Energy Access for Human Betterment

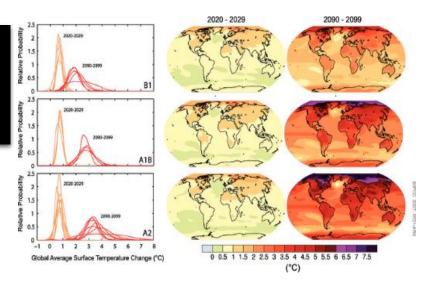
Professor Jatin Nathwani University of Waterloo Waterloo, Canada

Third Age Learning
Forbes Family Hall 1:30-3:30pm
RIM Park, Manulife Financial Sportsplex
2001 University Ave East, Waterloo
February 05, 2019





Climate Change Is the Driving Force











• Intergenerational Burdens

Energy Ecosystem

 Sustainable Technology Pathways for Resilience

Affordable Energy 4
 Humanity

Dispersed Power







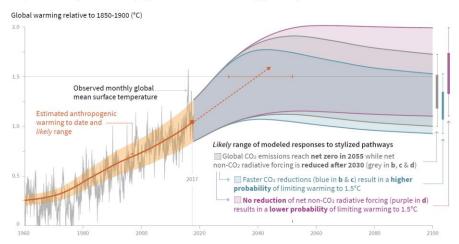
IPCC: Recent View

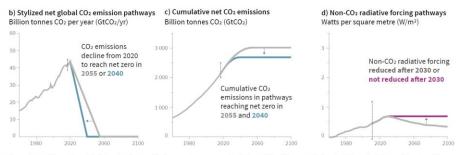
Observed RCP8.5 (a high-emission scenario) Overlap Level of additional risk due to climate change RCP2.6 (a low-emission mitigation scenario)

Source: IPCC Reports (2014, 2018)

Cumulative emissions of CO2 and future non-CO2 radiative forcing determine the probability of limiting warming to 1.5°C

a) Observed global temperature change and modeled responses to stylized anthropogenic emission and forcing pathways



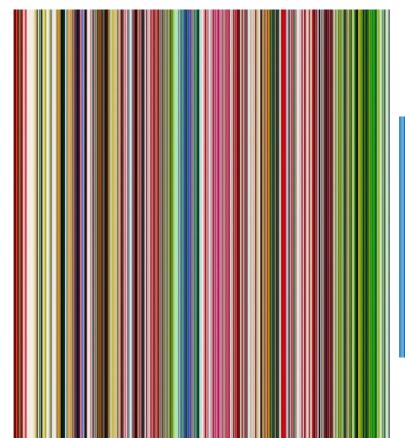


Faster immediate CO2 emission reductions Maximum temperature rise is determined by cumulative net CO2 emissions and net non-CO2 radiative forcing due to methane, nitrous oxide, aerosols and other anthropogenic forcing agents.

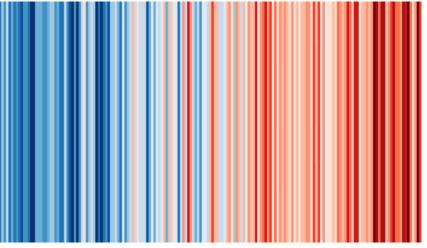




Gerhard Richter



Existential Global Challenge

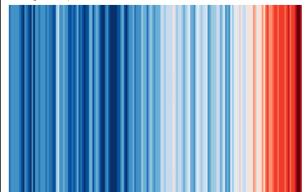




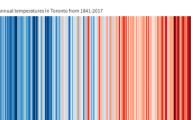


Rock Solid Evidence

Annual global temperatures from 1850-2017



The colour scale represents the change in global temperatures covering 1.35°C [data]

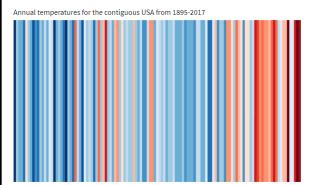


The colour scale goes from 5.5°C (dark blue) to 11.0°C (dark red) [data

DURHAM

UK warming stripes (1883-2017)

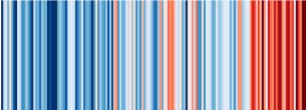
1890 1910 1930 1950 1970 1990 <u>2010</u>



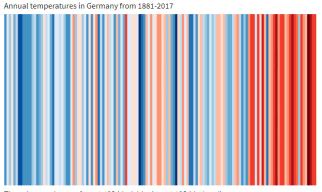
The colour scale goes from 50.2°F (dark blue) to 55.0°F (dark red) [data]

Source: Ed Hawkins, Climate Lab Book, 2018

Annual temperatures for Switzerland (1864-2017)

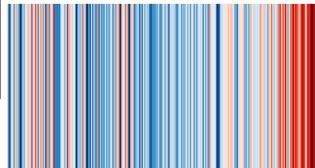


The colour scale goes from 3.0°C (dark blue) to 6.5°C (dark red) [data]



The colour scale goes from 6.6°C (dark blue) to 10.3°C (dark red)

Annual temperatures in Vienna from 1775-2017



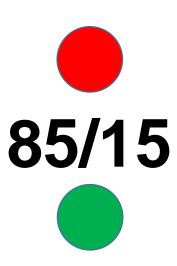
The colour scale goes from 7.5°C (dark blue) to 12.0°C (dark red) [data]





