Notes to accompany
Presentation by Professor Jatin Nathwani, University of Waterloo, Waterloo, Ontario, Canada.

at the
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Slide 1 – Climate Change: Paths to Global Energy Transitions

Climate change is not, at its core an environmental problem. It is an energy technology problem.

Two decades and two treaties on (UNFCC and Kyoto), climate diplomacy as practised by many governments of the world, has failed to produce any discernible real world reductions in emissions of greenhouse gases.

I refer to the UNFCCC process requiring an agreement amongst all nations through a treaty with targets and timeline as the T3 curse.

The core of the global effort to cut emissions will not come from a single global treaty; it will have to be built from the bottom up—through ambitious national action focused on specific opportunities to cut emissions

With alarm, a recent IEA report issued April 2013 entitled "Tracking Clean Energy Progress," notes "the picture is as clear as it is disturbing: the carbon intensity of the global energy supply has barely changed in 20 years, despite successful efforts in deploying renewable energy."

Slide 2 – Energy Transitions and the Global Challenge

Global energy consumption will double by 2050.

- 85% of today's energy is fossil based (only 2.5 TW is non-carbon,..)

A sense of the magnitude:

- 1 TW year of energy is equivalent to One thousand Darlington sized reactors (ie. 1000 MW capacity) operating 24/7[1 TW= 8760 TWh]

In simplest terms, the new growth to 2050, the next 15-16 TW of energy will have to be non-carbon based (hydro, renewables, nuclear):

- This is a multiple of 6 times todays non carbon energy capacity

- Or, the equivalent of putting in place the entire existing global energy infratsructure over the next 30-40 years

Simple Message: Challenge is BIG

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But also look out against the mantra, often doled out: “every little bit helps” If everyone does a little, we will achieve only a little”

Meaningful actions to decarbonize the global energy system have been frustrated because of a dysfunctional negotiation process that produces – at best - ineffectual and paltry commitments, subsequently circumvented by local and regional political considerations. Few are ready to compromise, options to enforce commitments are absent, and target setting has exhausted its relevance.

Slide 3 – World at Night

This satellite image of contrasting islands of light and darkness is a stark reminder of the essential problem: the 2 Billion people who have just about no access to electricity at all.

The source of the many of the public policy debates about energy access, energy security, energy affordability and what we may or may not be able to do about the unintended consequences to the environment and climate of energy use are rooted in this disparity.

If lack of access to modern energy services continue s to remain beyond reach for a large proportion of the world’s population, what case can we make for a sustainable energy future?

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The Benefits of energy use to humanity, the absence of which inflict miseries on the world’s poor on a scale that is comparable with those feared from climate change but with a difference: the benefits are real, here and now, not merely postulated.

Slide 4

At the bottom right hand here, a few milliWatts (mW) of ordered energy enables this gentleman full access and a window to the world’s knowledge base.

In sharp contrast, even though total amount of energy on the backs of these two women is much larger – by a few orders of magnitude higher – it is very much a damning indictment of energy poverty that characterizes the collection of fuel sources; the back breaking human effort, the ultimate inefficiency of conversion and the cost in terms of human time precludes opportunity for an improved quality of life.

Quality of Life = Access to Ordered Energy

Slide 5 – The central global energy challenge: how to de-carbonize

3 fundamental challenges shape our discussions of energy policies:

(i) dependence on coal for power and oil for transport

(ii) risk to the global environment from climate change, caused, again, primarily by combustion of fossil fuels (in all its forms)

(iii) lack of access to modern energy services by the world’s poor.

The move to a less carbon intensive energy system is now on the global policy agenda and is emerging as an important determinant of decisions and choice.

If *global* emissions are to be cut 50-80% by 2050 and 2100, respectively, doing so will require Herculean efforts to:

(i) increase energy efficiency/reduce energy intensity, and
(ii) develop the means of producing vast quantities of carbon emission-free energy in the next 50-100 years.

Slide 6 – Population Growth: Energy: Income

- Few things we do know with certainty and models of demography are about as reliable as any tool that can use to provide an informed view of the future.
  - The demand for energy will be largely determined by population demographics,
  - The existing structure of global economic production and
  - A slow but steady transition from energy poverty to some level of requisite need.
- Click 1: By 2050, world population could rise to around 9 billion (UN 2002). With no change in the global development profile, another two to three billion people would be living in poverty (base case).
- Click 2:
- The next profile reflects the UN goals to eliminate extreme poverty to a "low poverty" world .
- Click 3: And the next one is a depiction of a relatively "prosperous world".
- The pressures of population growth and the goals to raise living standards combine to set us a formidable energy challenge , either :
  - a doubling of energy demand or
  - a three fold increase from 2000.

