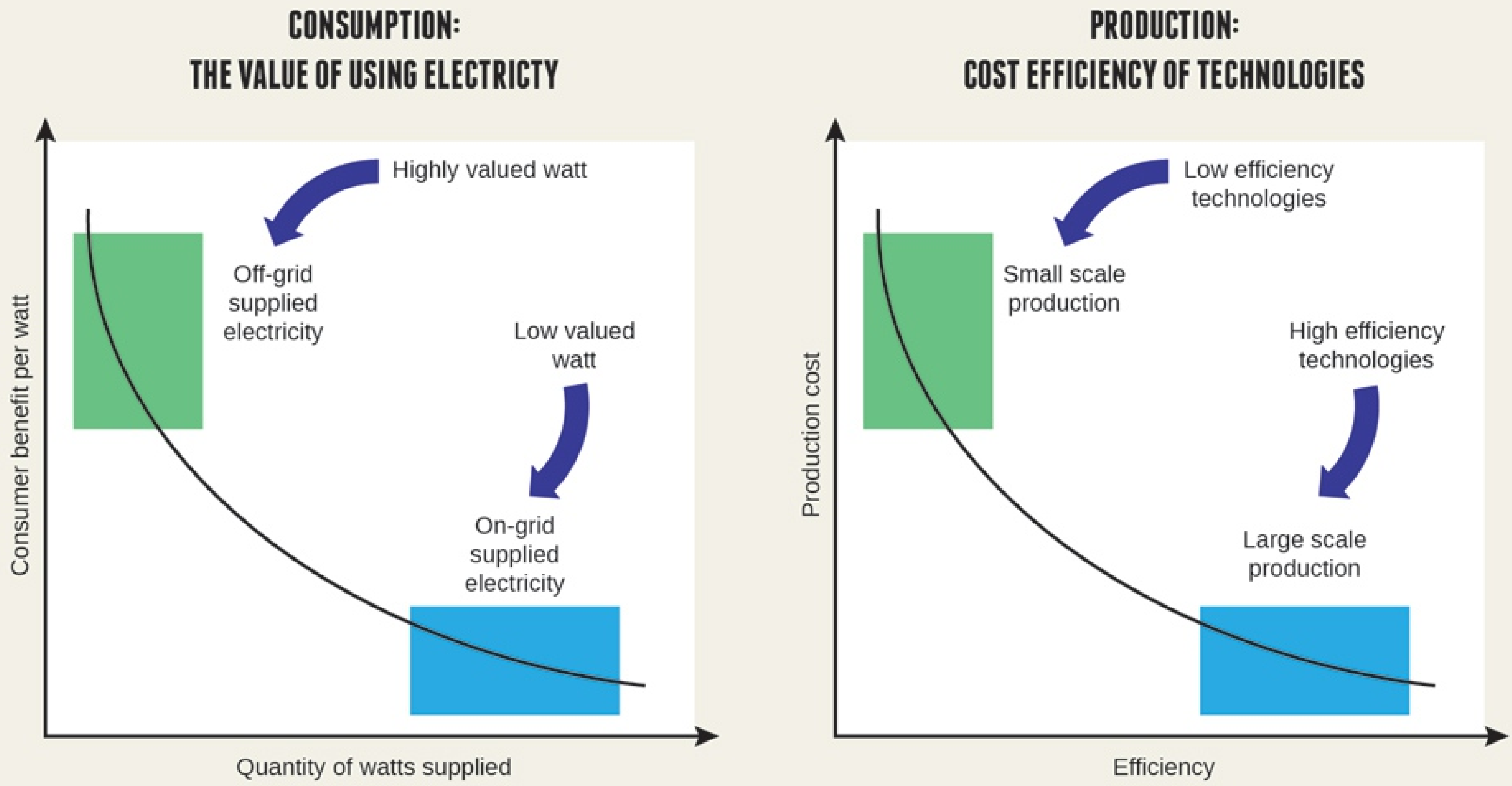


The thin film family: amorphous silicon, copper indium gallium diselenide (CIGS), cadmium telluride (CdTe), organic thin films and dye-sensitised integrated photovoltaic



Price ($)
500 c/kWh
50 c/kWh
Subsistence Power
Niche
Urban Scale
10c / kWh
Q (kWh)

Low Willingness To Pay: High kWh
High Willingness to Pay: Low kWh



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

Flexible, Portable, Light-weight and Resilient.