THE GLOBAL ENERGY CHALLENGE



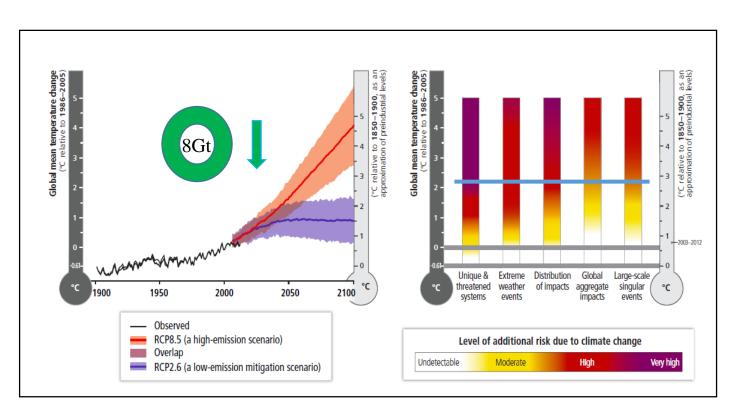


ALL NEW GROWTH MUST BE MET BY NON-CARBON SOURCES





CLIMATE CHANGE & EMISSIONS REDUCTION

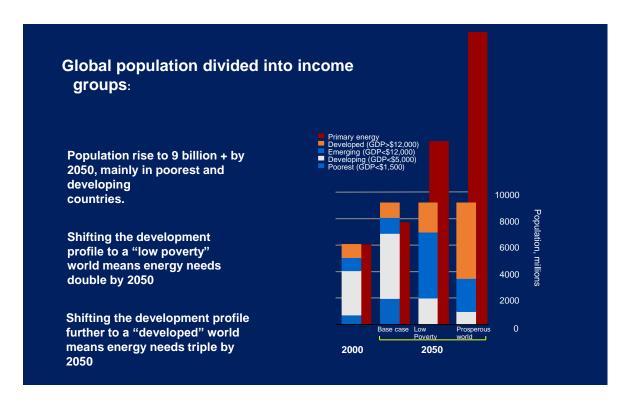






Source: IPCC Synthesis Report 2014

PROJECTED GROWTH IN ENERGY DEMAND

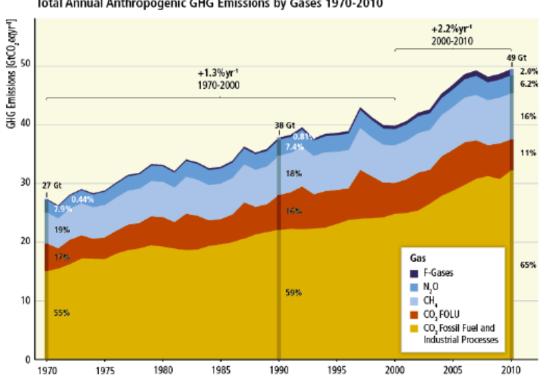


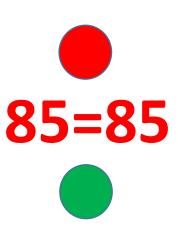




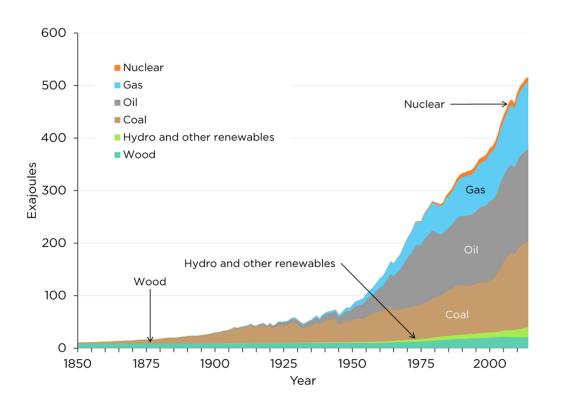
Emissions on an Upward Trajectory

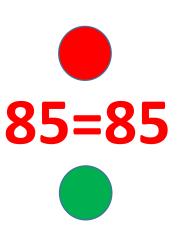






FOSSIL FUELS CONTINUE DOMINANCE





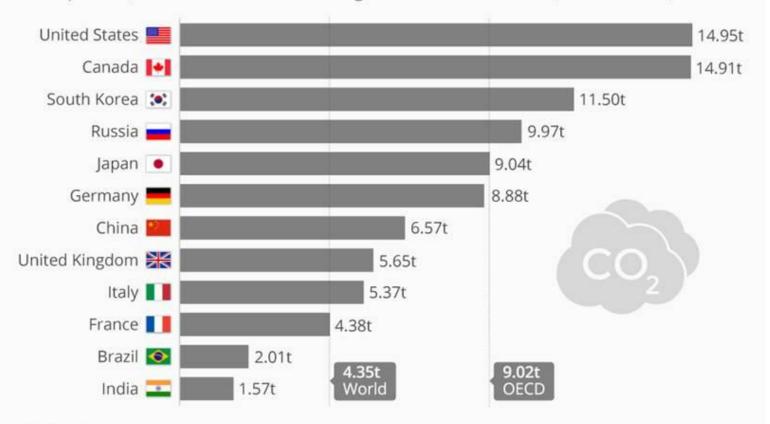
Source: Data compiled by J. David Hughes. Post-1965 data from BP, <u>Statistical</u> <u>Review of World Energy</u>. Pre-1965 data from Arnulf Grubler, <u>"Technology and Global Change: Data Appendix,"</u> (1998).





The Global Disparity in Carbon Footprints

Per capita CO₂ emissions in the world's largest economies in 2016* (in metric tons)





^{*} countries chosen based on 2017 nominal GDP

Sources: International Energy Agency, International Monetary Fund

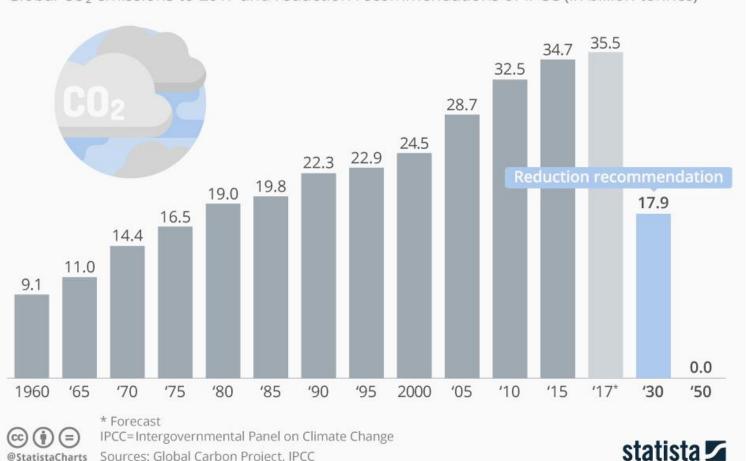






IPCC: Pull the Emergency Brake on Global CO₂ Emissions

Global CO₂ emissions to 2017 and reduction recommendations of IPCC (in billion tonnes)



@StatistaCharts Sources: Global Carbon Project, IPCC

https://infographic.statista.com/normal/chartoftheday 15737 global co2 emissions ipcc targets n.jpg





Global Energy Transition Needed – But How?





