Economic Contributions of Nanotechnology to Green and Sustainable Growth

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Key Probes:

1. Trajectories of emerging nano-science and engineering: knowledge development, exchange, & interdisciplinarity

2. Nanotechnology enterprise and applications: nano innovation - large & small enterprises; commercialization pathways; regional & international developments; policy outcomes

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Key Questions

- How can nanotechnology and its contribution to green and sustainable growth can be defined and measured?
- What are examples of green nanotechnology applications?
- What market forecasts are available?
- What are indicators of the economic impacts of these green nanotechnology applications?
- Do these assessments of economic impact consider the full range of economic benefits and costs including potential environmental and health and safety impacts?

Propositions

- Promise of the contribution of nanotechnology to green and sustainable growth is big
- Actual applications to date are relatively small
- Many potential green nanotechnology applications are not market ready and face competition from incumbent technologies
  - These relationships may to change in the future
- Full economic assessment of green nanotechnology applications needs also to consider the energy, carbon environmental, carbon, health, and other potential implications
- Need for anticipatory life-cycle assessments over the full cycle of production, use, fate, and disposal & recycling of green nanotechnology applications

World electricity generation and CO_2 emissions

Electricity source	Generating capacity 2009 Mil. GWh	Added generation capacity 2000-2009 Mil. GWh	% share of new generating capacity 2000-2009
Solar & wind	0.3	+0.26	6%
Hydropower	3.3	+0.6	13%
Nuclear	2.7	+0.1	3%
Fossil – coal, oil, gas	13.8	+3.6	79%
Total	20.1	+4.6	100%

CO_2 emissions from electricity & heat production	2009	Increase 2000-2009
Mil. metric tons	11.8 m.mt	2.7 m.mt

Sources: MIT Technology Review, March/April 2012. from International Energy Agency and US Energy Information Administration

Policy Thrust: "Green" Economy

- OECD Green Growth Strategy (2011)
  - Promotes economic growth and development with the preservation of natural assets and the environment
- Korea greenhouse gas emission reduction target of 30% by 2020 over base year 2005
- Ireland's National Development Plan €1.3+ billion
  - Waste management, sustainable energy, transport, environmental research
- China's Twelfth Year Plan includes six green pillars and greenhouse gas reduction targets

Potential contribution of nanotechnology to "green" growth

- Nanotechnology offers novel properties
- Potential contributions to "green" growth
  - Driving new wave of "greener" economic growth
  - Improved efficiency and performance of existing technologies
  - New efficient and high performing devices and systems
  - Contributions:
    - Direct: e.g. more efficient solar panels, clean water filters
    - Indirect: e.g. lighter materials, nano-coated longlife tool tips
- 60+ countries with national nanotechnology initiatives
  - US National Nanotechnology Initiative
  - 7 strategic areas, including photovoltaics, solar, & energy
  - 6% of FY 2012 NNI budget allocated to solar

Green and Sustainable Growth?

Some elements to consider

Elements	Green Growth	Sustainable Development
Efficient production & use	✓	✓
Waste reducing	✓	✓
Low carbon	✓	✓
Clean and safe	✓	✓
Renewable	✓	✓
Recyclable	✓	✓
Reusable	✓	✓
Resilient		✓
Responsible		✓
Equitable		✓
Intergenerational		✓

Definitions and measurement:

Nanotechnology

- Engineering of materials at the nanoscale (1-100 nm) with novel properties and features
- Global R&D in nanotechnology +$12b public and private (Sargent, 2010)
- Wide variations in market forecasts over next 10-20 years
- No comprehensive data on nanotechnology in products or applications
- Leaders in nanotechnology research and development: OECD countries (US, Europe, Japan, Korea, others) + China

Definitions and measurement:

Green industries, jobs and technologies

Green industries

- Producing goods and services that benefit the environment or conserve resources

- Sustainably produced inputs; minimal use of virgin raw materials; production processes that minimize the use of water, energy, and materials; production processes free from harmful toxins; reuse and recycling of solid waste streams; substantial reductions in emissions or effluents of harmful greenhouse gases and pollutants; and products that are built for longevity and durability Vesela & Ellenbecker, 2001)