Attractive Price.

Replace Si based PV in applications such as:

- Water pumps
- Refugee camps
- Military forward bases (>$1000/gallon delivered diesel)
- Distributed sensors (rugged for deployment)

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

Chicago City Hall Green Roof.

Rapid Urban Population Growth = Increasing Mobility Needs

200
5

3 Billion

2030

6 Billion

Additional 3 Billion People!

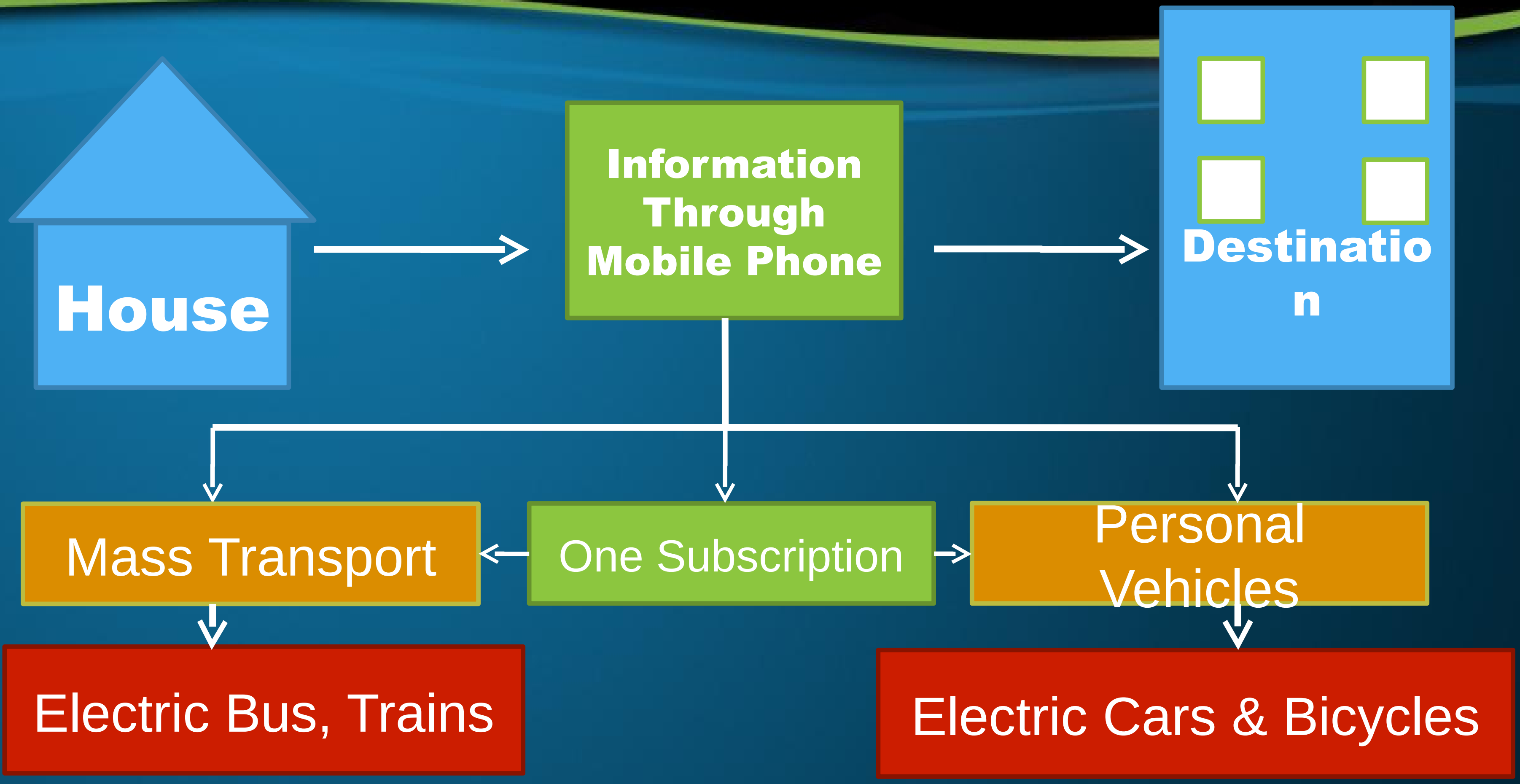
Air Quality

GHG Emission

Congestion

Shanghai, China

Jakarta, Indonesia



‘We Want Access, Not Ownership’