Intergenerational Obligations

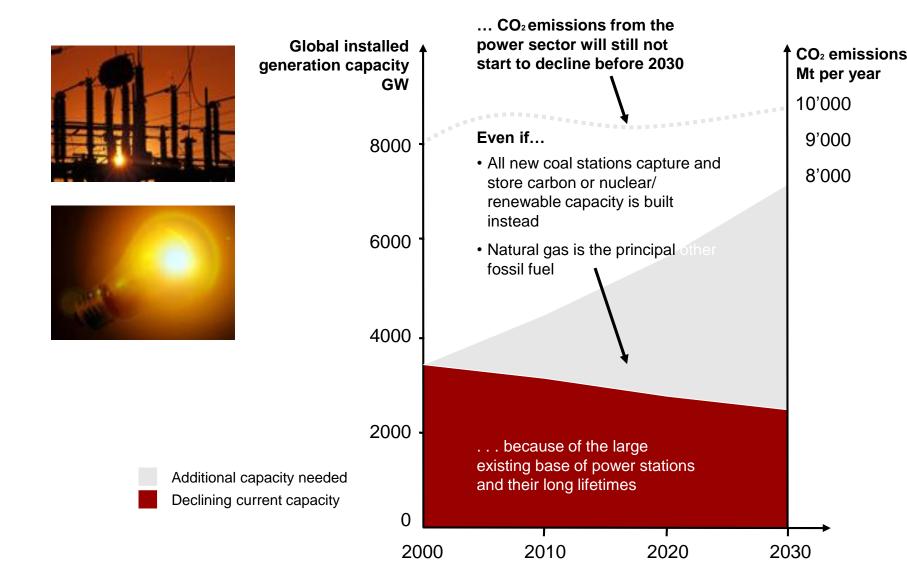




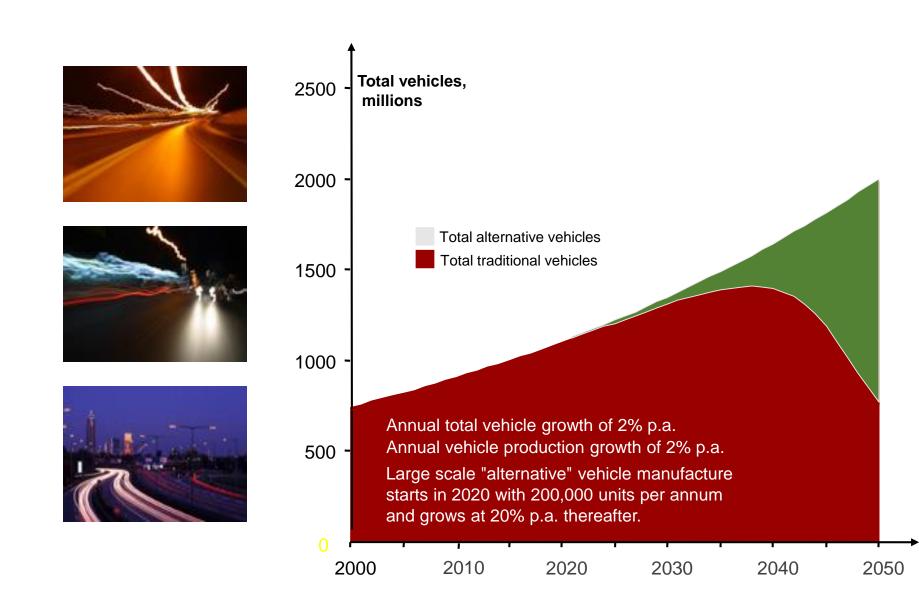


Global Transitions: Understanding Time Scales

Alternate power generation technologies: Impact on emissions



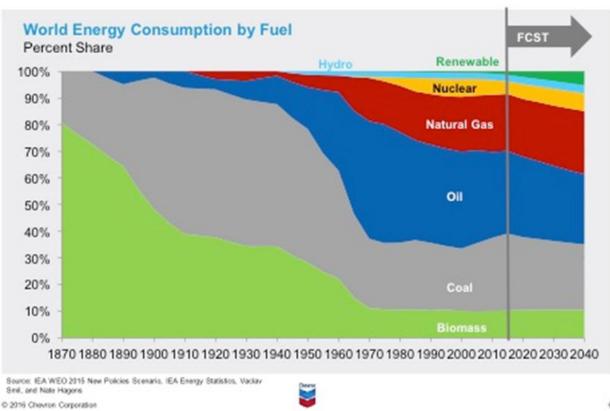
Transport and Mobility



The lifetime of energy infrastructure

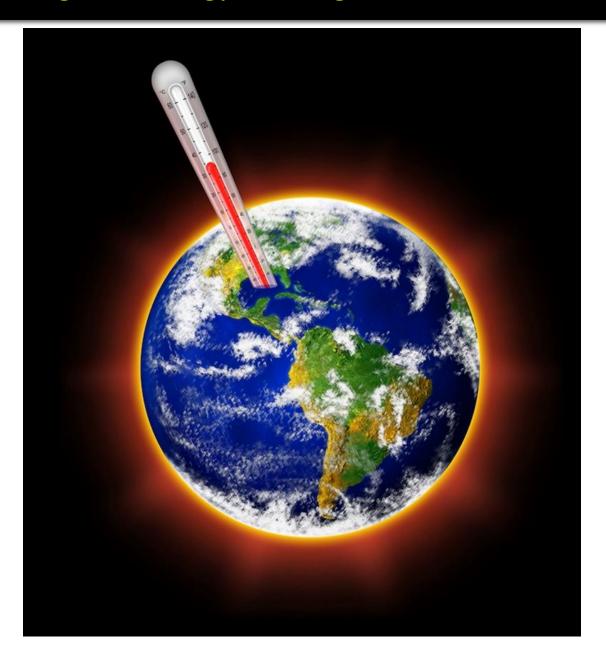
The rate of Buildings 45+++ years technological change is closely related to the Hydro 75+ years lifetime of the relevant capital stock and Coal power 45+ years equipment Nuclear 30 - 60 years Gas turbines 25+ years Motor vehicles 12 – 20 years

Energy transitions take generations



Residual Economic Asset Value of Energy System Determines Longevity

The central global energy challenge: how to de-carbonize





SOLUTIONS









Low-carbon energy ecosystem: WGSI.org





Baseload

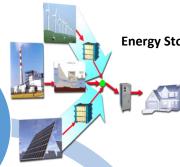
Renewables

Nuclear

Hydro

Bioenergy/Gas (RNG)

Geothermal



Energy Storage for Future Grid



Innovation

Off-grid

Micro-grids

Solar, wind, hydro...where they make sense



Smart urbanization

Enhanced smart electricity grids Electrified transport



THE WORLD AT NIGHT

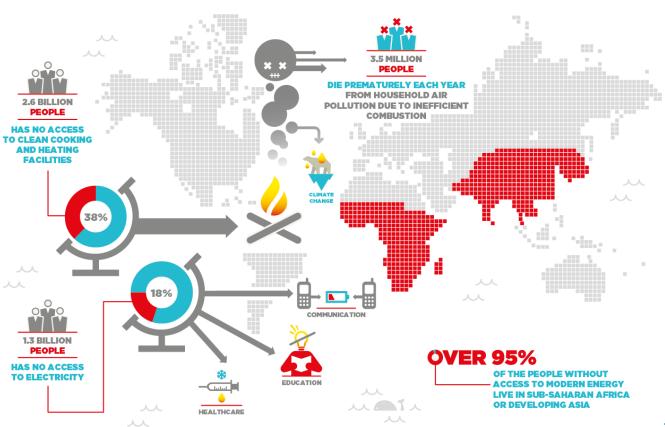
Billions with no access to modern energy services: Does it matter?







