# Global figures for a global challenge: the energy supply in the 21st century

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CENTER FOR METAMATERIALS AND INTEGRATED PLASMONICS

# Back in 1800

- First high pressure steam engines
  - Beginning of the industrial revolution
  - Extensive use of fossil fuels (coal first)
- First worries about the finite ressources provided by nature (Malthus, 1798)
  - The population reaches 1 billion human beings
  - Only renewable energies so far...
- Gave up inventing perpetual motion

# Nowadays

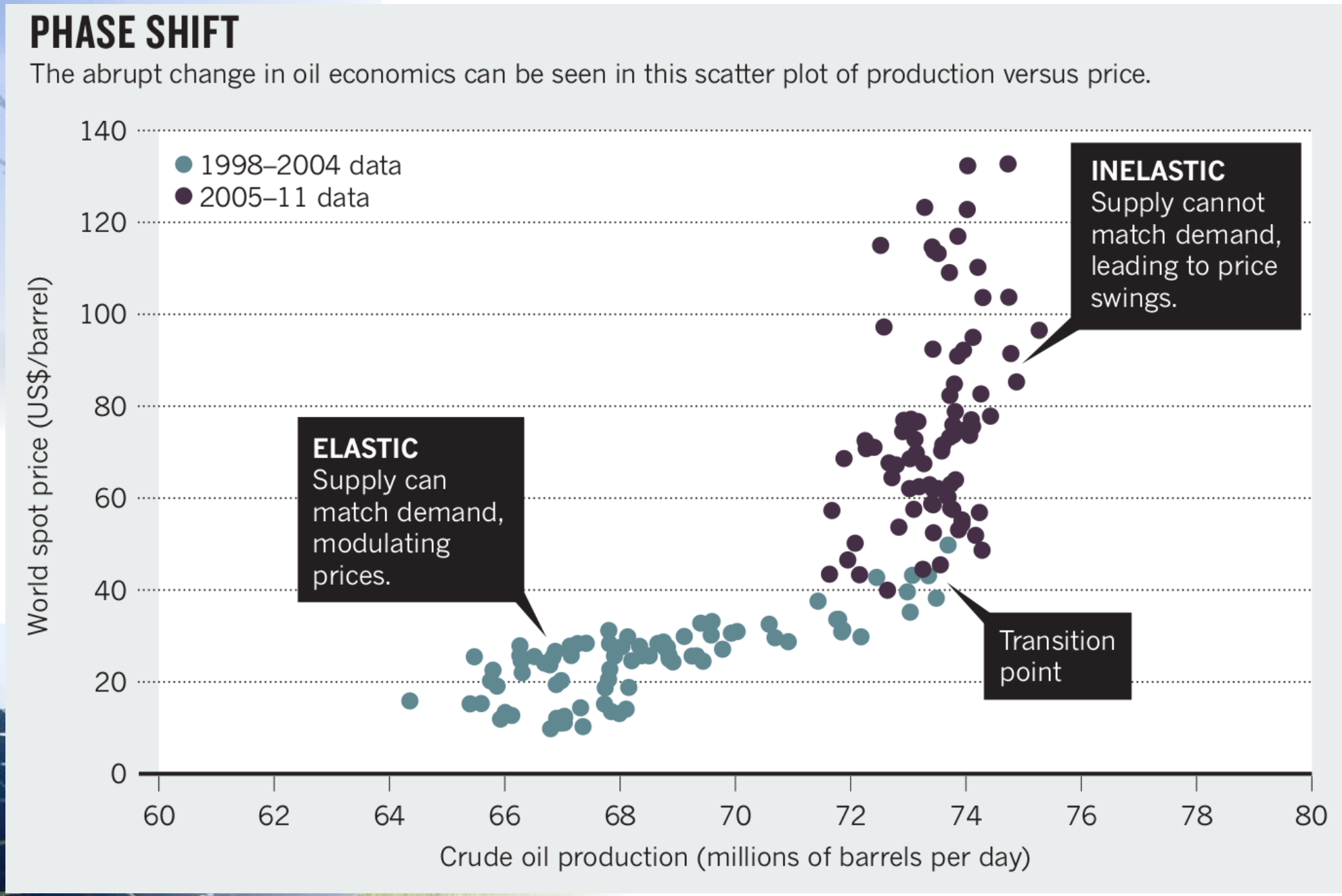
- We are consuming 500 ExaJoules (of oil equivalent)
  - Oil 33.6% (share declining, consumption increasing +3.1%)
  - Coal 29.6% (share increasing)
  - Gas 23.8% (share increasing +7%)
  - Nuclear (5.2%)
  - Renewable energies 7.7% (6.5% hydro)
- Still growing
  - Average growth of 2%, 5% last year
  - 0.7% growth per capita
  - Increase in population and energy are linked