Advanced Lithium Ion → Cars, Bicycles

Flow Battery → Bus, Fleets

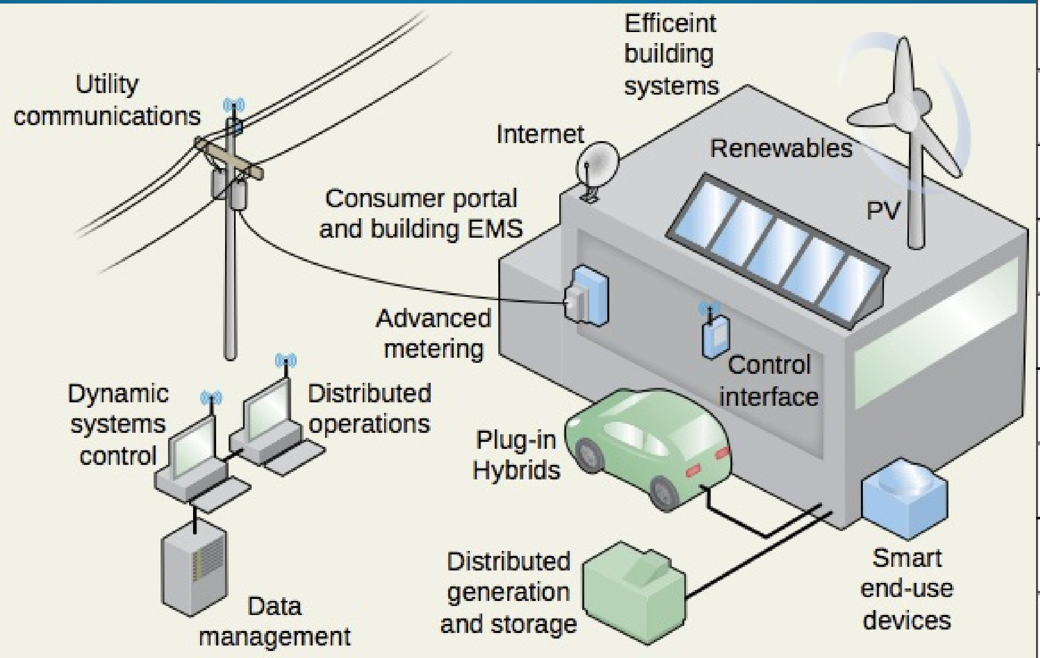
ICT (smart-phones, GPS) → **Integrating Information Access**