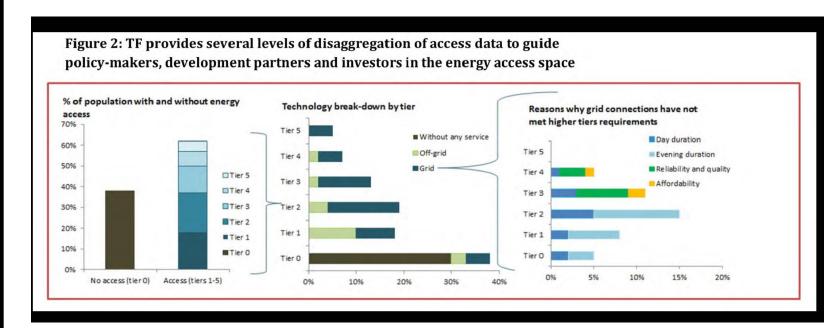
ENERGY INEQUALITY



Credit: IEA World Energy Outlook 2013



Global Population with Energy Deficient Services is much higher > 5 billion







ENERGY'S LINK TO LIFE QUALITY







THE POWER OF INNOVATION TO SAVE LIVES





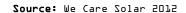
OPERATING ROOM AT NIGHT





SOLAR SUITCASE



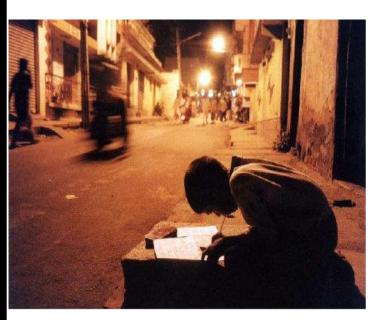






Homework Under Streetlight

Dismal Health Impacts







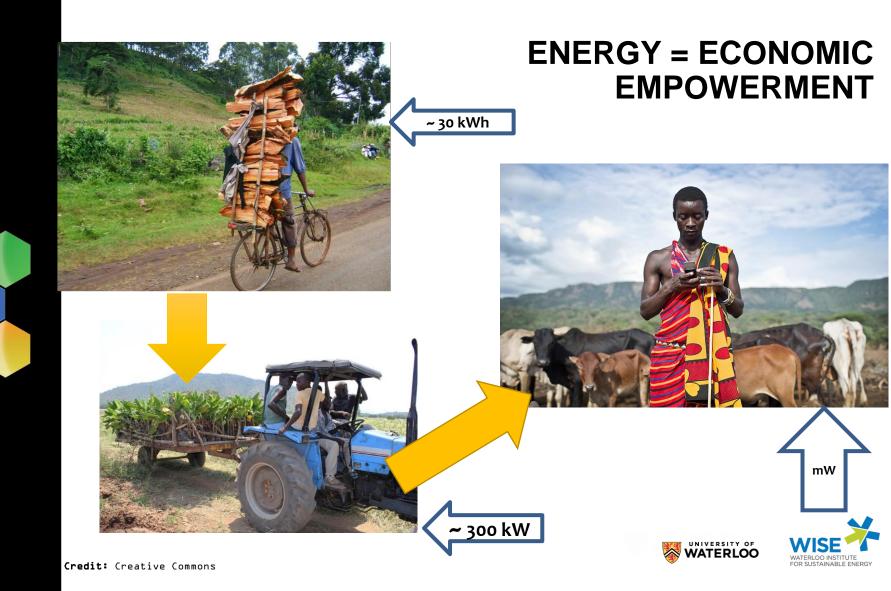


POWER LINES BUT NO POWER



Credit: James Fontanella Khan





ENERGY ACCESS = Improved Life Quality







ENERGY ACCESS TIERS



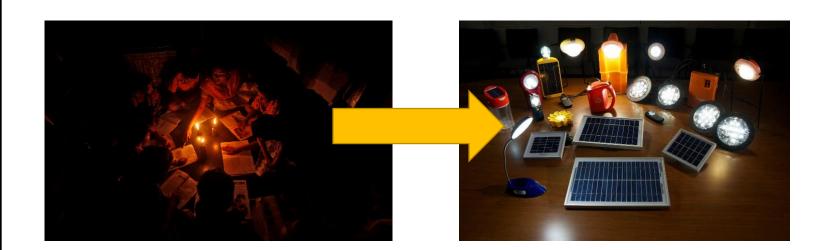




Credit: UN SE4All 2016

TIER 1 – SOLAR LANTERNS & PICO-POWER









TIER 2-3 – SOLAR HOME SYSTEMS













TIER 4-5 – RENEWABLE MICRO-GRIDS









Credit: UNDP Nepal 2016

AFFORDABLE & UBIQUITOUS ICT







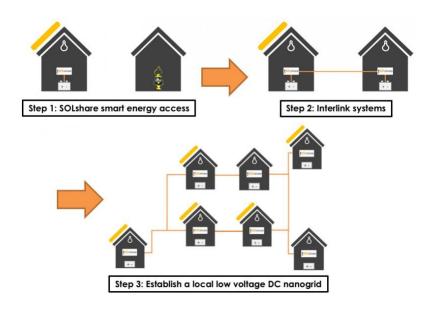




CONNECTING SYSTEMS FOR EFFICIENCY













SOLAR PROJECTORS FOR EDUCATION





Credit: One Billion & Boond





SOLAR-ENABLED OFF-GRID INTERNET

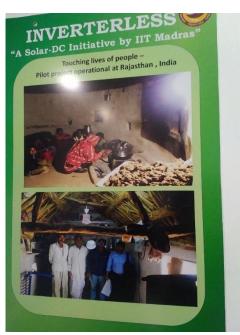


ENERGY – WATER – FOOD: Pathways to Self-Sufficiency

















INNOVATIVE APPLICATIONS













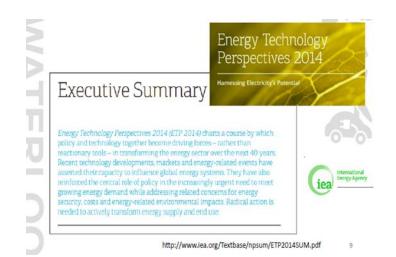
LOW COST
ROBUST
DURABLE
COMPACT
EASY TO INSTALL
EASY TO TRANSPORT
MODULAR & SCALABLE
LOW TECH ENTERPRISE
LOW MAINTENANCE — EASY TO OPERATE
LIMITED ADDITIONAL INFRASTRUCTURE

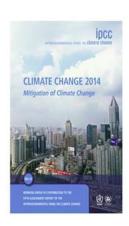


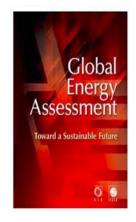




Radical action needed to deliver clean energy, affordable and accessible to all







Massive diffusion of new technologies for meeting thermal energy, motive power and electricity needs is required to meet the grand challenge of improving energy access....This requires innovation on both technological and institutional levels. Providing universal access to electricity is not just a moral imperative. ..it delivers substantial social, health and environmental benefits." GEA, Chapter 19, pp- 1401-1457

The coming energy revolution...









...will be led by scientists, innovators and entrepreneurs



Credits: Nokero; University of Waterloo









Rapid Urban Population Growth = Increasing Mobility Needs



2050 6 Billion

Additional 3 Billion People



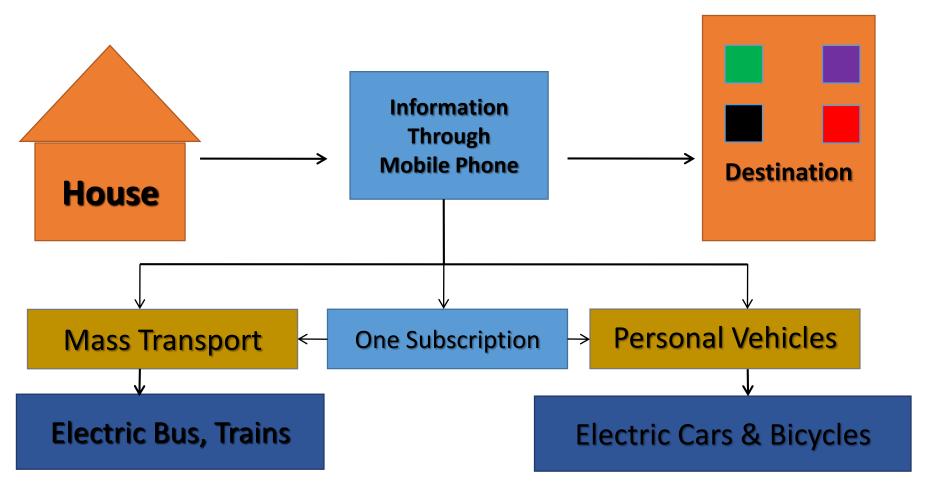
Air Quality

GHG Emission

Congestion

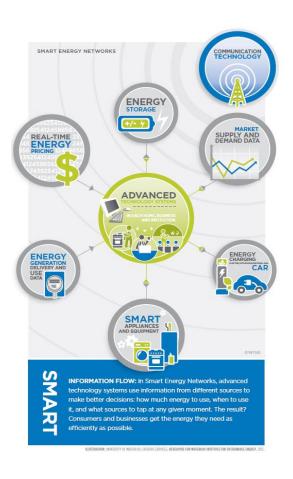


Emerging Innovations



We Want Access to Services: Not Ownership, Necessarily

Smart Urbanization Drives Smart Energy Networks

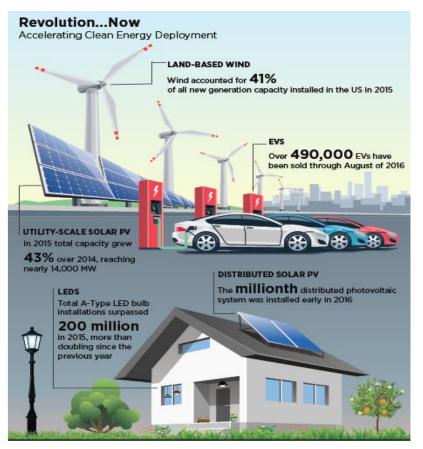








CRITICAL TECHNOLOGIES



- **Sensors / Internet of Things**
- Artificial Intelligence / Machine Learning
- Robotics
- Solar PV
- **Energy Storage**
- **3D Printing**
- 3D Visualization
- **Mobile Internet & Cloud**
- Big Data / Open Data
- 10. Unnamed Aerial Vehicles / Nano Satellites
- 11. eMoney / eFinance

Source: US DOE, 2016 'The Future Arrives for 5

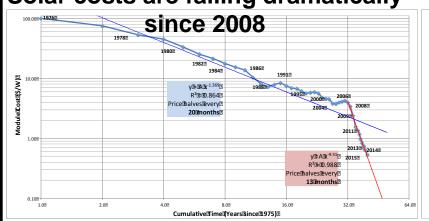
Clean Energy Technologies

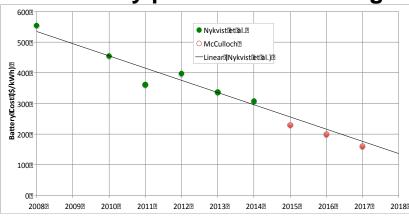




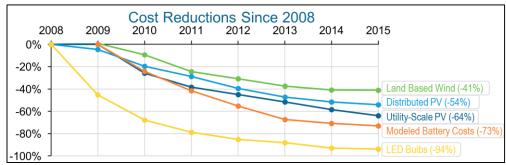
Solar costs are falling dramatically







Future Arrives for 5 Energy Technologies







Information and Communication Technologies (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 1	From 1,000s per sensor to 1,000,000s/sensor

On the road to trillions of censors: Exponential Unit Growth

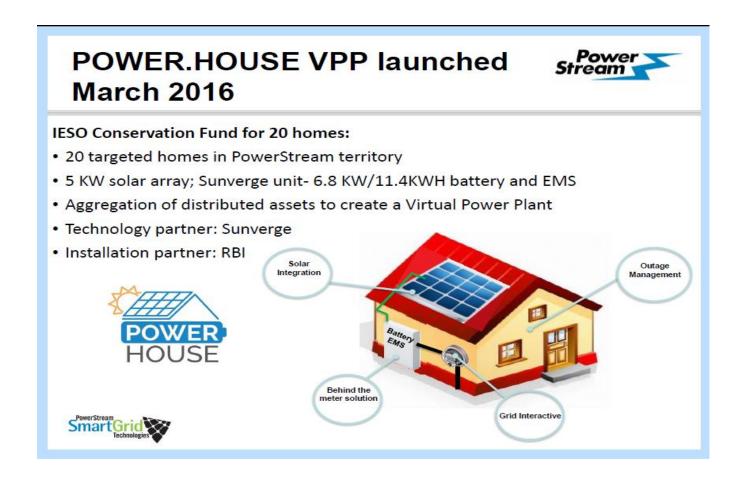
Copyright © 2016 Tony Seba Source: Janusz Bryzek, TSensors



