Green ecosystem

Opportunities for green research and innovation collaborations with California, Massachusetts and US on the federal level

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Bredgade 40
1260 Copenhagen K
Telephone: 3544 6200
E-mail: sfu@ufm.dk
www.ufm.dk

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Free text **Jeppe Dørup Olesen**
Science Attaché, ICDK Silicon Valley

Bergliot Borg Christensen
Science & Research Advisor, ICDK Silicon Valley

Louise Halberg Nielsen
Research & Innovation Associate, ICDK Silicon Valley

Torben Orla Nielsen
Science Attaché, ICDK Boston

Mikkel Worm Roslundh
Innovation Associate, ICDK Boston

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Contents

Abstract

Research in the green field, development of new technologies, and commercialization of these solutions play a crucial part in achieving Denmark's goals of reducing greenhouse gas emissions. This is a global agenda, meaning that Denmark can learn from other countries' efforts. Therefore, this report will cover the green ecosystem in the US on the federal level and in California and Massachusetts at the state level. The political focus in relation to the green transition in the US, California and Massachusetts is on reducing emissions especially in the energy sector. In broad terms, this includes renewable energy, energy efficiency, energy storage, energy transmission, smart grid, integrated resource planning, and electric transportation. This report offers insights into the political prioritization with climate and energy and how the federal government and state governments support research and innovation efforts in this field. A selection of relevant actors in the American, the Californian, and Massachusetts' ecosystem of clean energy research and development is described – both government agencies, universities, accelerators and incubators, corporates, and other financing models. This report also describes which international organizations the US and the states are part of regarding energy collaborations. Finally, the report suggests Danish opportunities for collaboration with the US, California, and Massachusetts in the broad field of climate and energy research and innovation.

Introduction

This report covers the green ecosystem at the federal level in the US and the state level in California and Massachusetts. When relevant, Massachusetts will be supplemented with examples from the North East Coast of the US. Research and development of green technologies is a global agenda, and the US - and California in particular – are international leaders in tech development and advanced in low emission energy. California is home to e.g. nearly half of the zero-emission vehicles in the US and 40 percent of North American clean fuels investments[1]. Massachusetts is a pioneer on the East Coast when it comes to offshore wind energy, by leading the development that has led to an unprecedented number of planned offshore wind parks all the way from Maine down to Virginia.

On the federal level, the current climate debate is focused on the energy sector. In broad terms, this includes renewable energy, energy efficiency, energy storage, transmission, smart grid, integrated resource planning, and electric transportation. However, most energy regulation takes place at state level.

California's climate strategy shares the focus on energy. In governor Newsom's 2019 state of the state speech the climate focus was on the energy future[2]. Within energy the focus is on energy efficiency, transportation, renewable energy, solar, energy storage, zero emission vehicles, smart grid and integrated resource planning[3]. More broadly, prioritized areas in California are energy and transportation as well as air quality, agriculture, waste and natural resources[4].

The Northeast US states' climate strategy has mainly been focused on reducing the emission from power production. The reduction of emissions in the power sector has been achieved through the Regional Greenhouse Gas Initiative. The program has been such a success, that they are expanding the program to include the transport sector under the Transportation & Climate Initiative. Besides these programs, the Massachusetts Department of Energy published their Comprehensive Energy Plan in December 2018. The plan outlines how to further lower the emission of greenhouse gasses.

It is evident that both the US on the federal level as well as California and Massachusetts on the state level focus on the energy sector in their climate strategies. Therefore, the energy sector will be the focus of this report. California has a wider climate focus on e.g. air quality, agriculture, water, and other sources of greenhouse gas emissions in addition to the focus on energy and electric transportation, but due to limitations in the scope of this report the primary focus will be the energy sector, as this is the shared focus of the federal government, California and Massachusetts. The focus on energy aligns with energy being one of the two largest sources of greenhouse gas emissions in the US along with transportation. Combined transportation and electricity account for more than half of the US' emissions[5].

1. Political conditions and organization

1.1 Strategy for green transition

1.1.1 The US federal strategy for green transition

The US energy policy is centred on the concept of *energy dominance*. This reflects a strategy to maximise energy production including oil, gas, coal, nuclear, hydro and renewables, expand exports, and be a leader in energy technologies. Within this strategy production of natural gas has gone up due to shale gas. A part of the energy dominance strategy is a focus on environmental deregulation – several climate and environment policies have been retracted during the current administration[6].