# Eternal energy growth ?

- It's been 200 years since the energy consumption growth started (more than 2% at that time)
- 2% average growth for the last 30 years
- How long can we sustain a 2% energy consumption growth ?
  - In 350 years from now, all land should be covered with solar panels with a 15% yield.
  - In 120 years with a 5% growth.
- Luckily, the population is about to stabilize. A 1% growth is likely.

# Hitting the ceiling

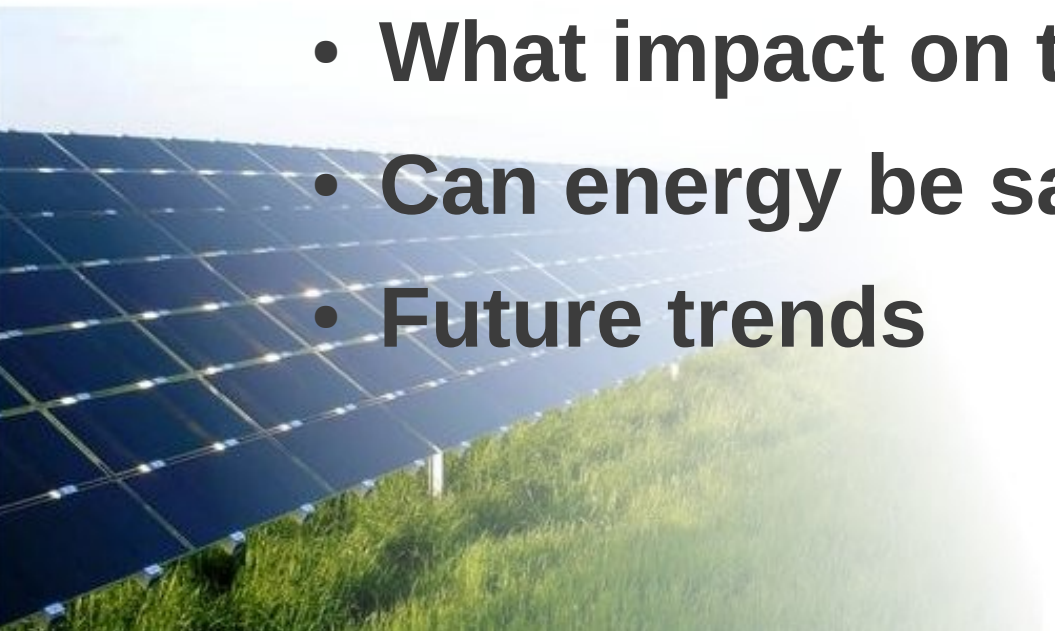
- We have consumed about half of the available oil
  - Easier to manipulate (liquid)
  - High energy density (around 10 kWh per kg)
- Tipping point ?
  - From an elastic situation (gently modulating prices, supply can match demand)
  - To an inelastic situation (price swings, no spare capacity)