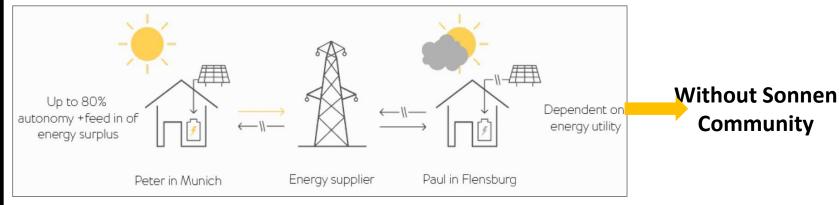


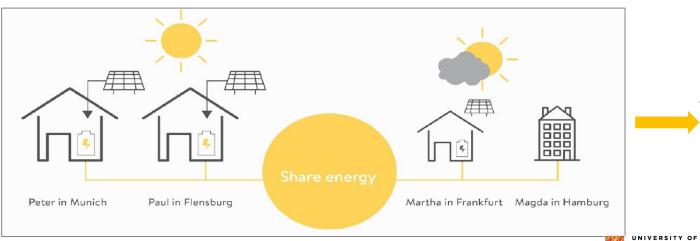


Homes As Virtual Power Plants?



SONNEN SMART COMMUNITY









WATERLOO

Power Plants on Wheels: 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 Journ









Lightyear One: Solar Car Charges by itself

Car as a Power Station: Nissan Leaf Qualified by the German TSO



UWaterloo Autonomoose





TaaS and BaaS: CHARGING STATIONS as Gateway Infrastructure:



2 kW EV Charging Station



10 kW EV Charging Station



30 kW EV Charging Shade Structure



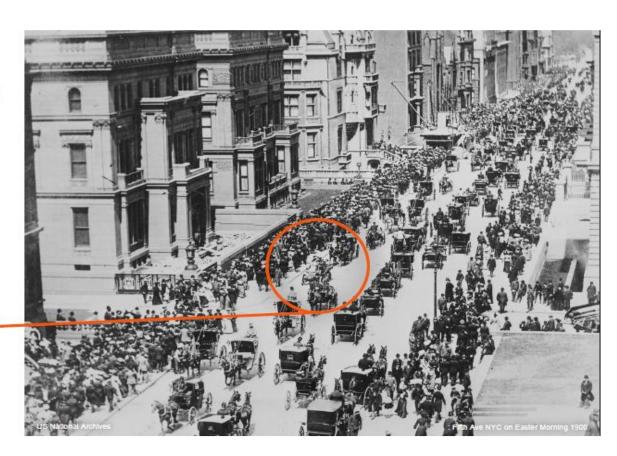
300 kW EV Charging





5th AVE NYC 1900

Where is the car?



Copyright © 2016 Tony Seba

5th AVE NYC 1913

Where is the horse?

George Grantham Bain Collection Photo: Easter 1913, New York. Fifth Avenue looking no

Copyright © 2016 Tony Seba



401 Toronto **2017**

Where is the EV?





401 Toronto **2030**

Where is **the**Gasoline Car?





Low-carbon energy ecosystem: **WGSI.org**





Baseload

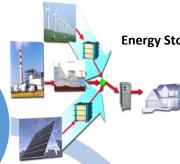
Renewables

Nuclear

Hydro

Bioenergy/Gas (RNG)

Geothermal



Energy Storage for Future Grid



Innovation

Off-grid

Micro-grids

Solar, wind, hydro...where they make sense

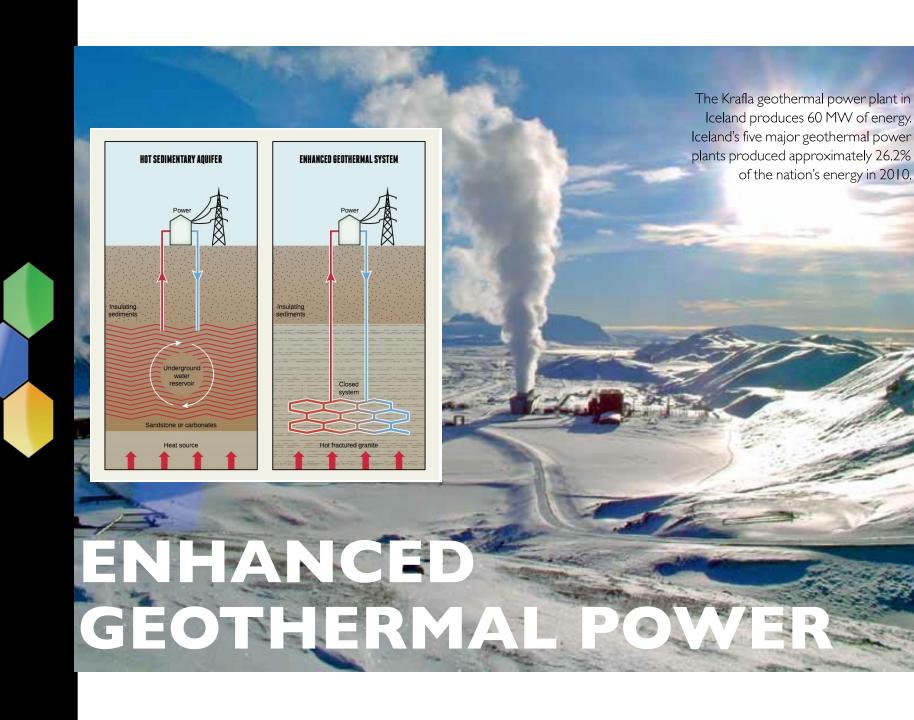


Smart urbanization

Enhanced smart electricity grids

Electrified transport





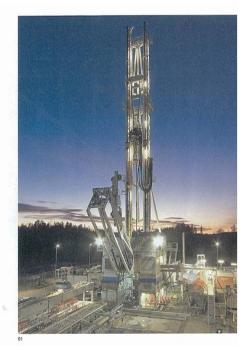


Energy from the Earth

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 simul-

taneously 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 tunneldrilling 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

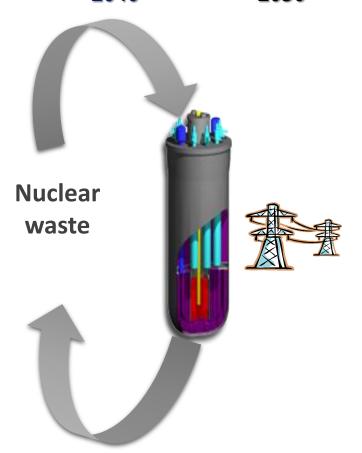




Advanced Nuclear: Challenging your assumptions about nuclear



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

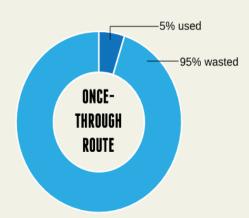




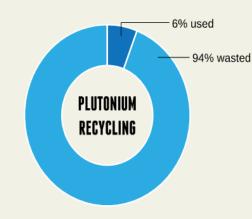
Comparing three nuclear fuel cycles

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

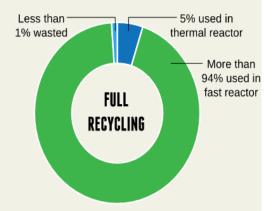
Fuel is burned in thermal reactors and is not reprocessed; occurs in the U.S.