Climate politics is a controversial subject in American politics dividing Democrats and Republicans, which has resulted in big strategic shifts over the last ten years as the party in control of government has changed. A key example is President Trump's announcement to withdraw the US from the Paris Agreement, which former President Obama committed to in 2015, promising that the US would reduce greenhouse gas emissions 26-28 percent below 2005 levels by 2025[7]. Another example is the recent proposal from the Trump Administration to change the National Environmental Policy Act from 1970. The proposed changes will limit the scope of environmental impact assessments that federal agencies must take before building public infrastructure projects[8]. The shifts are further seen with Trump replacing Obama's Clean Power Plan with the Affordable Clean Energy Rule[9]. Where Obama's Clean Power Plan established national carbon pollution standards for power plants and gave states tools to cut carbon pollution[10], the new rule does not set limits on carbon emissions but only calls for efficiency improvements[11], stressing fossil fuels as a path to economic growth[12]. This is a different path from the one Obama was taking with the Paris Agreement, Clean Power Plan and the Recovery Act of 2009. The latter entailed the largest single investment in clean energy in American history by investing $80 billion in clean energy, expected to produce further investments as much as $150 billion in clean energy projects[13]. However, 25 US states have independently joined the United States Climate Alliance and committed to reduce emissions consistent with the Paris Agreement, and much climate and energy policy happens at state level[14]. An example of energy policy happening at state level is 29 states' renewable portfolio standards – half of the growth in US renewable energy can be attributed to the different states' renewable energy requirements[15]. Another example is East Coast states committing to procure more than 19,000 MW of offshore wind by 2035[16].

1.1.2 California's strategy for green transition

California has a long-standing role of climate leadership among American states. In 2006 California set the goal of reducing emissions to 1990 levels by 2020[17], which California achieved in 2016[18]. California's current goals are 40 percent lower emissions by 2030 and carbon neutrality by 2045[19]. The current Californian governor

Newsom focuses among other topics on energy in his climate strategy including smart grid technology, sun- and wind energy[20]. One part of California's strategy to achieve carbon neutrality is the Renewable Portfolio Standard requiring 60 percent of electricity sales to come from renewable sources by 2030 and 100 percent to come from carbon-free sources by 2045[21]. Another key element in California's climate plan is the Cap-and-Trade program, which sets state-wide limits on emissions. Emission allowances are partly given and traded on auctions, and the surplus from the auctions is invested in programs that further the state's climate targets[22]. Lastly, a key program is the Low Carbon Fuel Standard. With a goal of reducing the transportation fuel pool's carbon intensity 20 percent by 2030 (compared to 2011) the program sets standards for the carbon intensity of fuels that transportation fuel providers must comply with[23]. This program is central as 41 percent of California's emissions come from the transportation sector[24].

California has a history of leveraging its position as a populous state with a large economy to set standards that affect other states as well. In the 1970 Clean Air Act, California was given an air pollution waiver, allowing California to set more strict standards for air pollution of motors than the federal government's standards. This de facto gives California right to set nationwide standards for car emissions, as other states and industry follows these standards. Car manufactures generally design all their vehicles to meet California's standards instead of producing two models. President Trump is taking steps to revoke California's air pollution waiver, and this is currently at trial[25].

1.1.3 Massachusetts' strategy for green transition

Like California, Massachusetts is among the ambitious states regarding reduction of greenhouse gas emissions. To achieve a long-term reduction in their greenhouse gas emissions the EEA (Executive Office of Energy and Environmental Affairs) has developed a 2050 Roadmap, which will help identify cost effective strategies that will help Massachusetts in reducing their emissions 80 percent by 2050. According to the most recent Massachusetts Greenhouse Gas (GHG) Inventory, greenhouse gas emissions in 2017 were 22.4 percent below the 1990 baseline and were on track to hit the 25 percent reduction by 2020 required by the Global Warming Solutions Act (GWSA)[26]. Despite Massachusetts reduction in greenhouse gas emissions, the population grew by 14 percent and miles traveled by car grew 24 percent in the same period[27].
Massachusetts is also working alongside regional states and partners through programs such as the cap-and-trade RGGI (Regional Greenhouse Gas Initiative) and the Transportation and Climate Initiative, and with alliances such as the US Climate Alliance.