J. Murray and D. King, **Nature** 481, 433 (2012)

# Outlook

- When will we have serious energy supply issues ?
- Is Nuclear Power able to help ?
- Can Renewable Energy (RE) sources be the solution ?
- What impact on the environment ?
- Can energy be saved ?
- Future trends



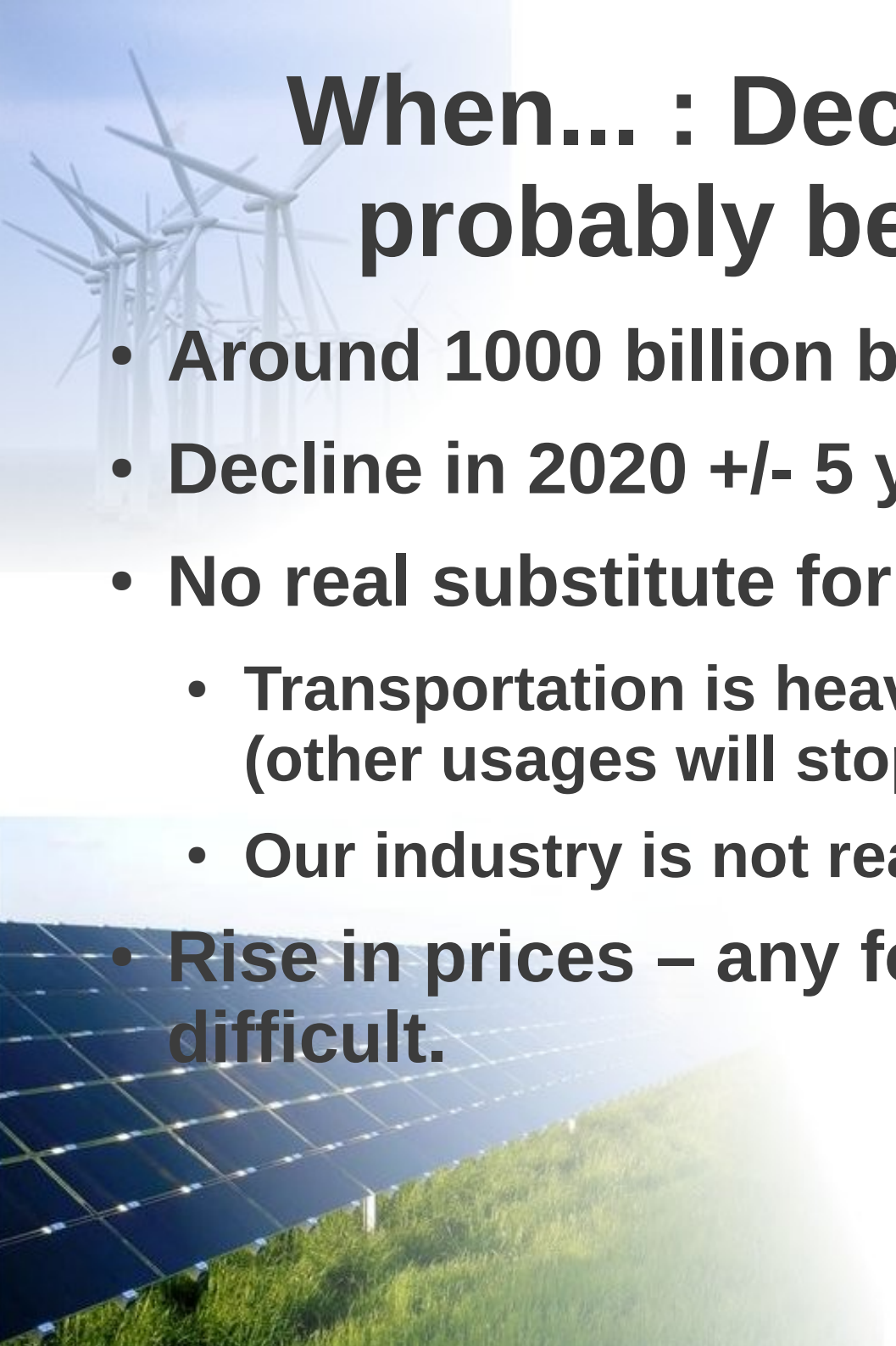
# When will we have serious energy supply issues ?