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 thermalreactor 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

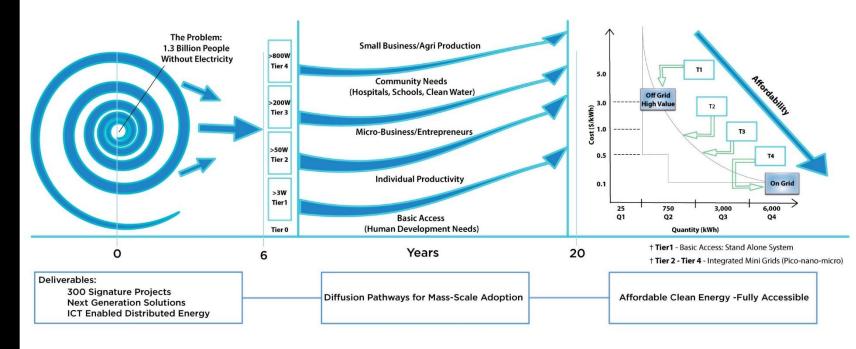
Cannot burn depleted uranium or uranium in spent fuel Can recover more than 99% of energy in spent thermal-reactor fuel

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





DRIVING A REVOLUTION IN AFFORDABLE ENERGY FOR HUMANITY







WHO WE ARE



A consortium of institutions and experts committed to enhancing research and development of innovative solutions to end energy poverty

- Co-Directors:
 - Dr. Jatin Nathwani, Ontario Research Chair in Sustainable Energy and Public Policy, Executive Director of the Waterloo Institute for Sustainable Energy, University of Waterloo
 - Prof. Dr. Joachim Knebel, Head of Division III: Mechanical and Electrical Engineering, Karlsruhe Institute of Technology





























Universal Energy Access:

Meets the Test of Climate Change + Human Betterment ✓

Energy



Affordable



4 Humanity



Can it be Done?









SUSTAINABLE GOALS









































World Energy Outlook 2017



" ... \$69 trillion"

Total cost of the International Energy Agency's Sustainable Development Scenario







"\$99 trillion ..."

That's how much money the US government estimates was in global cash and bank accounts on Dec. 31, 2017





Guideposts: shaping future directions

- I. Scale and complexity of change suggests transition to a low carbon economy will take a long time
- 2. Compelling global need for a noncarbon based source of high quality energy
- 3. Global dimension of energy poverty is an even larger and deeper social and economic problem

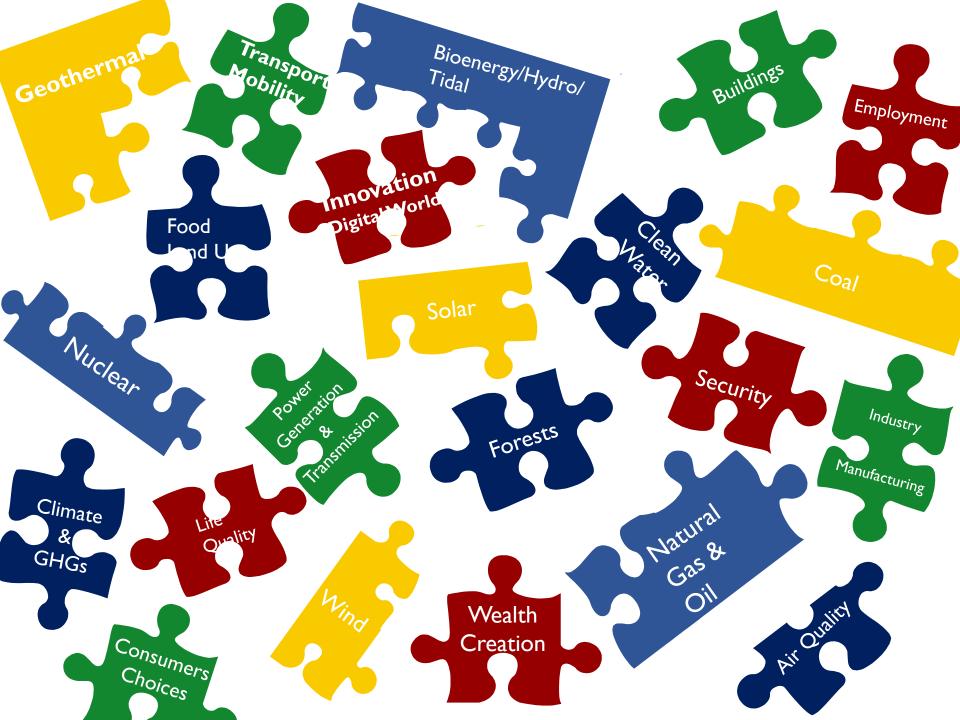


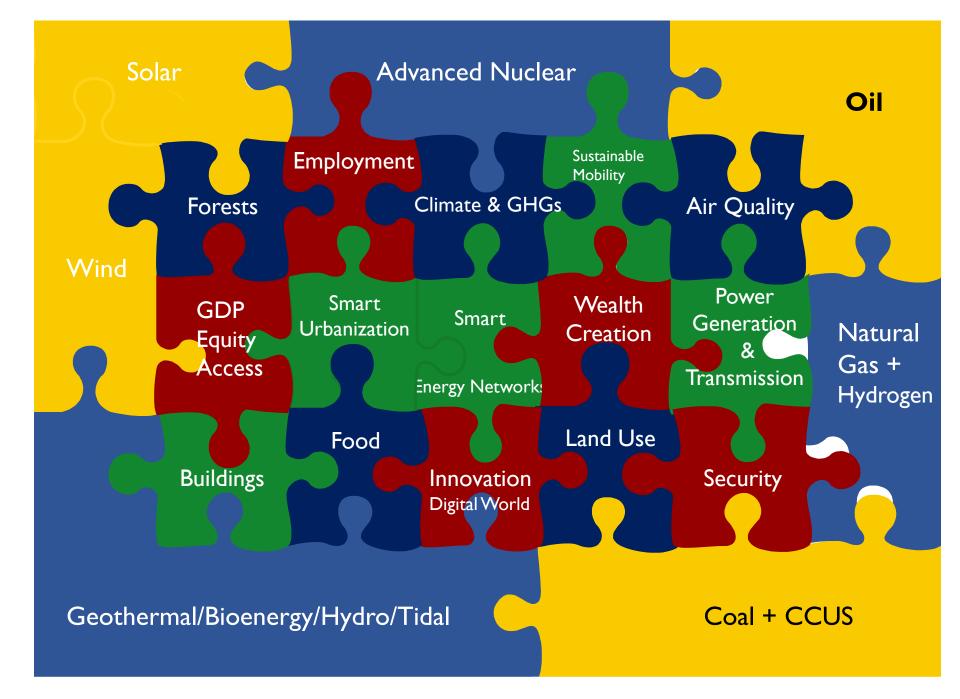




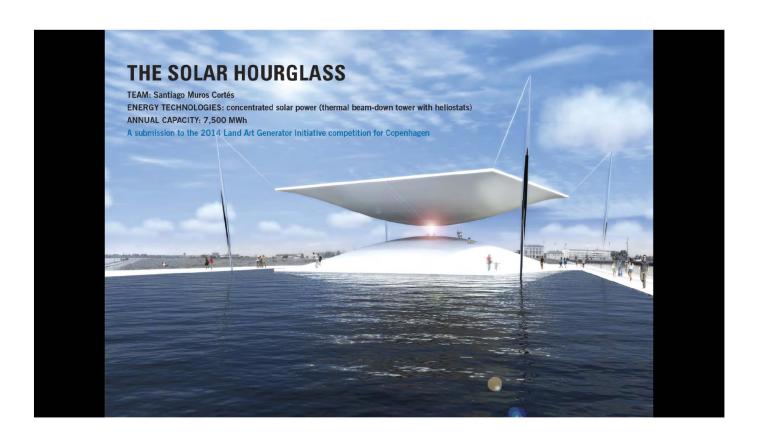














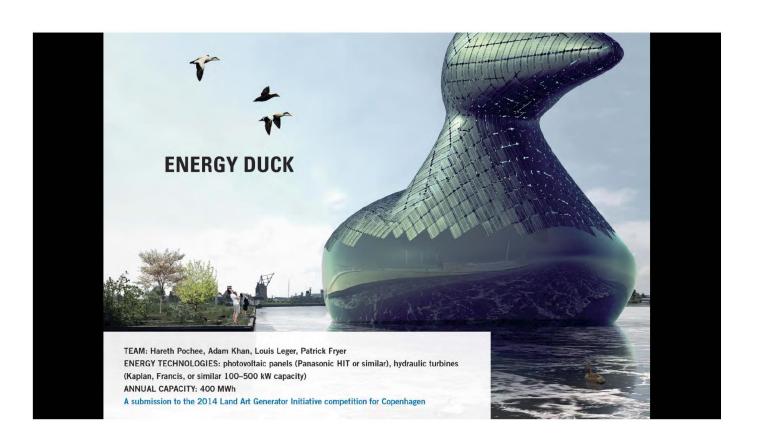
















THANK YOU

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Personal Webpage: https://wise.uwaterloo.ca/about/exec