Slide 7 – Meeting future energy needs

This shows the energy infrastructure of two IPCC scenarios.

The B2 scenario exhibits intermediate economic growth (essentially the « low poverty « world). For thius scenario, energy use is relatively low energy but still a doubling of today's figure). However, carbon intensity is relatively high (a lot of emissions per energy used).

The A1B scenario has more rapid economic growth (similar to the « prosperous world » shown earlier) and thus very high energy use, but at relatively low carbon intensity due to the introduction of more gas, nuclear, renewables and bio-products.

Slide 8 – Magnitude of change required for CO2 stabilization

1. It has become relatively clear that a reduction in the order of 6-7 Gigatonnes of carbon emission will be necessary to get us to a level of 550 ppm carbon-dioxide associated with a 2-3 degree rise in temperature.
2. This is a near«Revolutionary» step-change: the requirement for our the global energy system to reduce emissions on such a scale.
3. Why? Let me translate for you:

- What does it mean to reduce One Giga-tonne of carbon emissions per year?
- About 700 conventional 1 GW coal fired power stations or
- About 1400 1GW CGGT power stations or
- About 600 million SUVs off teh road or one and a half billion hybrids
    - [Context: Today there are 900 million vehicles in the world]

The IPCC scenarios, with 15 and 16 GtC emissions go along with the 1000ppm stabilisation scenario identified for energy demand in the previous slide: a low poverty scenario or a relatively prosperous world.

Slide 9 – Is there an acceptable limit for CO2 emissions?

1. The graph on the left shows global annual CO2 emissions (inGt of carbon) from all sectors.
    - Note the increase in emissions since 1980. Already contributed to a global warming of 0.3 to 0.4 degrees Celsius until today

2. The scale on the right shows the temperature differences with respect to 1990.
3. Whate we have here are the IPCC projections of emissions range associated with the A1B and B2 scenarios, or story lines, with the corresponding increasess in temperature between roughly 2 and 4 degrees C by 2100.
4. A scenario that would stabilise global CO2 concentrations in the long-term at about 1000ppm (roughly 4 times the pre-industrial level of about 280ppm) leading to about the same temperature increase by 2100.
- Because of the time lags involved in the reaction of the climate system to emissions, temperature increases by 2300 would be much higher (**the third temperature bar)**
5. The impacts arising from the indicated temperature rises can be summarised with these three bars from the IPCC Synthesis Report
    - 1: ecosystems like coral reefs
    - 2: flooding, droughts, storms
    - 3: could affect gulf stream, other low probability but high impact events).
6. The 550 and 450 ppm emission profiles would limit the estimated temperature rises to 1-3 degrees Celsius by 2100, but would also require much earlier reduction of global GHG emissions.

Slide 10 – The lifetime of energy infrastructure

Out of all this emerges yet another uncomfortable observation.
The capital stock of the ENERGY system has a long life time:

- Anywhere from 25-75 years ; and
- What is built or bought today, once built, creates a technological lock-in.

Given that the embedded energy infrastructure has huge inertia and building new facilities takes anywhere from 5-10 years, to transform the energy system to a less carbon intensive system may well take anywhere from 20 to 50 years .

Slide 11 – Alternate power generation technologies: Impact on emissions

Let us look at one of the reference scenarios described by the IEA in its *World Energy Outlook 2002.*

To meet global demand, electricity generating capacity will need to double over a 30 year period from 3500 to around 7000 GW). And this scenario assumes a build out 1400 GW of coal capacity and 2000 GW of natural gas capacity (to meet new requirements and replace retired facilities. This would see CO2 emissions from the power sector nearly double over this time period.
(FIRST CLICK) But what if all new coal fired power plants were replaced by nuclear or renewable capacity ? Or coal with carbon capture and storage? instead? Would that be sufficient for power sector emissions to start declining?
(SECOND CLICK) At best, we could stabilize emissions from the power sector with these technologies.
(THIRD CLICK) The 45+ year lifespan of existing and planned facilities gives us a considerable legacy through to 2030 and beyond.