# Oil

- Close to the maximum production
  - Despite shale oil and sand oils (small part of the proven reserves)
  - Despite better retrieval methods
  - Maximum oil production in 2008
  - Discoveries : 15 Gb in 2011, consumption 30 Gb
- EROI is quickly declining
  - 100> in the 30s
  - 30 in the 70s
  - 10 for conventional oil in 2005
  - 2 to 5 for unconventional nowadays

# When... : Declining oil will probably be the signal

- Around 1000 billion barrels left (6500 EJ)
- Decline in 2020 +/- 5 years probably
- No real substitute for oil
  - Transportation is heavily dependent on oil (other usages will stop).
  - Our industry is not ready (CTL,GTL)
- Rise in prices – any forecast is extremely difficult.



# Gas

- A lot of gas left (6500 EJ)
- Decent EROI (10)
- Not much to expect from better technology, here :
  - 70% of gas can be extracted with existing technologies.
- Decline in production can be reasonnably expected 10 years after oil.

# Coal

- A lot of coal left (26000 EJ)
- Very high EROI (80)
  - Easily available
- Used for electricity production essentially
  - 50% consumed by China
- Decline in 40 year maybe if the energy consumption growth is around 2%
- C-C bounds means more carbon dioxide released.

# Can Nuclear Power help ?

# Current nuclear power

- Currently : about 9 EJ
- 3rd Generation :
  - 2.85 MT of U235 accessible
  - 17.1 MT ultimately
  - Could provide 9 EJ for hundreds of years
  - But not 500 EJ per year
    - EROI from 5 to 15
    - 6 years for an EPR power plant

# Future of nuclear power

- 4th Generation (breeders)
  - Could be a solution for thousands of years.
  - Not ready before at least 30 years
- Nuclear fusion
  - Would be a solution
  - Not ready before 100 years
  - We don't know if it will be ready some day

# Can Renewable Energy be the solution ?

# Global overview

- RE has to be the solution
  - 2100 : very low fossil fuel reserves
  - or very low use of fossil energy anyway

- RE is abundant (per year)
  - Solar energy 3900000 EJ
    - Wind 28 400 EJ
    - Biomass 3000 EJ
    - Hydro 150 EJ
  - Geothermal 1300 EJ

# Solar energy

- Photovoltaics
  - Quite low EROI : around 7 (but 30 years !)
  - “Energy cannibalism”
    - Expensive
    - Efficiency is not the problem
  - 0.01 EJ in 2005 with a 20% growth :
    - 2.5 EJ (oil equivalent, 1EJ actually) in 2030
    - 96 EJ in 2050 (means 100 EJ spent)
  - Potential 1600 EJ
  - Intermittent
- Concentration Solar Plants
  - Project only (DESERTEC in the Sahara)
  - Unknown EROI
  - Melted salts for energy storage

# Wind

- High EROI : 18
- Actual : 1.2 EJ
  - (3.2 EJ oil equivalent)
- Potential : 230 EJ
  - 24 millions of 2MW wind turbines
- Growth of 20 to 30% a year
  - 2030 : 100 EJ (oil equivalent)
  - 2050 : Full potential
- Highly intermittent
  - Works only 30% of the time
  - Equivalent capacity with fossil fuel needed
  - Not everything would be used

