R&D Outlook for Decarbonization Opportunities

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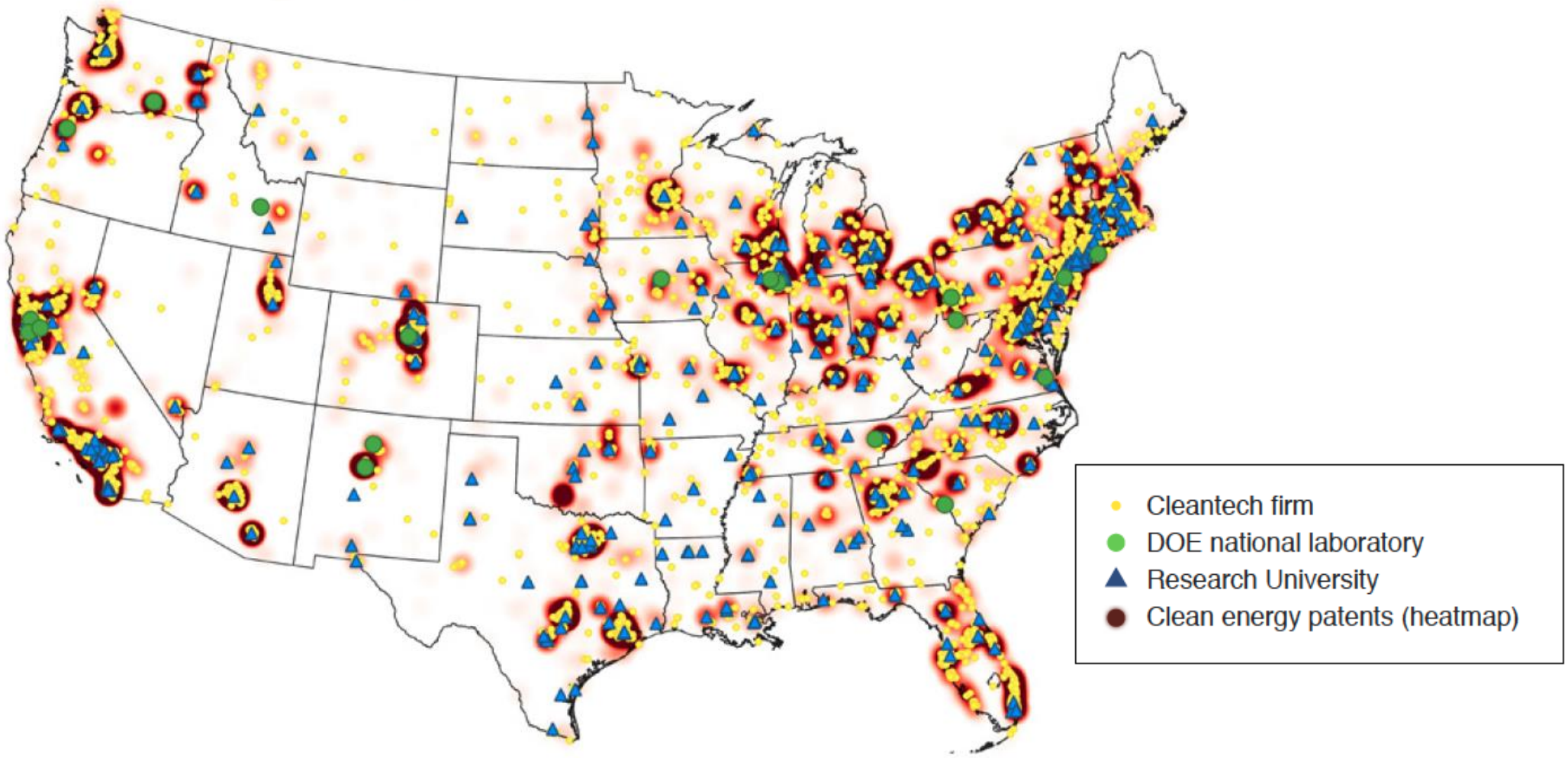
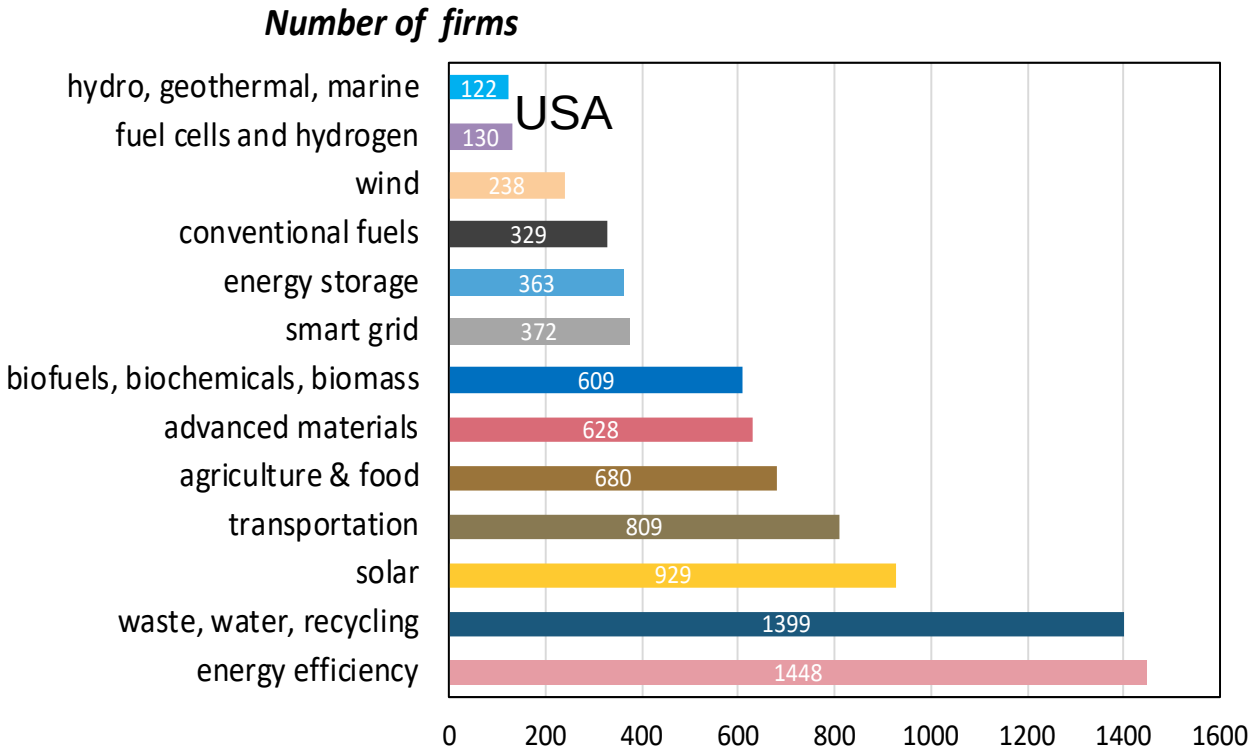
US Clean Energy Innovation System