1.2 Green research strategy

1.2.1 The US' federal green research strategy

On the federal level, some actors argue that there is a lack of political continuity and consensus regarding research and development funding and direction[28]. Each year Trump's budget proposal includes sizeable reductions in research and development, this year (2020) even proposing to eliminate ARPA-E, who does research in renewable energy and energy efficiency. However, the proposals have not been passed by congress in the prior years[29], and the federal government still funds a considerable amount of energy research and development through among others Department of Energy (DOE), Defense Advanced Research Projects Agency (DARPA) and National

Science Foundation (NSF), as research in the US is primarily funded from federal sources[a]. The federal research and development (R&D) budget was $135 billion in 2018, and from this DOE received $17 billion for energy R&D (including both green and fossil energy R&D)[30].

1.2.2 California's green research strategy

There is more political continuity on prioritizing green research in California, where most state sponsored energy research is focused on demonstration projects and bringing technology to market. California has a high level of private and public R&D and outstanding universities and research institutes, that compare very favourably to similarly sized countries in Europe[31]. California's total public R&D budget was $633 million in 2018, with $243 million, $41 million, and $36 million awarded to respectively energy, environmental and natural resources, and transportation[32]. In addition to state sponsored research, California also receives federal R&D funding. Approximately $14.4 billion federal R&D funds are spent in California each year, and about $1.3 billion of this comes from DOE[33].

1.2.3 Massachusetts' funding of green research

Massachusetts receives $3.6 billion of the federal R&D funds each year, about $108 million of the funding comes from the DOE[34]. The funding is primarily used for R&D contracts and project grants. Harvard University receives about $6 million, MIT receives $9 million, Boston University receives $3 million, and UMass receives $3 million from the DOE[35]. The largest contribution is the $28 million from the DOE to support the Laboratory for Nuclear Science at MIT[36].

Massachusetts also supports clean energy R&D and market development centres and incubators. The programs range from funding market development centres and incubators to programs that help demonstrated technology to market.

1.3 Government authorities

1.3.1 Federal government authorities

The two most relevant federal agencies for the green transition are the Environmental Protection Agency (EPA) and Department of Energy (DOE) [b]. With a budget of $18 billion yearly, EPA is responsible for regulation and standards on the environment and energy[37]. Many environmental programs have been delegated to the states and EPA handles the remaining at federal level. EPA collaborates internationally – including with Europe through both the European Commission, member states and multilateral organizations. Focus areas of activities with Europe are air quality, resource efficiency, chemicals management and research cooperation[38]. However, as the EPA is a regulatory agency, their financial capabilities for international projects are limited[39]. DOE addresses energy and environment challenges through research and development efforts – they promote the American Energy Dominance strategy by supporting e.g. renewable energy, carbon capture and fossil energy[40]. Relevant sub departments include ARPA-E, IA (Office of International Affairs), Office of Science and EERE (Office of Energy and Efficiency and Renewable Energy). E.g. EERE has several

[a] These actors will be elaborated in section 3.

[b] Other relevant agencies are Council of Environmental Quality, Federal Energy Regulatory Commission, Environmental Council of the States, Department of Transportation, and American Council for an Energy-Efficient Economy.

multilateral energy relationships and IA has international energy cooperation, through the International Energy Agency among others[41].

1.3.2 California's government authorities

Related to climate transition the most relevant state agencies are California Environmental Protection Agency (CalEPA), California Air Resources Board (CARB), California Energy Commission (CEC), California Public Utilities Commission (CPUC), and California Independent System Operator (CAISO)[c]. CalEPA handles broader environmental regulation in California and has several multilateral agreements e.g. the Under2 coalition and the International Zero Emission Vehicle Alliance[42]. CARB administers programs and actions that are part of advancing the state's climate goals, including the Cap-and-Trade program, the Low Carbon Fuels Standard, and work with zero emission vehicles among others[43]. CEC is the primary energy policy and planning agency and administers several clean energy research and development programs that drive innovation in fields related to clean energy[44]. CPUC is the primary regulating and supervisory authority of services and utilities[45]. CAISO is responsible for managing the electric grid and maintaining reliability while increasing the amount of renewable energy on the grid[46].