# Hydroelectricity

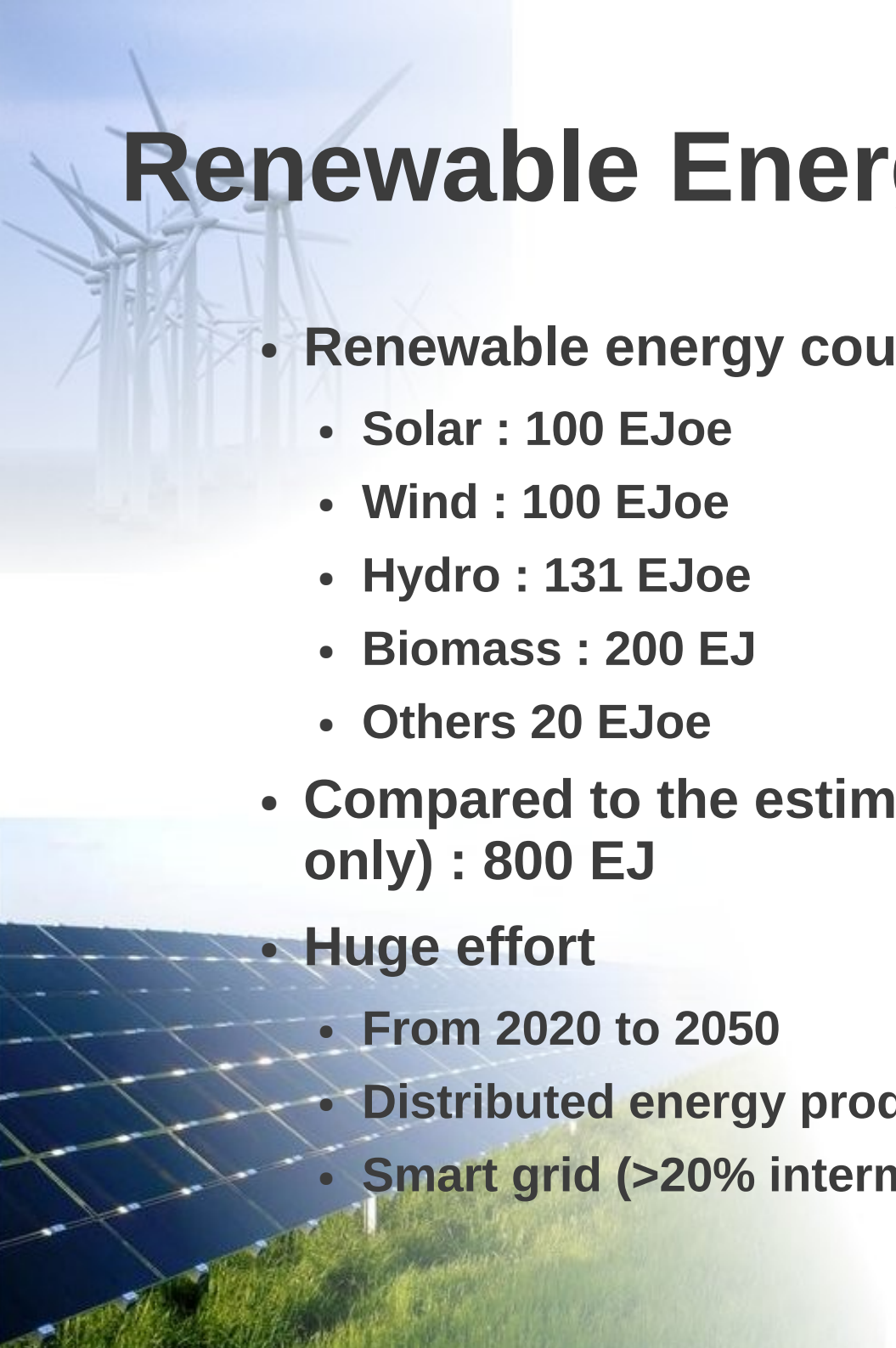
- Actual : 12 EJ (32 EJoe)
- Potential : 50 EJ (131 EJoe)
- EROI > 100
- Perfect energy source