Slide 12 – Light duty vehicles
To illustrate the challenge in changing our energy infrastructure and in reducing the associated GHG emissions, the following two cases present « even if » scenarios with very optimistic assumptions and look at the likely outcomes.
Limiting CO2 emissions from transport to sustainable levels is an important goal in addressing climate change. As Mobility 2030 (WBCSD 2004) points out, “even under optimum circumstances, achieving this goal will take longer (probably quite a bit longer) than two or three decades”.

Take the case of light duty vehicles (LDVs), which today represent around half of the transport sector's CO2 emissions. In 2000 there were 750 million such vehicles in use with this number growing by 2% per year. To achieve significant CO2 reductions from transport, these vehicles would have to be replaced with new advanced technology vehicles. However, the typical life of a car is some 12-20 years and also, the need to refit fuelling stations with lower carbon fuels could limit the take-up of new vehicles.

The illustration on the slide shows that even if large-scale deployment of vehicles that emit no CO2 at all could start relatively early and progress at a rapid rate (FIRST CLICK, QUOTE SECOND TEXT BOX), it would not be until 2040 that the total number of traditional vehicles in use begins to decline.
This means that GHG emissions from all LDVs would not begin to decline until that time, unless emissions for traditional vehicles decline significantly (for a detailed assessment on the carbon impact of specific vehicle technologies, see WBCSD 2004).

Slide 13 ‘Usefeul Energy: Efficiency: Waste?? Sankey Diagram

1. Two Main Points: It takes a lot of primary energy (oil, gas, coal, uranium, wind, water, biomass) before it is processed, converted and transported to useful energy services.
   - In this case, we are looking at 12Exajoules of energy to end up with 5 EJ of useful energy. And this is by design: we value high quality energy more than a lump of coal or a bucket of

woodchips. (1 Exajoule (EJ) is = 277 TWh; in Ontario we consume a total of 160TWh say 0.5 to 0.6 EJ of electricity

The pyramid of energy consumption with “losses” at every turn is not necessarily simple bad engineering: it reflects in its complexity, one of the most fundamental laws of physics, the second law of thermodynamics.

Low grade energy is funnelled to high grade energy. As Feynman noted:
“it is the order in energy that is important.” Order is the very subtle aspect of energy.

Thermodynamics gives us a rigorous measure of order- not just a concept but a precise quantitative measure – entropy. Entropy is measured in units of energy divided by temperature.

Laser is a perfect example: it has very low entropy; it is fiercely hot, although it appears to be ice cold as it knifes through the air without heating the room.

A laser beam depends on a complex array of power plants and wires, chip fabrication, power supplies and Ac to laser drivers and coolers to that beam of laser photons.

The pyramid of energy to get to Bits and Photons requires a lot of thermal energy. It take some 6600 kWh of thermal energy (4 barrels of oil) to get to 2000 kWh of energy at power plant output. Chip fabrication: 1000, power supplies and conditioning: 400, laser drivers: 200; laser photons: 20

EINSTEIN observed that classical thermodynamics is

“the only physical theory of universal content which.. within the framework of its basic notions, will never be toppled.”

Slide 14 –

Slide 15 – A Balanced Mix of Options

	Growth	**Energy use**	**Carbon intensity**	**Emissions**
B2	Intermediate	Double	High	High (15 Gt)
A1B	High	Triple	Low	High (16 Gt)
«9 Gt»	High (desired)	Double	Low	Low (9 Gt)

Conclusion: if what we desire is high growth, similar to A1B scenario (point to the middle A1B), then only a combination of low energy use AND low carbon intensity of energy can deliver the emissions reductions associated with a doubling of energy demand for a 550 ppm emissions path.

If you look at the far right, you are looking at a global nuclear capacity of some 2500 GW and wind power on a similar scale. This picture, developed by the World Business Council for Sustainable

Development is neither a forecast nor a prediction but a hard look at what scale of effort maybe required for transition to a low carbon economy.

But if you are practical hard headed power system operator this can be somewhat disconcerting: nuclear and wind, as noted by a good colleague, make particularly terrible dance partners: one is incapable of moving on the floor and the other is all over the place.

What I have done is drawn you a picture and highlight the need for a balanced mix of options. Whether it is a carbon constrained world or a resource constrained world, a vast gulf exists between expectations and reality on the ground.

Let me leave you with a few questions that I hope will set the course for a useful day of debate and exchange of ideas.

Slide 16 – How do we manage the big risks?

SHALE GAS is the revolution that puts the proverbial nail in the coffin of climate change diplomacy. Two decades and two treaties on (UNFCC and Kyoto), climate diplomacy as practised by many governments of the world, has failed to produce any discernible real world reductions in emissions of greenhouse gases.