1.3.3 Massachusetts' government authorities

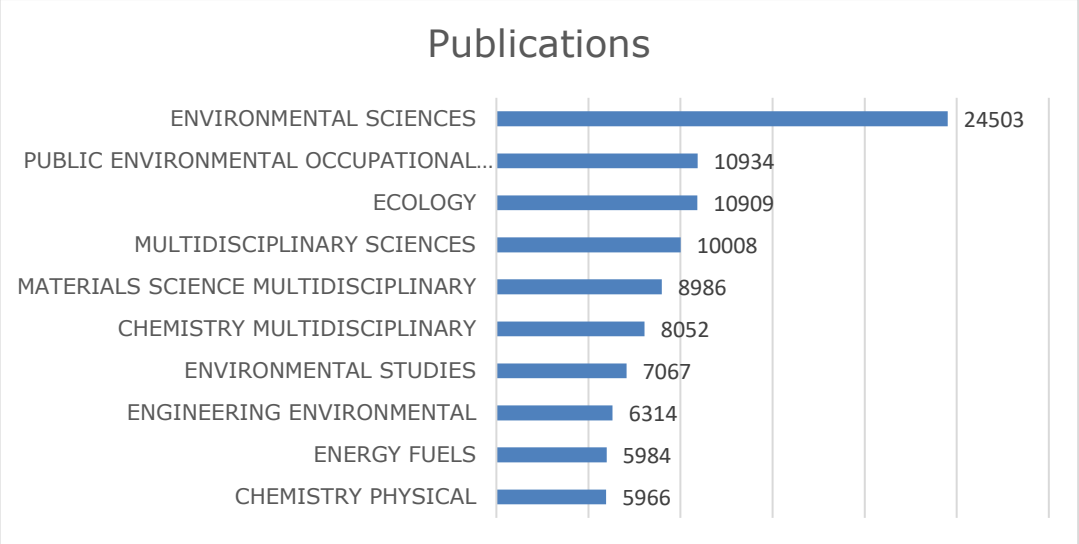
Executive Office of Energy and Environmental Affairs: The department oversees the six environmental, natural resource and energy regulatory agencies in Massachusetts and Massachusetts is the first state in the nation to combine energy and environmental agencies under one Cabinet secretary. Department of Energy Resources is a department under the Executive Office of Energy and Environmental Affairs[47] (see 3.2.3 for further information).

[c] Other relevant agencies are Office of Business and Economic Development (GO-biz) and Office of Planning and Research (OPR). GO-biz is an office for business development doing business assistance in general. OPR is a state planning agency that coordinates climate actions and federal grants for environmental goals.

2. Positions of strength

2.1 Positions of strength in research

Bibliometric analysis shows that the focus of American research within the green area covers a broad spectrum of energy and material science, public environmental health, ecology, engineering, chemistry, and energy fuels. The table below shows the research categories with the most publications related to the green area. It shows the number of publications within each category within the last 5 years[d]. The category with most publications is environmental sciences, which captures a broad range of publications on wastewater, fresh water, agriculture, energy storage, material science, and solar energy. The bibliometric analysis indicates that the broad field of energy is a strength position in research consistent with the political prioritizing of clean energy. In addition to the politically prioritized area of clean energy, American research has other strength positions within the green area as well.



2.2 Government support for strength positions

The priority for the US government's energy research grants is to advance knowledge through early-stage research and development that is unlikely to be undertaken by the private sector due to high risk, while the private is expected to invest in the development and commercialization of these ideas. Both the public and the private sector play roles in driving innovation, and the government (both federal and state level) has a range of initiatives supporting private sector research and innovation[48].

[d] The bibliometric analysis was made using web of science, search for "clean OR decarboniz* OR environment* OR sustainab*" within the last 5 years in USA. The results were refined to leave out engineering electrical electronic, as this category included irrelevant results for analysis of the green area.

2.2.1 Examples of federal government's support

The federal government supports private sector research and innovation indirectly through the R&D tax credit, which is a tax incentive rewarding companies that conduct R&D[49].

Department of Energy (DOE) supports innovation and technology development in several ways. One is their Loan Project with more than $40 billion in loans and loan guarantees available. With this DOE supports and accelerates deployment of commercial-scale clean energy projects that are typically unable to obtain conventional private financing because of their high technology risks[50].