# Biomass

- Biofuel (ethano, biodiesel)
  - EROI : 1 to 2
  - Nowadays 2 EJ
  - Especially subsidized in the US (corn ethanol, EROI subject to debate)
  - Energetically not sound.
- Biomass
  - Yield 0.2 to 0.5% for wood
  - EROI : extremely high
  - Potential : 200 EJ

# Renewable Energy Sources 2050

- Renewable energy could *potentially* provide 550 EJoe
  - Solar : 100 EJoe
  - Wind : 100 EJoe
  - Hydro : 131 EJoe
  - Biomass : 200 EJ
  - Others 20 EJoe
- Compared to the estimated demand (1% growth only) : 800 EJ
- Huge effort
  - From 2020 to 2050
  - Distributed energy production
  - Smart grid (>20% intermittent sources), storage



# Impact on the environment

- Consuming energy has a lot of impact on environment
- Climate change :
  - 500 ppm carbon dioxide in the atmosphere ?
  - Well above the recommended 2 C degrees increase in the average temperature (IPCC 2007)
  - May change around 2020.
- Ocean acidification ($CO_2$)
- Biodiversity loss due to land occupation (biomass, hydroelectricity, wind turbines, solar panels)

# Can energy be saved ?

# Energy consumption : what for ?

- In developed countries (OECD),
  - From 23% to 33% is consumed by housing (for heating and air conditioning mainly, lighting only a bit)
  - A third is used by transportation (oil)
    - Half can be attributed to personal vehicles
  - From 25% to 33% by industry
    - Essentially for refining, metals and paper (commodities)
  - Around 20% by services
    - From shops to schools. For heating, lighting and appliances (computers).

# Saving Energy

- This consumption scheme is the result of cheap (virtually free) energy
- Heating is unnecessary, AC can be more efficient
  - Well insulated homes, smart houses
- Actual personal cars are a waste of energy (and of time in large cities)
  - Usually oversized
  - 15% average yield of the motors
- Energetically weird situations
  - Tomatoes grown in northern countries like Netherlands and canada, during winter, and exported to France or the US respectively.