Websites: wise.uwaterloo.ca and https://ae4h.org/









Additional Background



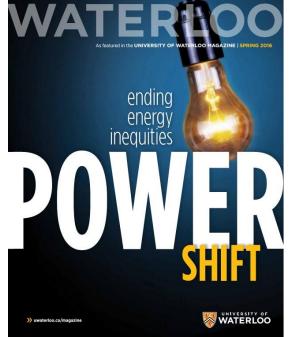
ROAD MAP FOR A LOW CARBON ENERGY FUTURE

WGSI.org





Michael Brooks Nigel Moore MARCH 2017







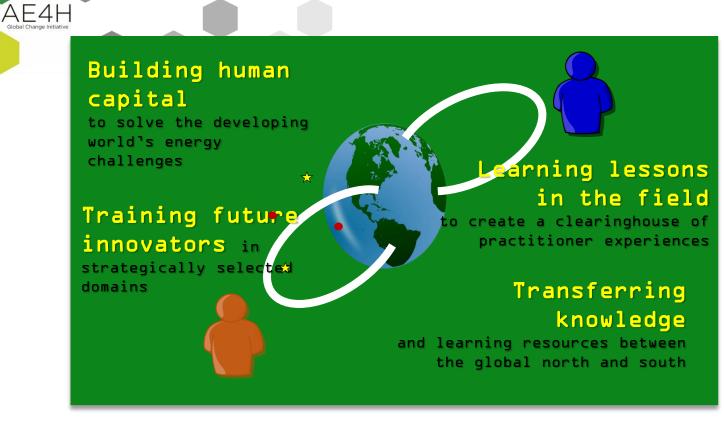
Source: Nathwani, et.al WGSI (2012)

Contact: Nathwani@uwaterloo.ca



AE4H Global Program:

Knowledge Creation – Knowledge Transfer

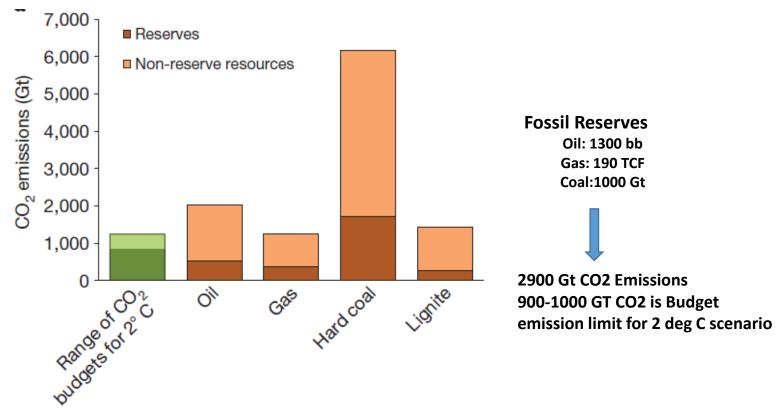








Fossil Fuels as Stranded Assets? Financing Intergenerational Burdens of Energy Transitions

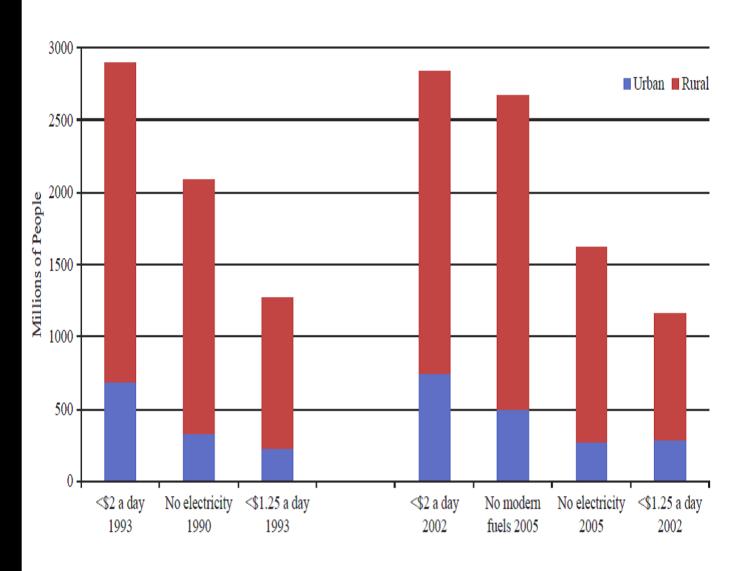


Source: McGlade, C and Eakins, P, Nature, v 517,187, Jan 8, 2015





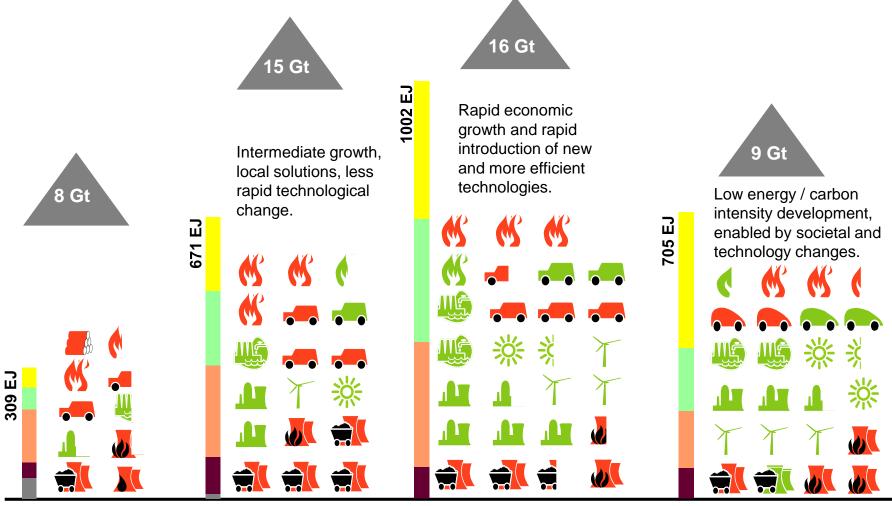
Billions with no access to modern energy services:



Source: GEA 2012, data from IEA 2002, 2007, Revlon et al 2007

Meeting Future Needs: A Balanced Mix of Options







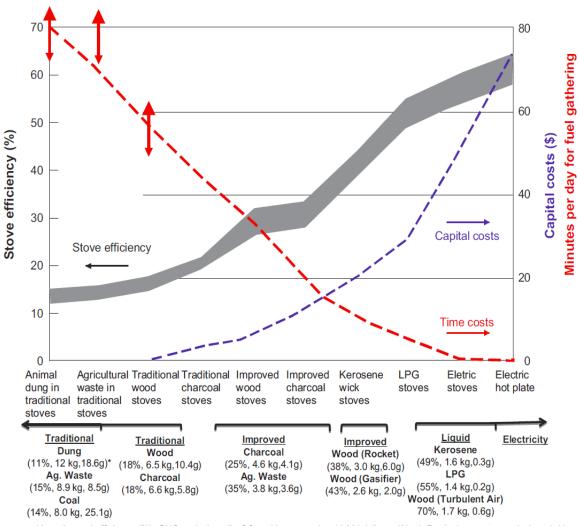
2050 (B2-AIM)

2050 (A1B-AIM)

2050 (550 ppm trajectory)



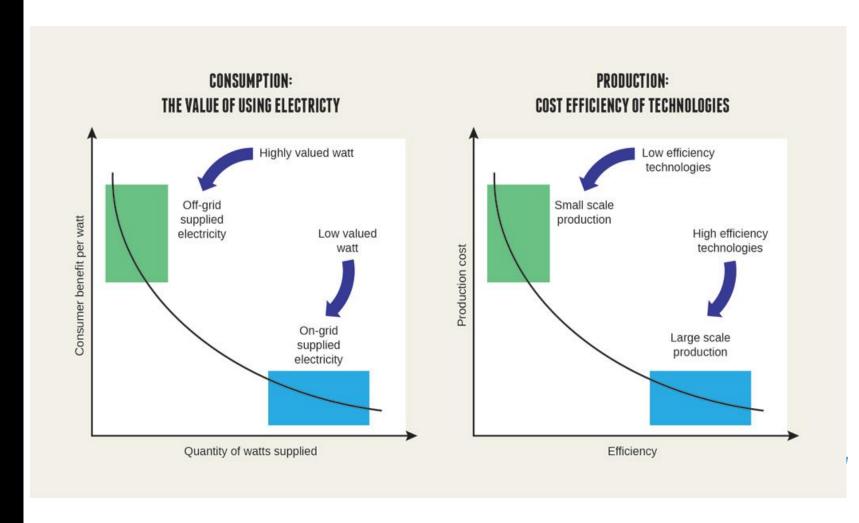
Cost of Energy Services: Time vs Fuel vs Capital



^{*}Avg. thermal efficiency (%), GHG emissions (kgCO ₂-e/day assuming 11 MJ delivered/day), Particulate matter emissions (g/day assuming 11 MJ delivered/day).