Green jobs ("green collar" jobs

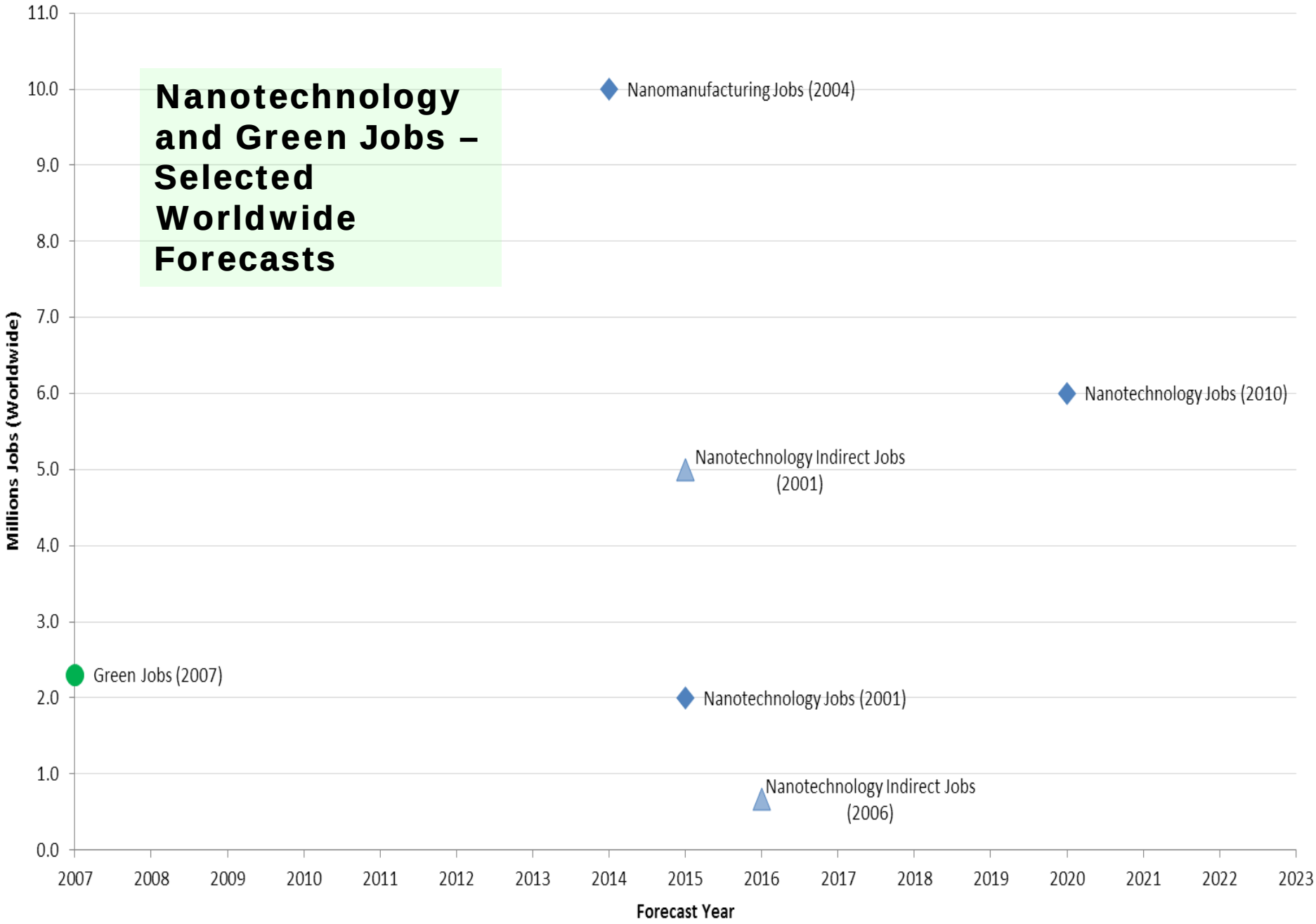
- US BLS: Renewable energy, Energy efficiency, Pollution production/control, Natural resource conservation, Environmental compliance/education

Green patents

- US Green Technology Pilot Program: alternative/renewable energy, energy storage, energy distribution, energy conservation/efficiency, GhG reduction, carbon sequestration, environmental, friendly farming