In 1992, the global community came together in RIO - with much fanfare - and the goal was to cut greenhouse gas emissions to 1990 levels within a decade.

- Emissions in OECD countries overshot by 12% in 2000 and notwithstanding promises in Kyoto (1997) to reduce emissions by a further 5%, emissions rose by some 20% in OECD countries a decade later.
- The failure of the world as a whole was even more spectacular with global emissions increasing by an additional 40% from 1990 levels.
- Global emissions are poised to rise by another 30% in the next 2-3 decades.
- It has now become abundantly clear that a single minded focus on CO_2 emissions reductions - as the lynchpin for managing the risk of climate change through a negotiated treaty is no longer credible.

The underlying reason for failure is the structural flaw in the UNFCCC-Kyoto model and the framing of the threat to climate as a policy issue. Treaties, targets and timelines, namely the T3 curse - without any serious consideration of cost and national capacity for effective change – run up against the unsavoury calculus of domestic politics.

Also see Nathwani paper on : Global Energy Transitions: Coming to terms with our intergenerational burdens.”

http://dl.dropboxusercontent.com/u/10269662/Global%20Energy%20Transitions_Coming%20to%20Ter ms%20with%20Intergenerational%20Burdens_COMPLETE%20PAPER%20Sept%2012%20JN%20FINAL.pdf

Slide 17 – Climate Change: Paths to Global Energy Transitions
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Slide 18 – Low-carbon energy futures: WGSI.org
Based on the Equinox Blueprint: Energy 2030
Also see: http://dl.dropboxusercontent.com/u/10269662/Equinox%20Blueprint%20-%20Equinox%202030.pdf

The energy ecosystem comprises several and interrelated links that not only connects and re-inforces components of the system but also the agents and decision-makers responsible for specific outcomes.

Getting to a low carbon energy future places a huge premium on innovation.
Off-grid access and meeting the needs of 1.6 billion who have no access to electricity at all is one of the core considerations in delivering a better quality of life.
A powerful trend towards urbanization means smart urbanization: that includes better buildings, electrification of transport, distributed resources, renewables on a larger scale and base load generation as the backbone.

Additional Back Up Note: World GDP and CO2: Embedding Efficiency
In the last 30 years, world GDP grew at 3%; carbon emissions rose half as fast (i.e.1.5%, actually 1.3%).

Suppose by 2100 we wish to reduce *global* emissions by 75% from current levels. Suppose further, that over the course of the twenty-first century, the “trend” rate of global GDP growth is 2.3%. To achieve the emission reduction target would require that by 2100:

(i) global energy intensity is improved by a factor of 3, namely, average annual rate of decarbonization of global output must be raised from 1.3% to over 4.0%

(ii) carbon emission-free energy in 2100 is *two and a half times greater* than the level of *total* energy consumed globally in 2000.

Slide 19 – Large-Scale Storage for Renewable Energy

Two challenges for renewable energy: Land Use and Variability

The greatest technical challenge of variability and intermittency is integrating these technologies into developed electricity systems.
Low power density and dispersed nature of the resource brings into play the question of land use and social friction.

The pathway that was imagined at the Equinox Summit for making renewable electricity production a large part of our electrical future focused on the development of large-scale storage capacity…

…in particular, large-scale battery technologies that could store the electricity when it is being produce, and release it when we need it, making the electricity produced as reliable as coal.

Slide 20 – Land use can be benign

Slide 21 – Or, not so benign

Slide 22
Comparison of energy densities makes the obvious point: low power densities will bring into question the competing requirements for land use.
This has particular relevance when implementation is at GW or TW scale of power..

Slide 23 – Power Systems Need Flexibility as well as Energy & Capacity

Slide 24
An illustration of wind power’s somewhat tenuous relationship between availability and need. Something akin to a spousal relationship: “Honey, you are not there when I need you, and ever present when I wish you were some place else.”

Slide 25 – EEX: Wind & PV Energy in Germany (KIT)
With a total of 63 GW.

German Cost Data:
Electricity Prices for Households in Germany : 25 centsEuro/kWh
Renewable Subsidies: 5.3 cents Euro/kWh in 2013; 3.6 cents/kWh in 2012
Total Subsidies: Euro 20 billion in 2013

From 1998 to 2011: Total Household Prices growth: 46% (of which Taxes and Subsidies grew by 170%; Generation and Distribution by 5%)

Slide 26
With unpredictable output, if Gas becomes the compensating power for delivering firm power, then the path down towards serious de-carbonization will remain elusive.