Young firms advance innovative clean energy technologies

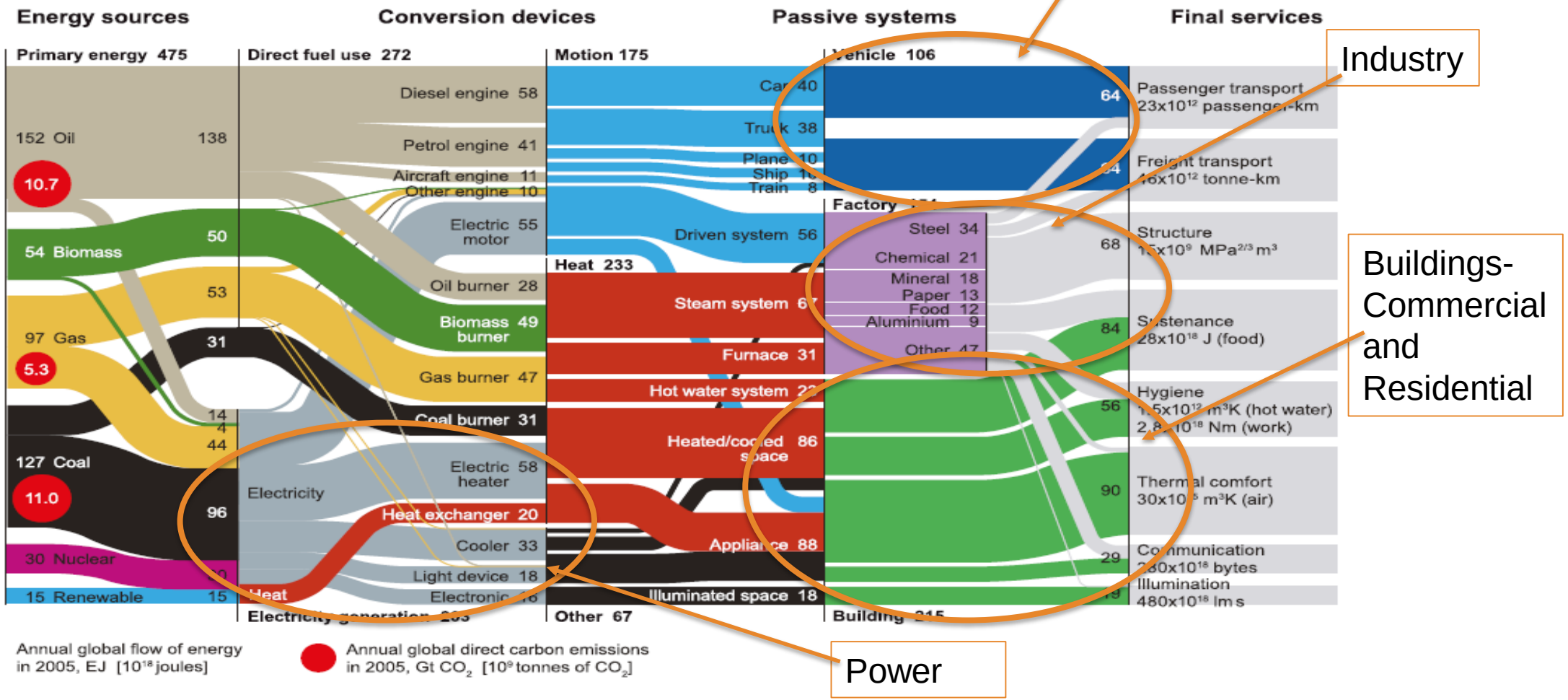


Source: i3

Growing areas of opportunity

- Energy storage, grid modernization and demand reduction
- Biotechnology in clean energy and clean agriculture
- Carbon dioxide removal, management and re-use
- Clean fuels and displacement of energy-intensive products
- Mobility – EVs, vehicle automation, transportation systems
- Integrated systems – AI and ‘internet of things’
- New concepts in nuclear power to improve safety and lower costs

Decarbonization Challenges



Transport

Industry

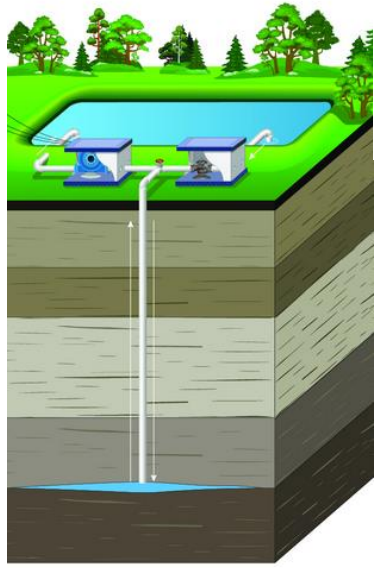
Buildings-Commercial and Residential

Power

Cullen & Allwood, Energy Policy 38 75-81 (2010)

Innovation

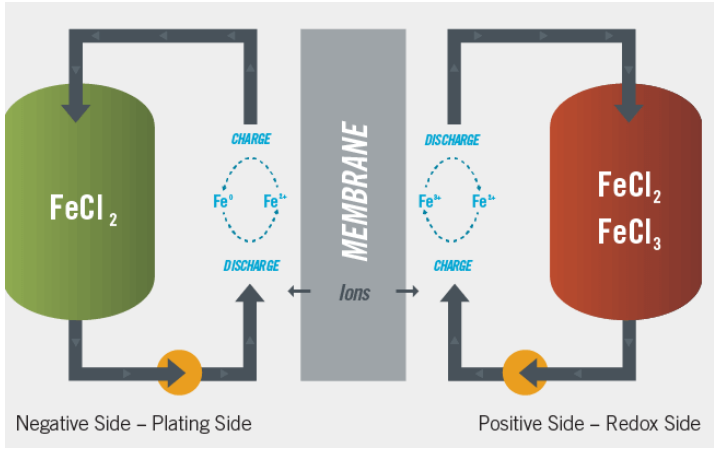
- **Supply Chains, Learning Curves, and Enabling technologies**
  - For every ‘big-picture’ carbon-mitigation technology, hundreds of innovative technologies are needed in its development, deployment, operations, performance improvements and cost reductions
- Example: Innovative technologies under development to provide energy storage for grid integration of distributed, intermittent renewable power requires energy storage