Smart Urbanization

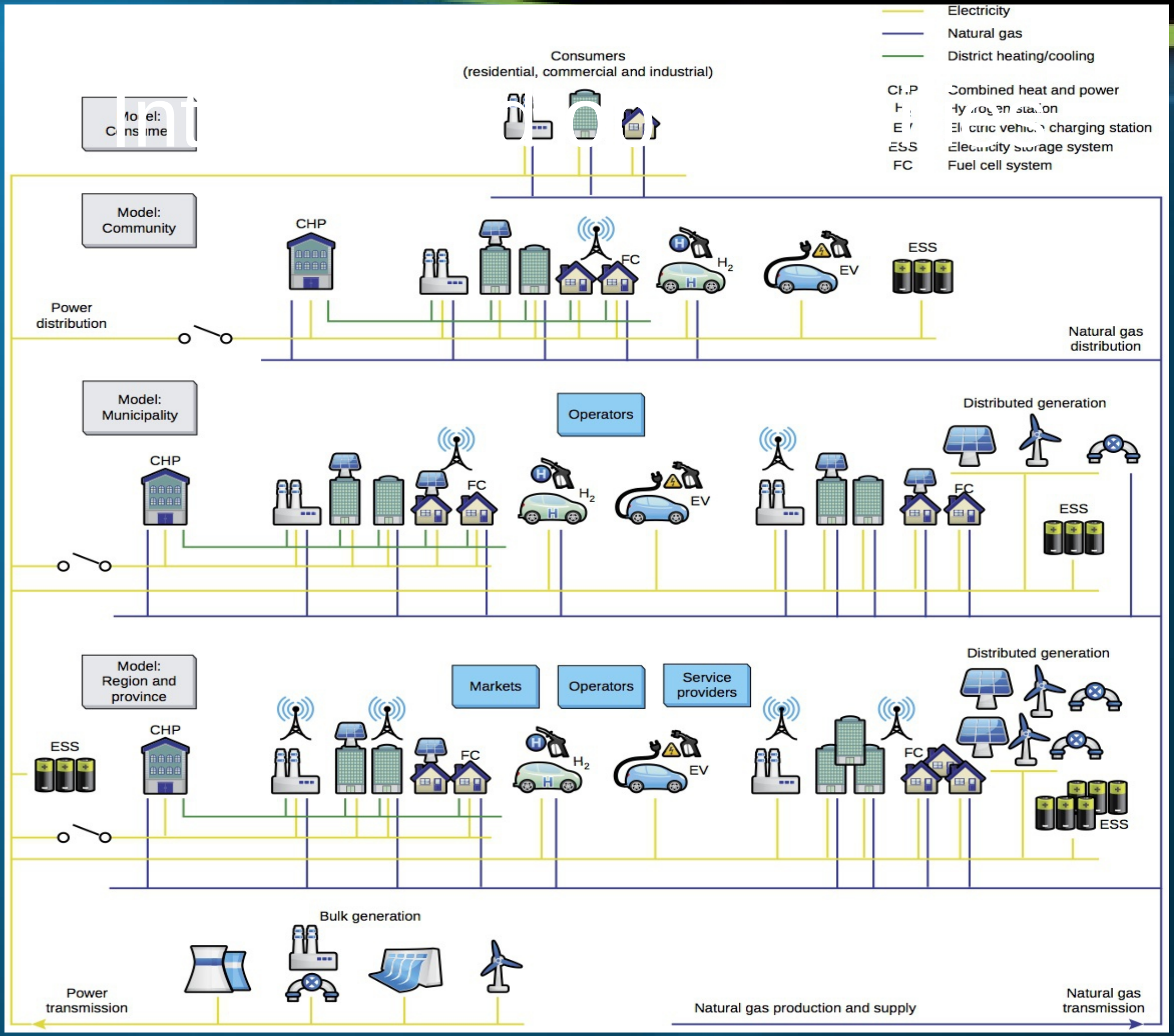
- Need an intelligent infrastructure that can accommodate renewable energy solutions:
  - Matching load with renewable energy availability
  - Electrification of transportation