On the pathway to global de-carbonization, it would be a tragedy of profound proportions if we slip into using coal or natural gas as the fill in power to cater to the variable, intermittent nature of renewables.

For such a huge installed capacity base of renewables in Germany (63 GW, increasing to 74GW in 2020), its Greenhouse Gas emission intensity is 5 times higher than France (Germany 0.519 kg CO_2e per kWh to 0.099 France) or 9 times Sweden (0.061 kg CO_2e/kWh) or 3 times Canada (0.252 kg CO_2/kWh) or 4 times Ontario.

Slide 27 – A New Metropolis on the North American Continent?

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Slide 28 – Energy Storage for the Future Grid

Slide 29 – Enhanced Geothermal Power

Next we'll explore the second pathway: Enhanced Geothermal.
If it could be tapped for electricity production, the heat at the centre of our planet offers and almost inexhaustible supply of energy.

But reaching this energy source is not trivial; the biggest reservoir of heat is not near the surface, but deep underground – starting from 4kms, and with the most potential lying as deep as 10km.
The pathway outlined in our blueprint focuses on the most important steps for developing the potential of EGS technologies: demonstration projects that can improve our understanding of the challenges we will face in drilling and extracting heat from those depths, and prove the business and policy communities the long-term potential of this clean and abundant energy resource.

Slide 30 – Enhanced Geothermal Power

SCIENTIFIC CHALLENGES AND OPPORTUNITIES

We focus on EGS as an illustrative technology:
While conventional geothermal power plants are limited to where hydrothermal resources exist, EGS can be implemented over vast areas of the globe where hot dry rocks are found.

EGS involves enhancing the permeability of the Earth's crust by opening pre-existing fractures and/or creating new fractures deep into ground, typically more than 1.5 km below the surface.

The image on the right hand side shows that one well is drilled and pressurized to create fractures, while a second well is drilled into the far side of the fracture zone. Cold water is then pumped down one well and steam extracted from the other.

Slide 31 – Enhanced Geothermal Power

Major barriers to this expansion have been the

- high front-end capital costs of geothermal projects,
- lack of investor confidence and financing.
- Lack of data is an impediment – only a small number of wells have been drilled worldwide to date.
- Until the technology is sufficiently de-risked, exploration of the resource will be limited to isolated, government-supported development.

Engagement by major financial and energy players will be needed to make the cost projections attractive to investors.

Slide 32 – Advanced Nuclear Power

The third baseload pathway is: Advanced Nuclear.

Nuclear energy remains a controversial topic today.

But the potential for nuclear power to provide low-carbon electricity also cannot be overlooked. This pathway takes a long view on the potential of new nuclear technologies, and lays out some steps for further exploring how it can contribute to our electrical future.

Slide 33 – Challenging your assumptions about nuclear

At our summit, we explored the possibility that new – advanced nuclear reactor designs – can:

- Dramatically reduce nuclear waste – including burning existing waste from old reactors to generate energy;

- Avoid producing fissile material that can be used to make nuclear weapons;

  - And have basic safety features that do not allow the potential for meltdowns.
  - To enhance public acceptance and at the same time de-carbonize base load generation: at scale!

Slide 34 – Advanced Nuclear Power

SCIENTIFIC CHALLENGES AND OPPORTUNITIES

Nuclear energy has proven its capacity to deliver reliable low-cost, low-carbon baseload power on a large scale.

Build-out of the existing technological base offers the possibility of providing energy on a terawatt scale. Closing fuel cycles to reduce nuclear waste and making nuclear fission sustainable over a thousand years.

If the world is to move away from fossil fuels in electricity generation, it is unlikely without a transition to Advanced Nuclear Technologies.

Slide 35 – Advanced Nuclear Power

Going from the once through fuel cycle (<5% energy used, 95% waste created), to full recycling via IFR, reduces waste <1% and >99% energy utilization

A transition to advanced nuclear offers the potential of an inexhaustible non-carbon energy resource on a TW-scale

Slide 36 – Off-Grid Electricity Access
Not everyone is on the grid and has access to baseload power.
The Equinox Summit also looked at addressing the ‘energy poor’ with the fourth pathway: OFF-GRID ELECTRICITY ACCESS

Slide 37 – Electricity Access for All
Blunt problem statement + our take on a possible solution.