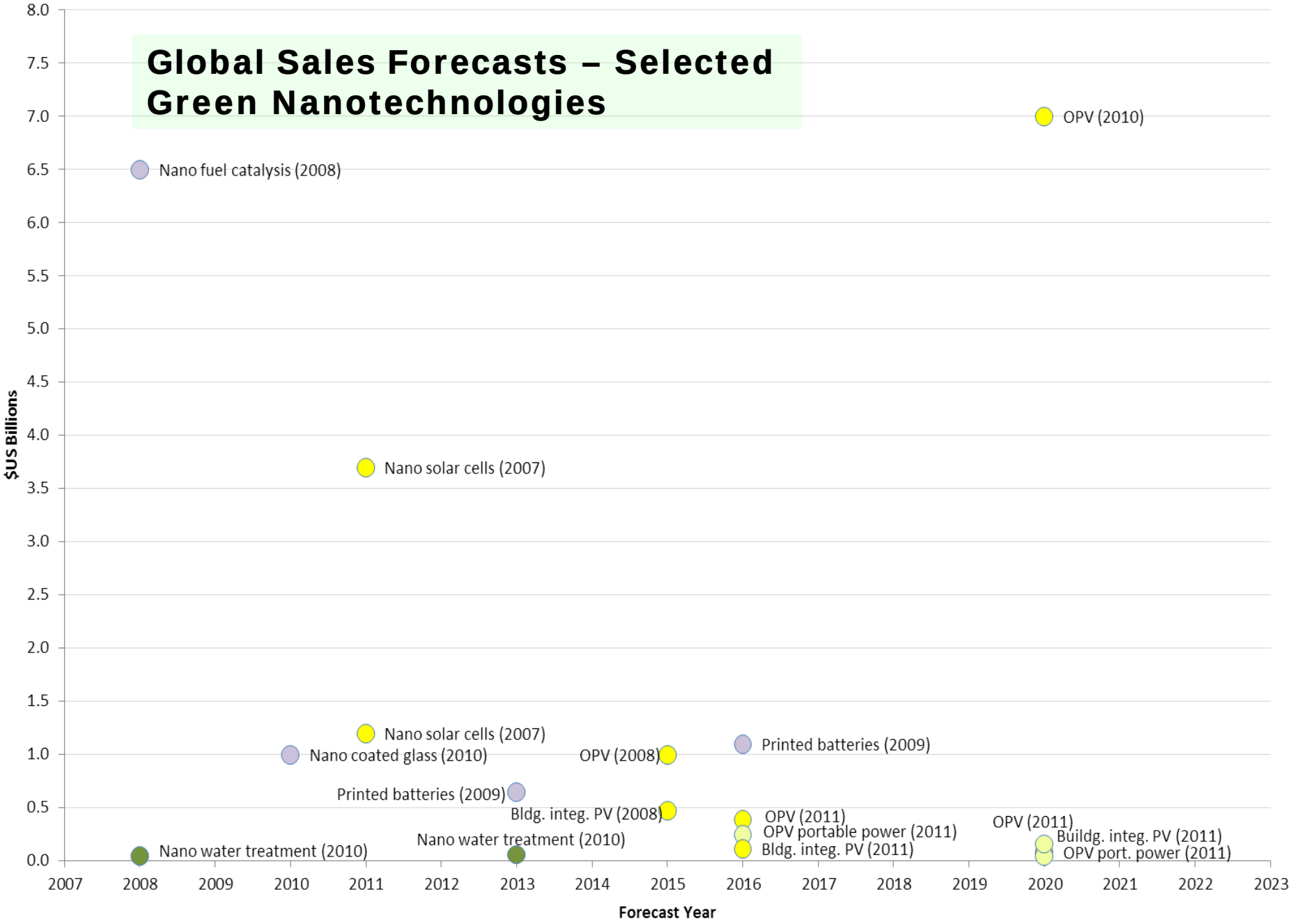
- WIPO: alternative energy, transportation, energy conservation, waste management, agriculture/forestry, administrative/design/regulatory, nuclear power generation

Nanotechnology and Green Jobs – Selected Worldwide Forecasts



Invernizzi (2011); UNEP (2008). Year of estimate in parentheses

Global Sales Forecasts – Selected Green Nanotechnologies



Cientifica (2007); Lux Research (2007, 2010); BCC Research (2009); Global Industry Analytics (2012).