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

Smart Grids



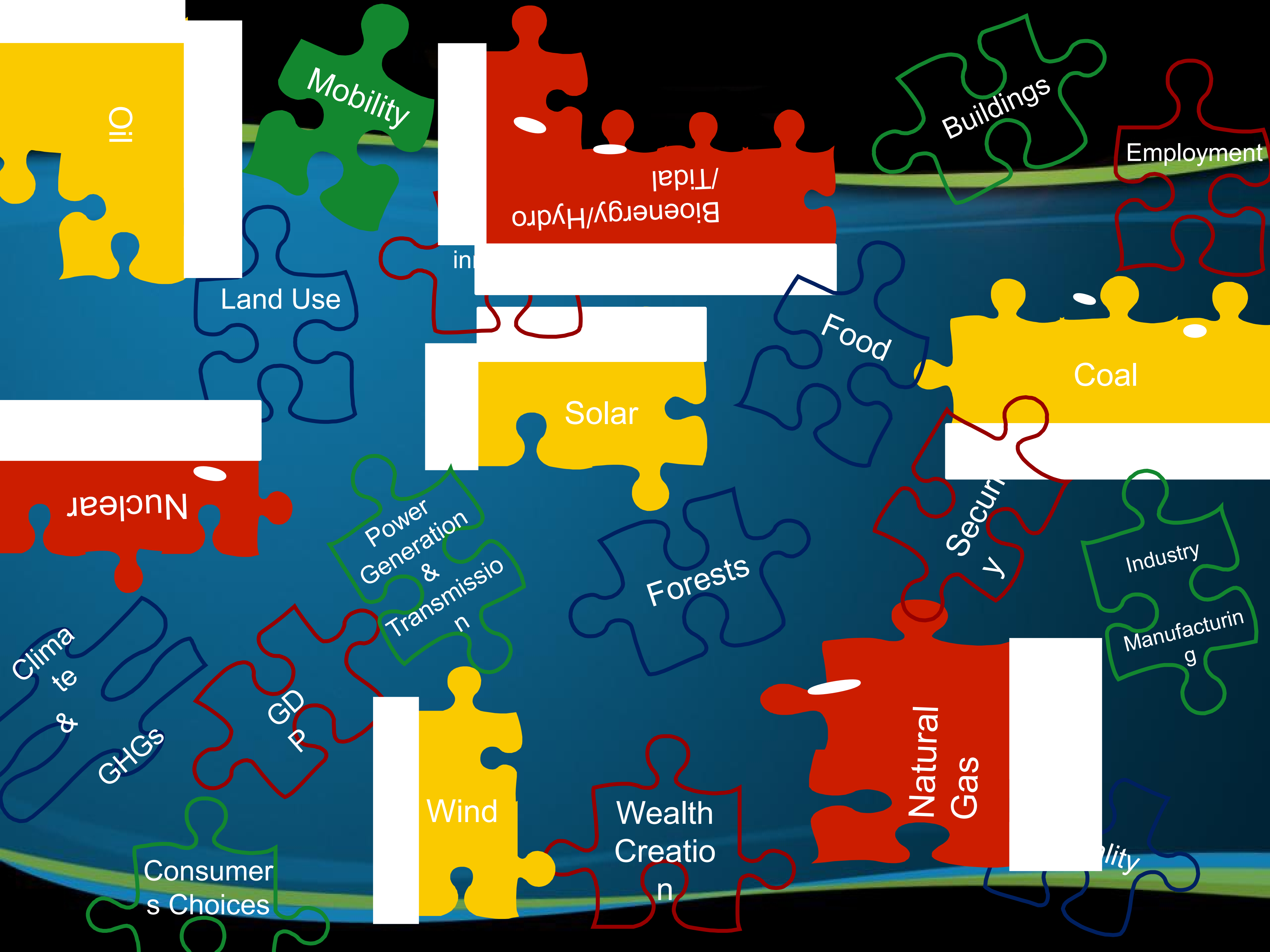
Existing grid	Smart Grid
Electromechanical	Digital
One-way communication	Two-way communication
Centralised generation	Distributed generation
Hierarchical	Network
Few sensors	Sensors throughout
Blind	Self-monitoring
Manual restoration	Self-healing
Failures and blackouts	Adaptive and islanding
Manual check/test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



Electricity
Natural gas
District heating/cooling
Combined heat and power
Fuel cell system
FC
Consumers
(residential, commercial and industrial)
Model:
Community
CHP
FC
H2
EV
ESS
Power
distribution
Natural gas
distribution
Model:
Municipality
Operators
Distributed generation
CHP
FC
H2
EV
FC
ESS
Model:
Region and
province
Markets
Operators
Service
providers
Distributed generation
ESS
CHP
FC
H2
EV
FC
ESS
Bulk generation
Power
transmission
Natural gas production and supply
Natural gas
transmission

Guideposts: shaping future directions

1. Scale and complexity of change suggests transition to a low GHG economy will take a long time
2. Global dimension of energy poverty is an even larger and deeper social and economic problem
3. Compelling global need for a non-carbon based source of high quality energy
4. Radical improvements necessary: OOM efficiency/cost
5. The power sector will be characterized by a low carbon intensity
6. A balanced mix of energy resources is key to achieving sustainable prosperity and environmental performance.