Quidnet Energy

Geomechanical pumped storage

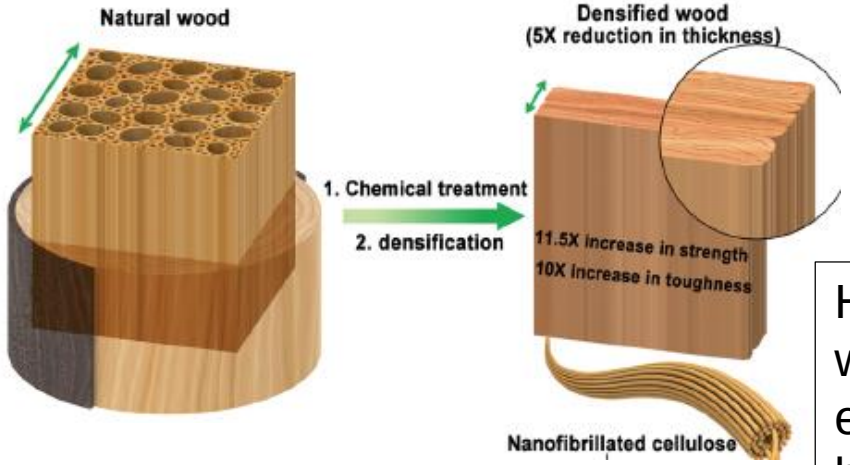
ESS INC
CATALYZING A CLEANER FUTURE



Flow Battery based on low-cost Iron

Innovation

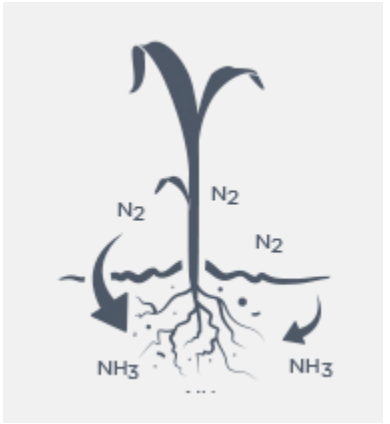
- **Processes that are difficult to decarbonize may be replaced by alternative approaches**
  - Industrial production of commodities such as steel, aluminum, fertilizer, concrete, fuels and chemicals have limited opportunities for improved efficiency
- Example: Innovative technologies under development to replace green-house gas intensive products with alternatives that deliver the same function



INVENTWOOD™
From Nature | For The Future

High-strength wood to replace energy-intensive building materials such as steel and concrete.

PIVOT BIO



Discover microbes that can work symbiotically to fix nitrogen for crops and reduce demand for fertilizer

Innovation

- **Carbon Utilization**
  - Remove or displace the carbon atoms in CO_2 for formation of useful products

ETCH

Replace direct natural gas combustion:

$$CH_4 + O_2 \rightarrow CO_2 + heat$$

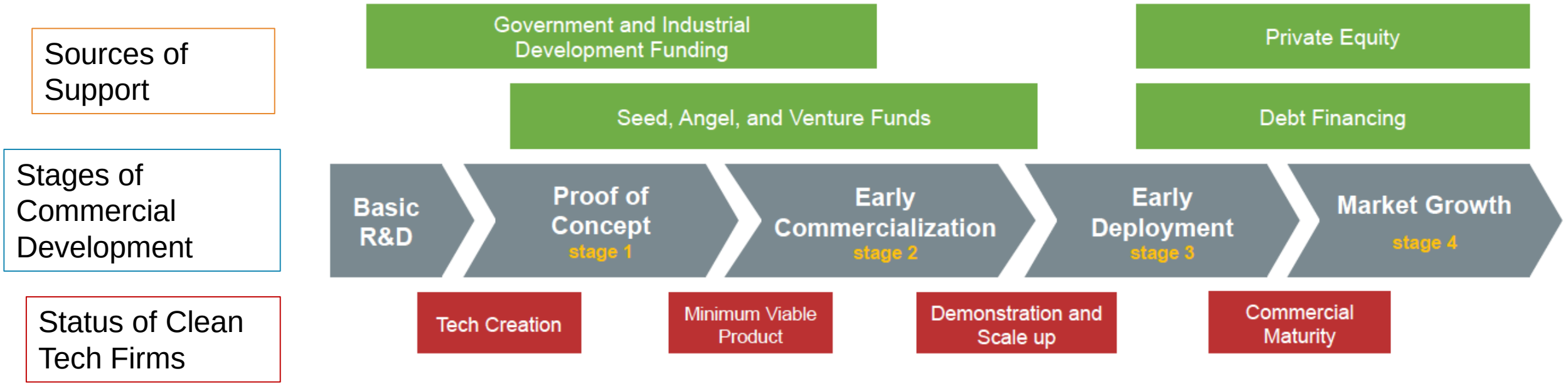
With alternative process

$$CH_4 \xrightarrow{Molten\ NiCl_2} C(solid) + H_2 + heat$$

opus 12

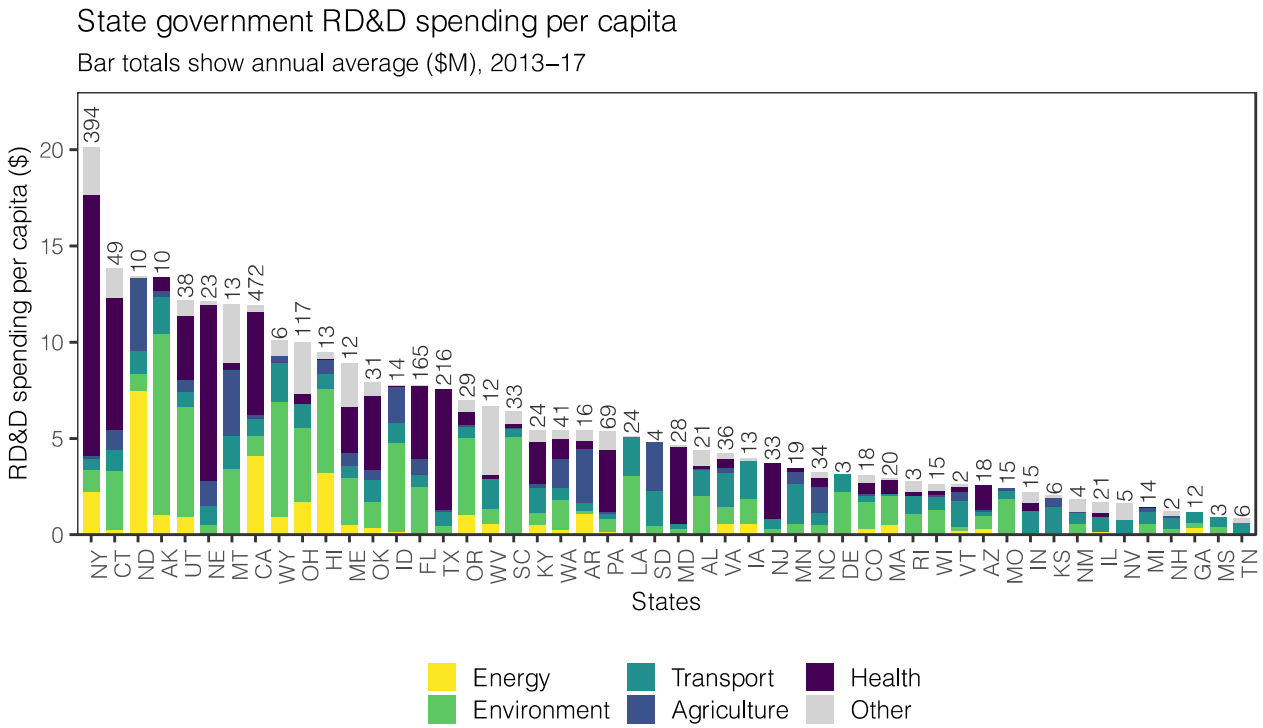
$$CO_2 + H_2O + Electricity \rightarrow C_xH_yO_z + O_2$$