Today, over 2billion people lack adequate access to electrical power and heat, dramatically reducing the quality of education, of healthcare, of work… quality of life that they lead.

Bring the myriad benefits of electrical power to these communities – of which roughly 85% live in rural areas – was a major consideration discussed at the Equinox Summit.

There was a desire to bring these benefits quickly, in ways that created better, cleaner electrical systems, and avoided some of the major challenges of existing, infrastructure intensive energy systems – systems that take years and large capital to build, have legacies that last decades…

With these goals in mind, the pathway that emerged from the summit focused around the creation of inexpensive, portable and durable technologies that could generate even small amounts of electricity…

The first few watts of electrical power that can dramatically improve the quality of life for those two billion people – and lay the foundations for expanded education and economic development.

Lightweight organic solar voltaic, coupled with portable battery technologies were the technological foundation for this pathway, which Jatin will overview shortly…

Slide 38 – Powerlines But No Power

Slide 39 – Off-Grid Electricity Access

SCIENTIFIC CHALLENGES AND OPPORTUNITIES

The strength of Organic Photovoltaics lies in the diversity of materials that can be designed and synthesized for the absorber, acceptor and interfaces.

The goal is to design more efficient and stable devices.

Often referred to as "solar by the metre", their plastic nature makes them easy to transport, use and install. They are light and can be installed into or onto irregular surfaces due to their extreme flexibility. They can be installed in a piece of cloth, rolled up and carried to the installation point, and laid across a roof. Installation requires no specialist equipment or skills. The tent on the right hand side has the capacity for 2KW of power from flexible solar panels daily.

Slide 40 – The context

Recognize that the price of power varies with context and beyond cost and price, think in terms of value delivered.

Slide 41 – Low Willingness to Pay: High kWh

High WTP for Low KWh
(Off-grid, remote)
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- SYSTEM cost includes panels, packaging, electronics including inverters, and installation.
- To beat 8-10 cents/kWh wholesale low carbon power at 12% capacity factor, 4% cost of capital:
- <$1400/kW system cost with 20 year life
- <$800/kW system cost with 10 year life
- In Arizona, <$2100/kW.
- This week's announcement for PV in Israel: $6060/kW (about half is BOS); earlier US announcements were as low as $4500/kW

Today, ~5 year life

Slide 42 – High WTP, Low kWh

High WTP, Low kWh
(Subsistence Power)
State of the technology

System: PV + Battery + Light, Cell Phone Charging
Organic PV can be transformational because it is flexible (easy to transport on your back) and rugged (doesn't break).
It can also be emplaced on complex surfaces, and has the possibility of integrated power and light
Batteries are currently lead-acid. Not scalable. Needed: 5000 cycles, price of lead-acid
subsistence power)

Possible extension of light and personal electronics phone charging:

Medical refrigeration
Perhaps personal refrigeration

Won't handle cooking

Slide 43 – Low Cost Innovations: Critical Pathways for Human Development Goals
Slide 44 – Medium WTP, Medium kWh
Slide 45 – Realistic Partnership Potential
Slide 46 – Smart Urbanisation
Slide 47 – Rapid Urban Population Growth = Increasing Mobility Needs
Slide 48
Slide 49 – Emerging Innovations
Slide 50 – Enabling Technology
Slide 51 – Smart Urbanization
Slide 52 – Smart Urbanization
Slide 53 – Smart Urbanization
Slide 54 – Guideposts: shaping future directions

1. **Global trend is towards electrification of the economy.**
2. **High Value, Ubiquitous**. There are good reasons to single out electricity. No other kind of energy form provides such instant and effortless access. It is cheap, it is ubiquitous and range of services it provides remain unsurpassed. Electricity's advantages go beyond easy access and clean and silent at point of use: it is flexible, versatile and can be converted to light, heat, motion and chemical potential and can be adjusted at point of use with very high precision.
3. The trajectory for electricity consumption in any economy, anywhere you look is upward. This is linked to the most recent trend rising amounts and faster delivery of precisely controlled information. **Over 100 years, US primary energy consumption rose 10 fold; electricity consumption rose 30 fold.**
4. **Electrification A Blessing In Disguise?**
   If electricity will likely account for a steadily increasing share of the overall energy demand, this shift from direct fuels consumption to electricity end use offers the best opportunity to reduce carbon emissions.
   The carbon intensity of power generation in the US has fallen by 10% over the past two decades because of increased use of nuclear and wind and a shift from coal to gas.

Slide 55
Slide 56
Slide 57
Slide 58