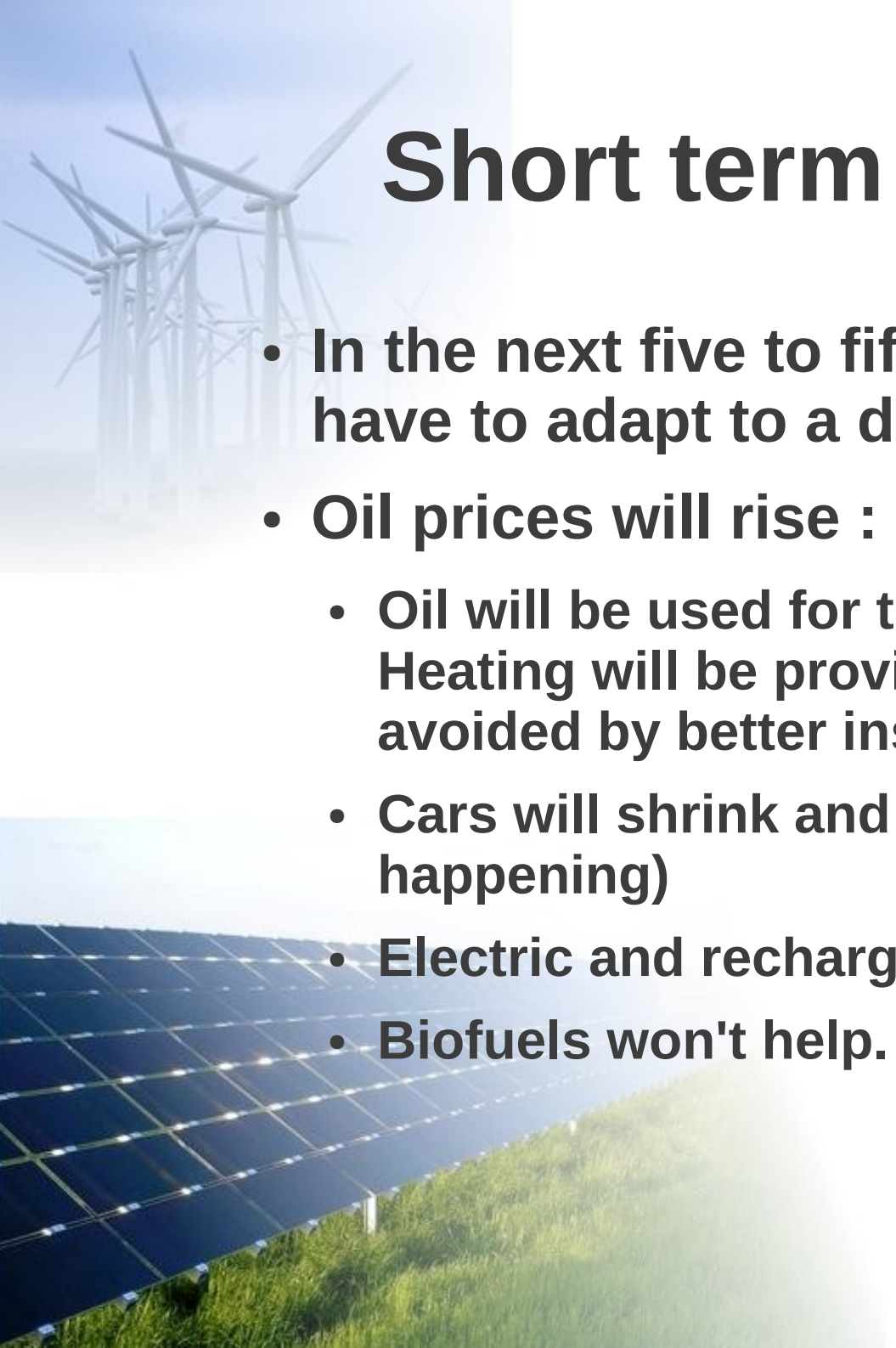
# Efficient energy use

- Huge shift towards efficient energy use
- Most obvious improvements
  - Insulation
  - Trains, bicycles and boats instead of cars and trucks (infrastructures !)
  - Light electric cars, hybrids for long distances
  - Less commodities (refined oil, plastic, paper and metals)
- Developped countries
  - 200 GJ per capita per year
  - 63 GJ would probably be enough for almost the same level of comfort
  - Around 600 EJ for the whole world