PV = Photovoltaic; OPV = Organic Photovoltaic. Year of estimate in parentheses.

Green Nanotechnology Application Areas: Examples

Nanotechnology Application	Green Benefits	Market Estimate (Worldwide)
Nano-enabled solar cells	Lower cost, less toxic, more abundant materials	US$1.2 billion for 2011 (2007 estimate)
Energy storage	Improved performance of existing materials, long-term use of new, less expensive, more stable, durable, efficient materials	US$3.7 billion in 2011 (2007 estimate)
Nanogenerators	Self-powering of small electronic devices	
Thermal energy	Integration into existing materials for greater insulation, UV protection, water resistance.	Aerogels: US$646.3 million by 2013 Nano-coated glass: US$1 billion in 2010.
Fuel catalysis	Greater efficiency and performance in fuel use	US$5-US$8 billion a year as of 2008
Water treatment, desalination, reuse	New clean, safe water sources	US$6.6 billion in 2015

Reliability of forecasts of green nano applications

- **Nanostructured photovoltaics**: must reach performance, cost levels of existing non-organic PVs
- **Energy storage**: substitutes for rare materials not yet technologically available
- **Nanogenerators**: applications of nanogenerators await market commercialization
- **Thermal energy**: cost, product integration
- **Fuel catalysis**: role of nano-derived synthetic methods in full fuel catalysis market (what share should be attributed to nano?)
- **Water treatment, desalination, reuse**: market in developing countries v. research in developed countries; EHS issues

Benefit-Cost Analyses of Green Nanotechnology Economic Impacts

- Going beyond market forecasts to assessments of benefits and costs

- Among the most detailed work: Walsh et al. (2010) – presented at this conference
  - Green nanotechnology case studies – including nano-enabled food packaging, PVCs, nano anti-fouling paints, nano environmental remediation technologies
  - For the UK, general find modest benefits of nano-enabled technologies over incumbents

- Multiple issues of measurement and assumptions
  - Timing and distribution of various benefits and costs,
  - Interest rates and opportunity costs
  - Relative advantages of green nanotechnologies compared with conventional applications.
  - Measurability of indirect effects, including on supply chains and other spillovers to third parties and the environment

Economic assessment from a broader sustainability perspective

- Green nanotechnology applications may save energy costs and reduce carbon emissions in use, but:
  - Significant energy may be required for upstream production
  - SWNT-lithium batteries currently would require so much energy to produce as to be economically non-feasible and potentially producing significant carbon gases and other wastes
- Some green nanotechnology applications raise environmental, health and safety (EHS) concerns.
  - nZVI (nano zero valent iron) in environmental remediation – potential downstream entry into water sources and food chains
  - Quantum dot technologies containing cadmium and selium
- Variations among countries in development, use and regulation
  - Developed countries + China + other BRICS produce green nanotechnology applications – may be used worldwide under varying regulator regimes – or may not spread to developing countries due to IP and other market issues

The challenge

- **Labeling of promoting a nanotechnology as green**
  - does not necessarily mean that the technology or its applications are sustainable or risk free
- **Potential benefits, costs and risks** of new green nanotechnologies (and all nanotechnologies)
  - need to be compared against the benefits, costs and risks of incumbent technologies
- **Need for full-life cycle assessment**
  - assessment of economic, environmental and societal implications of a product's full life cycle: "from the extraction of resources, through production, use, and recycling, up to the disposal of remaining waste" (European Commission, 2010)
- Need to develop ***anticipatory*** **processes of life-cycle assessment**
  - Building LCA into early R&D and commercialization considerations
  - Regulatory reviews and codes of practice (in R&D as well as industry)
  - Economic projections, market forecasts, and cost benefit analyses
  - Data, evidence, validated scenarios to inform engagement, governance, and decision-making

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Further information

- Shapira, P., and Youtie, J. (2012) The Economic Contributions of Nanotechnology to Green and Sustainable Growth, Working Party on Nanotechnology, Organisation for Economic Cooperation and Development, DSTI/STP/NANO(2012)14.
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