Oil
Mobility
Bioenergy/Hydro
/Tidal
Buildings
Employment
Land Use
in
Food
Coal
Solar
Nuclear
Power
Generation
&
Transmissio
n
Secur
y
Forests
Industry
Manufacturin
g
Clima
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&
GHGs
GD
P
Wind
Wealth
Creatio
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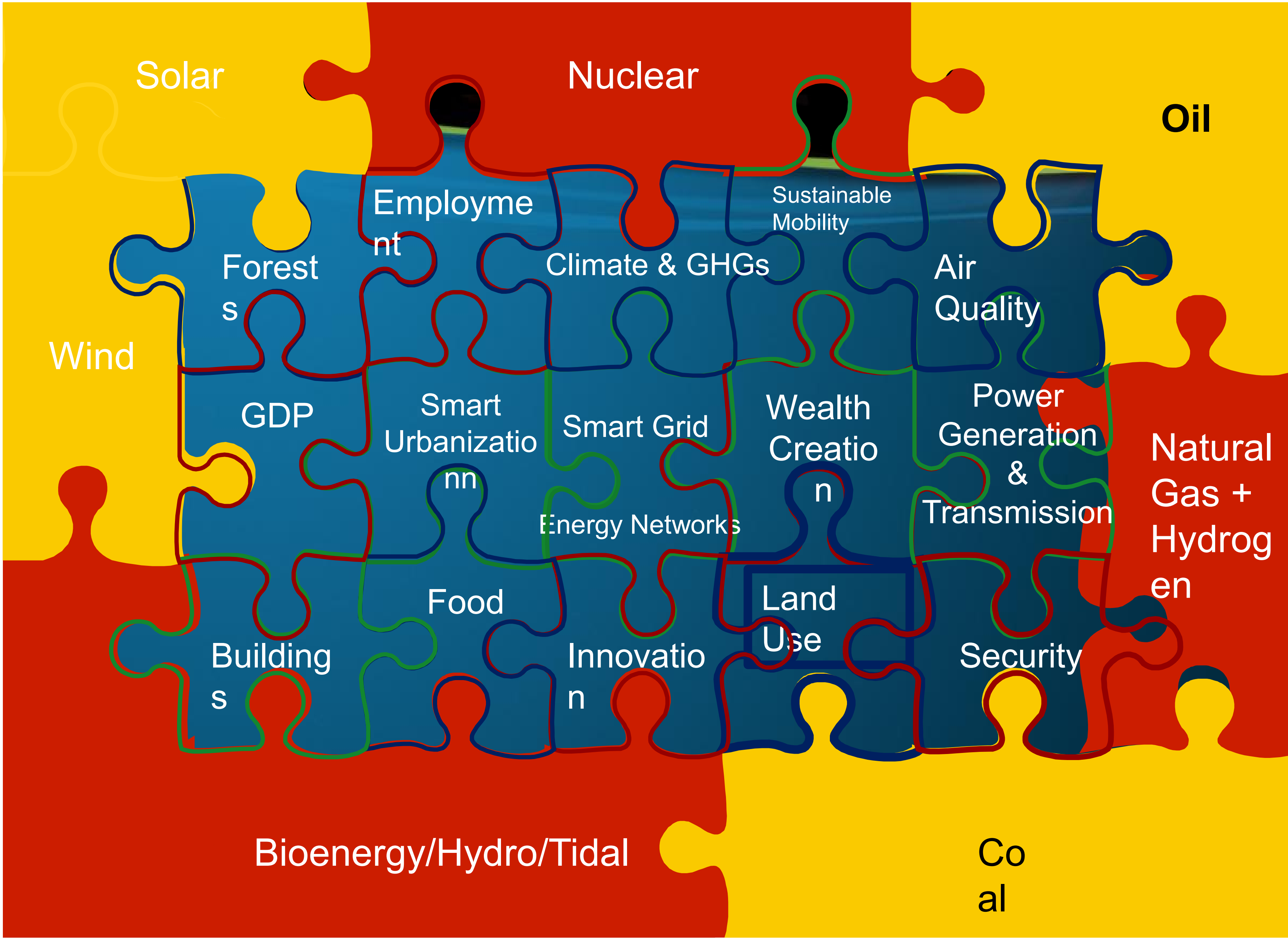
Natural
Gas
lity
Consumer
s Choices

Paths to a Sustainable Life Quality


Solar
Nuclear
Oil
Wind
Employme
nt
Forest
s
Climate & GHGs
Sustainable
Mobility
Air
Quality
GDP
Smart
Urbanizatio
nn
Smart Grid
Energy Networks
Wealth
Creatio
n
Power
Generation
&
Transmission
Natural
Gas +
Hydrog
en
Food
Building
s
Innovatio
n
Land
Use
Security
Bioenergy/Hydro/Tidal
Co
al

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