# Trends

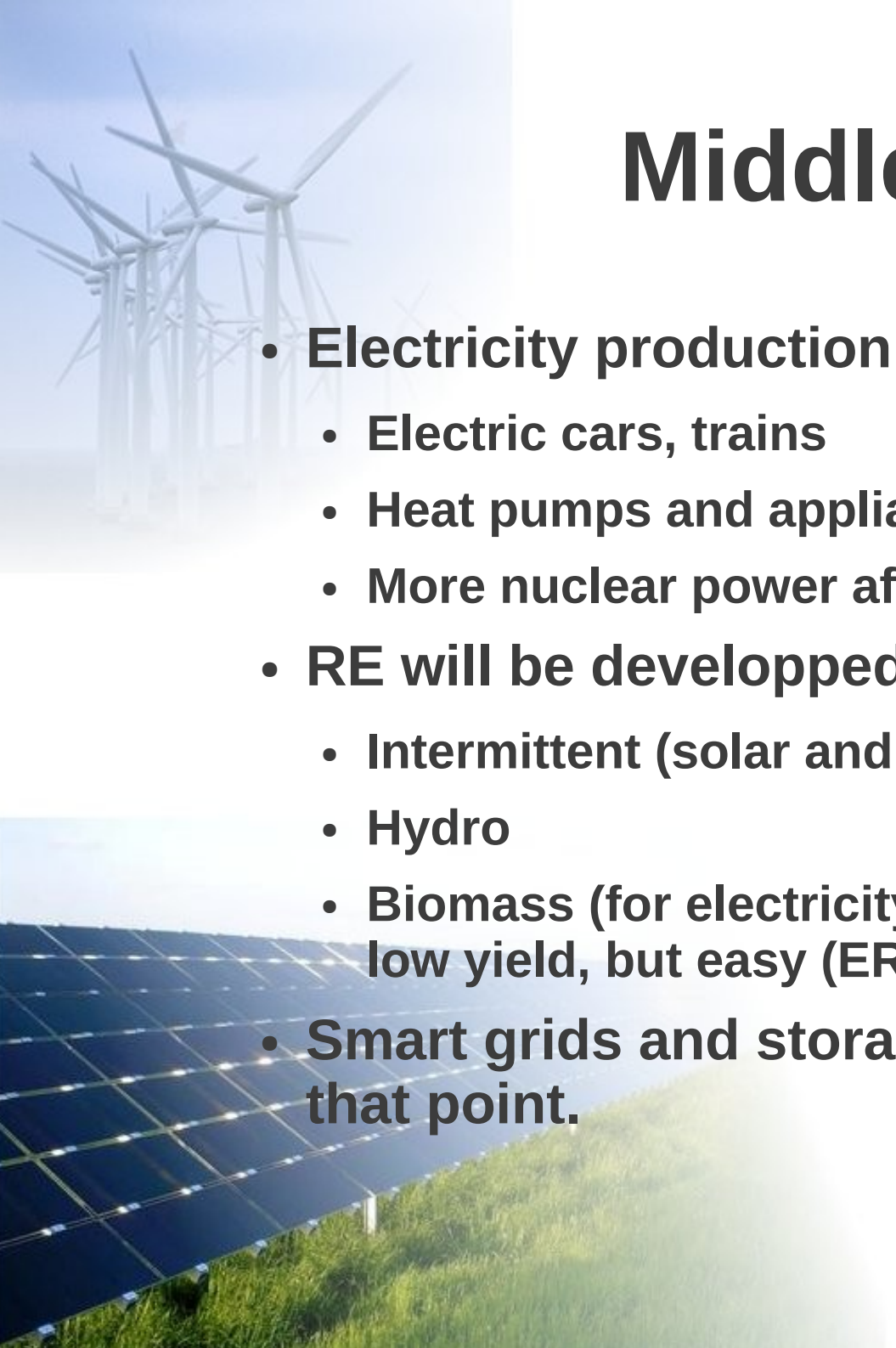
# Short term (ten years)

- In the next five to fifteen years or so, we will have to adapt to a decreasing supply of oil.
- Oil prices will rise :
  - Oil will be used for transportation essentially. Heating will be provided by gas, heat pumps and avoided by better insulation.
  - Cars will shrink and be more efficient (already happening)
  - Electric and rechargeable hybrid cars
  - Biofuels won't help.



# Middle term

- Electricity production will continue to grow quickly
  - Electric cars, trains
  - Heat pumps and appliances
  - More nuclear power after 2020
- RE will be developped heavily
  - Intermittent (solar and wind)
  - Hydro
  - Biomass (for electricity generation, not for fuels). Very low yield, but easy (EROI>100).
- Smart grids and storage will have to be ready at that point.



# Long term

- **By 2100**
  - **We should not be dependent on fossil energy any more.**
  - **Fossil fuels will have provided the energy for humanity to grow, progress and let's hope, learn to leave without them.**
  - **The climate will probably have warmed a lot, except if the decrease in oil production initiates a vast transition.**
  - **Let's just hope a negative answer is not the solution to Fermi's paradox (that extra-terrestrial civilizations have disappeared because they were not sustainable).**

# Suggested references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