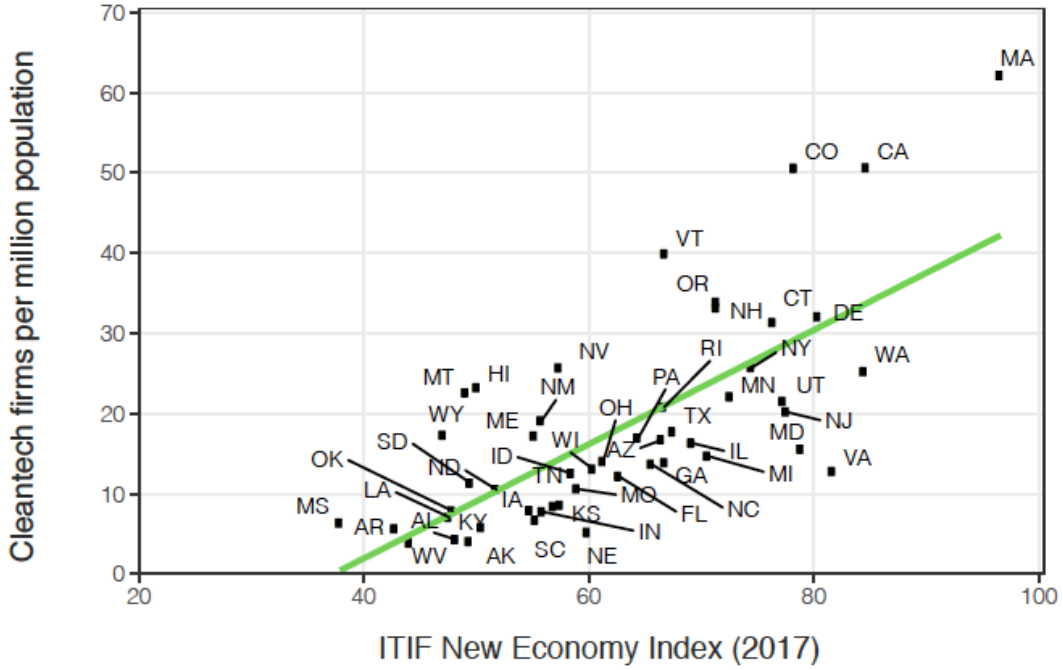
Rocky road from R&D to clean energy impact



Innovations that start in the state should grow in the state, and become the high-tech clean energy firms that help shape Maryland's economic future – but it requires a good innovation system to make that happen.

Federal Funding can be activated by State Priorities



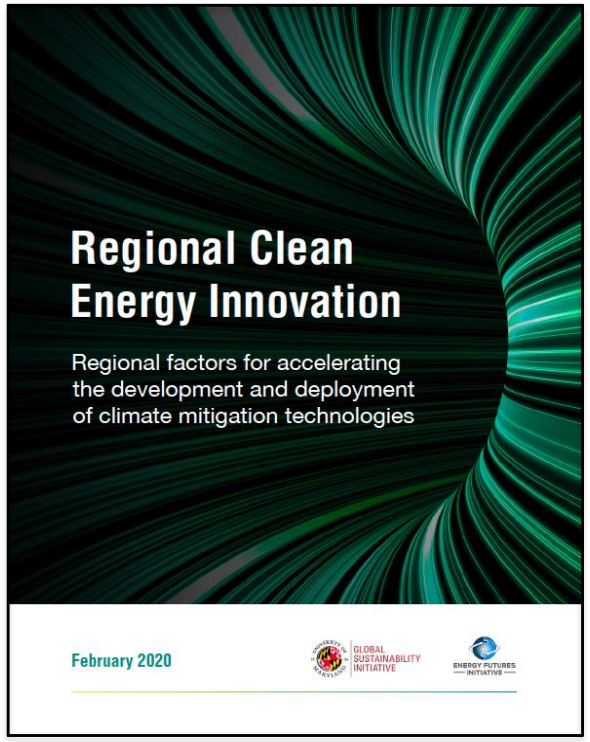


Direct State R&D spending is small compared with Federal funding levels, but State policies play a significant role in number and health of clean energy firms in the state.

Improving Outcomes for Clean Energy Innovation

- **Use a broad definition of Clean Energy Technology**
- **Create well-defined clean-energy goals linked to regional technology strengths**
- **Coordinate environmental, societal and economic-development goals and actions**
- **Offer targeted support for clean energy RD&D – both direct seed funds and developmental support**
- **Expand impact by coordinating actions of state agencies with Universities, Federal Laboratories, non-profit innovation organizations, utilities programs, and local industry**

State Policies and Clean Energy Innovation



K. Surana *et al., download at:*
http://go.umd.edu/regionalenergy

E.D. Williams *et al., download at:*
https://energy.umd.edu/news/story/new-report-recommends-a-path-for-the-future-of-marylandrsquos-clean-energy-economy