# Investment, productivity and innovation in energy technologies



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## Outline

The energy problem

Patents as traces of innovation

The Worldwide Energy Technologies Database

The inventiveness of nations

Temporal trends

Networks of co-invention and technological change





### The world's energy production system must change because of CO<sub>2</sub> emissions

Today fossil sources account for 80% of energy demand:

coal	<b>25.0%</b>
natural gas	<b>21.0%</b>
petroleum	<b>34.0%</b>
nuclear	<b>6.5</b> %
hydro	2.2%
biomass and waste	11.0%



Only **0.4%** of global energy demand is met by **geothermal, solar, wind** 

**50%** of the electricity generated in the U.S. is from **coal**.

The future of coal MIT report, 2007

China is currently constructing the equivalent of:

- two 500MW coal-fired power plants per week and
- a capacity comparable to the entire UK power grid each year





## the promise of solar





energy / day 174 PWatt

area necessary for world's energy needs at 8%

current technology





#### THE PATH TO GRID PARITY





Ideas That Change the World

Theoretical

Division

Projects in Energy Science & Technology at Los Alamos National Laboratory and the Santa Fe Institute

Worldwide patent database in Energy Technologies Jasleen Kaur



NSF grant "Modeling the Dynamics of Technological Evolution" Doyne Farmer and Jessika Trancik (SFI) http://www.santafe.edu

Mapping Sustainability Science and Technology

NSF award with Katy Börner (Indiana University, Bloomington)

"Open Model" geopatial location and tracking [google maps] of the world's energy production / distribution / consumption networks PI: Rajan Gupta (LANL, NMC IAS) http://openmodel.newmexicoconsortium.org/













innovation, investment production and cost in Energy Science and Technology

Is the world energy system moving towards de-carbonization? how? can it be accelerated?

Are there universal features to scientific & technological innovation?











### Evidence for underinvestment in energy science & technology USA 1976-1999



Innovation periods in energy technologies correlate with high prices





## The worldwide energy patent dataset













### which nations innovate in which sectors?





## Patenting trends worldwide







### energy patterns

US Patent and Trademark office

Japanese Patent office



Two periods of explosive growth in the late 70s and since late 90s





### country temporal patterns



China is a recent newcomer with explosive growth Europe has had sustained but low levels of patenting over decades





### Regional distribution of patents technology & nation









Growth is approximately exponential







Yearly invention rates in fossil fuel technologies

have been ~ constant since the 80s







Invention output in **renewables** is increasing faster than in fossil fuel technologies







Rates of invention in renewable technologies have steadily increased





Number of new Patents, Inventors

# Patterns of energy innovation in time **biofuels**



**Biofuels** are a relatively new area of invention,

with a fast accelerating rate of innovation





Number of Patents, Inventors

Returns in technological innovation to investment in funds and people

Marginal Returns

Output 
$$\Delta Y(t') = f[\Delta X(t)] \sim [\Delta X(t)]^{\beta}, \quad t' \ge t$$
  
Input  $\Delta X(t) = scaling relation$ 

**Returns to Scale**: in  $\Delta Y$ =Patents *vs*.  $\Delta X$ = R&D funds, labour

 $\beta=1$  : each unit of input produces one unit of output  $\beta<1$  : diminishing returns: each new author -> less papers/author  $\beta>1$  : increasing returns: each new author -> more papers/author





# Marginal returns to labor fossil fuels



Patenting in oil and coal shows moderate increasing returns to labor





# Marginal returns to labor renewables



solar and wind show stronger returns to labor investments than fossil fuel technologies





Number of Patents

# Worldwide funding for energy R&D vs. patenting trends



Funding data from International Energy Agency 2006 report

**Renewables** are overtaking **fossil fuel** technologies in terms of innovation and increasingly in R&D funding





# Returns in innovation to R&D investments



**Renewable** technologies' patents show greater returns to R&D investment relative to fossil fuels





## structural changes in emerging fields

### networks of scientific and technological development





# The network structure of scientific & technological change



### **Related work**

#### Uzzi & Spiro.

Collaboration and creativity: the small world problem *American Journal of Sociology*, 2005, 111:447-504.



Douglas & Gerstein, RNAi Development PLoS Comp Bio 2007.



#### Leskovec, Kleinberg & Faloutsos

Graphs over Time: Densification Laws, Shrinking Diameters and Possible Explanations *KDD 2005* 





## Topological transition

fraction of edges in largest component







### Topological transition fraction of edges in largest component









### Network of co-patenting hydrogen fuel cells







## Networks of co-invention hydrogen fuel cells













# Networks of co-invention wind







# Networks of co-invention solar







# Networks of co-invention solar







# Networks of co-invention coal



# Networks of co-invention coal







# Networks of co-invention petroleum







# Networks of co-invention petroleum







# Sector to Sector network common inventors between sectors







## Summary & Outlook



Networks of co-invention show densification and eventual topological transitions as fields mature

Relations to installed capacity and cost, assignees and inventor properties





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