Source: GEA 2012, Chapter 2

VALUE & COST OF ENERGY AT DIFFERENT TIERS



Credit: Waterloo Global Science Initiative 2011

Comparison of carbon intensity of electricity production

Average yearly decarbonization rate from 2010 - 2015 (Table 3)

Country	GDP 2010 Million EUR 2010 chain linked	GDP 2015 MILLIon EUR 2010 chain Uniked	GHG emissions 2010 Tonnes of CO ₂ eq	GHG emissions 2015 Tonnes of CO ₂ eq	GHG emissions per GDP 2010 Tonnes of CO ₂ eg/ MEUR	GHG emissions per GDP 2015 Tonnes of CO ₂ eq/ MEUR	Av decarbonization rate of the economy per year 2010–2015 Tonnes of CO ₂ eq/MEUR/ year
Slovakia	67 57 7	76 494	46692960	41415090	691.0	541.4	-29.9
Czech Republic	156718	170326	140558690	128 820 670	896.9	756.3	-28.1
Romania	126746	142 982	121402540	117810040	957.8	824.0	-26.8
Ireland	167583	238 677	64029690	62425330	382.1	261.5	-24.1
Turkey	581024	818863	412713630	486 235 900	710.3	593.8	-23.3
Finland	187 100	186 537	77321490	57538900	413.3	308.5	-21.0
Hungary	98826	108694	66122360	61639540	669.1	567.1	-20.4
Bulgaria	38231	41274	60811330	62 021 120	1590.6	1502.7	-17.6
United Kingdom	1841692	2040 921	643 931 270	536 901 780	349.6	263.1	-17.3
Belgium	365101	410 247	136 642 480	121 641 890	374.3	296.5	-15.6
Denmark	243165	257 528	65 642 610	50 983 620	270.0	198.0	-14.4
Sweden	369077	410 225	66 689 510	55885800	180.7	136.2	-8.9
Germany	2580060	2800913	965 969 780	926479010	374.4	330.8	-8.7
Netherlands	631512	657561	224451910	206712600	355.4	314.4	-8.2
France	1998481	2097166	527 682 100	474606680	264.0	226.3	-7.5
Italy	1604515	1558317	514 136 770	442777 620	320.4	284.1	-7.3
Austria	295 897	312614	87 130 050	81000490	294.5	259.1	-7.1
Switzerland	441 086	478556	58764280	53093870	133.2	110.9	-4.5
Norway	324 043	353 138	56 501 690	55444740	174.4	157.0	-3.5
Spain	1 090 935	1070710	369 564 740	350403200	341.9	327.3	-2.9
Greece	226 031	184468	120 915 100	98608630	534.9	534.6	-0.1
Portugal	179 930	172190	72 120 450	72085210	400.8	418.6	3.6

Countries that are successful in metric 3 have put in place the right policies to quickly reduce their carbon emissions. While mostly countries with high GHG emissions per GDP are in the upper end of the ranking, countries that stand out as positive examples are Ireland, Finland, UK, Belgium and Denmark with an already low ratio of GHG emissions per GDP but still a high average decarbonization rate.

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https://www.electricitymap.org/?page=map&s olar=false&remote=true&wind=false

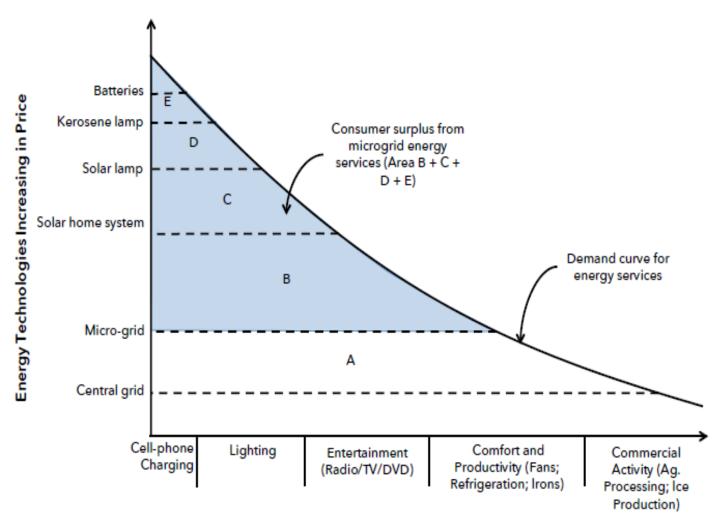
Total GHG emissions per GDP 2010 baseline (Table 1)



In metric 1, countries who have chosen to massively example of wo-carbon electricity and/or countries gifted with a favorable hoppography for hydropower are leading the way. It is interesting to see that Austria is doing much worse than Sovitaerland while having similar topography. The ream of for this is that Austria decided to not use nuclear energy but instead fosal fluest land nuclear energy was promoted in the 1905 for environmental reasons to avoid the construction of fosal fluef fired power stations after the hydropower capacity had resched its limits.

Data source GDP: Euristat [9]

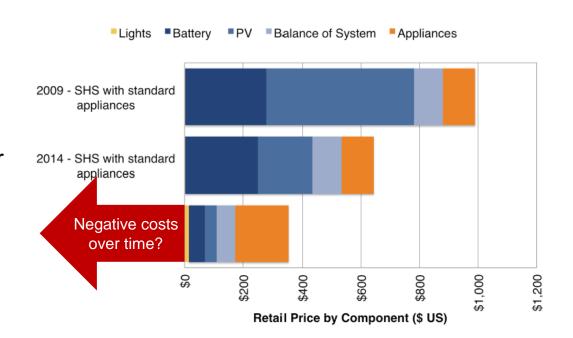
Smart micro-grids create a consumer surplus



Solar Home System + Super Efficient Appliances = Affordable Service

But, what if the appliances themselves generate income?

- ✓ Irrigation pumps for farmers
- ✓ Fridges for cold beverage sales
- ✓ Hair clippers for barbers
- ✓ TVs for local cinemas



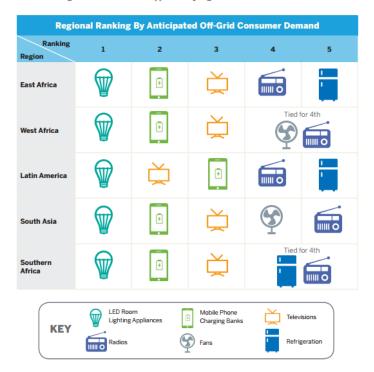
Source: "Powering A Home with Just 25 Watt solar PV with Super Efficient Appliances," Phadke et al, LBNL 175726, April 2015





Super Efficient Appliances – Make the Most Out of Every Watt!

Table 2: Rankings of Household or SME Appliances by Region



Global LEAP Awards
Outstanding Off-Grid
Appliances
2014 Buyer's Guide

Global LEAP Awards
Outstanding Off-Grid
Appliances

2014 Buyer's Guide







World Energy Outlook 2017



" ... \$69 trillion"

Total cost of the International Energy Agency's Sustainable Development Scenario





Climbing the Access Ladder for Life Quality



Source: Acumen Fund, 2012