Small Business Innovation Research (SBIR) is a government program intended to help small businesses conduct R&D. It is the largest innovation program for small businesses in the US with approximately $2.8 billion in funding per year. It provides funding as grants to domestic start-ups and small businesses engaging in 11 federal agencies' designated research topics with potential for commercialization[51]. The SBIR program thereby enables small businesses to explore the technological potential of federal research and provides incentive to commercialize it. The program is of considerable size for energy technology development, as e.g. DOE's 2020 budget for the program is $111 million[52].

Another part of the federal government's support of innovation is the Small Business Technology Transfer Program (STTR). STTR is distinguished from SBIR by requiring the small business to formally collaborate with a research institution making it a public-private partnership. STTR's focus is transfer of technology and bridging the gap between basic science and commercialization[53].

The National Network for Manufacturing Innovation (NNMI) is another example of federal government support for innovation. NNMI is a triple helix partnership with $183 million in federal funds attracting $304 million in state and private investment[54]. The manufacturing institutes create space for industry and academia to collaborate in joint labs and research facilities with the goal of technology transfer to US manufacturing industries. This helps companies overcome technical obstacles to scale-up new technologies and products[55].

Initiatives aimed at promoting market pull exist at federal and state levels to complement direct support programs. At the federal level, an important example is energy tax credits. The first residential energy tax credits were established in 2005 and different variations have continuously been in place since then[56]. The current scheme runs until the end of 2020 and gives tax deductions for energy efficiency improvements in homes and commercial buildings. The tax credits for energy efficiency include installing renewable energy equipment, e.g. solar, geothermal, wind or fuel cells[57]. In addition to residential energy tax credits, investment tax credits and production tax credits exists for solar and wind energy among others[58].

Another example of a federal market pull initiative is the Energy Efficient Mortgage Program, which enables homeowners to finance energy efficiency improvements. The homeowner can borrow a larger amount than otherwise approved in order to pay for the appliance cost and installation of energy efficiency improving technology. The same can be done to pay for solar and wind energy systems[59].

2.2.2 Examples of California's government support

Apart from the aforementioned Renewable Portfolio Standard, Low Carbon Fuel Standard, and the Cap-and-Trade program, California supports innovation within green technologies with several programs.

Firstly, a major program is the Low Carbon Transportation Program, which has received $533 million in funding for fiscal year 2020 alone. The program covers a broad range of initiatives with the purpose of accelerating deployment of clean vehicle technologies and improving access to clean transportation for all. The program includes incentives to buy zero-emission vehicles (electric vehicles, including hydrogen fuel cell electric vehicles) for consumers and the heavy-duty sector, as well as supporting advanced technology demonstration and pilot projects in the heavy-duty sector. The incentives for consumers are targeted low-income consumers to improve accessibility to clean transportation[60].

Secondly, California supports development of green technologies through the Electric Program Investment Charge (EPIC). The EPIC program invests more than $130 million annually in clean energy research and development as well as demonstration projects and clean energy entrepreneurship[61]. A part of EPIC is the Energy Innovation Ecosystem, which was launched as a response to private sector investors withdrawing from the cleantech sector around 2013. The ecosystem supports clean energy entrepreneurs with access to network, funding opportunities, mentoring, facilities, and expertise[62].

Thirdly, from 2006 to 2016 California has supported solar efforts with a total investment of $3.3 billion. Most programs have ended as market prices have dropped making incentives unnecessary[63]. The programs supported solar energy in homes, businesses, farms, schools, government, and non-profit organizations[64]. California still indirectly supports solar energy through the solar mandate in the new building code, requiring all new homes to have solar panels from January 2020[65].

Besides these programs that directly support research and innovation, California has regulation and incentives to create market pull as well. California has several initiatives helping consumers finance energy improvement projects in their homes. One is the PACE (Property Assessed Clean Energy) program, where property owners pay energy efficiency and renewable energy improvements using private sources of capital and repays through their property tax bill for up to 20 years. PACE programs exist for both residential and commercial properties, and in many other states as well[66].

Another program in California is SGIP (Self Generation Incentive Program) which provides incentives to support existing, new, and emerging distributed energy resources with rebates for several kinds of energy systems[67]. Currently, the program focuses on energy storage with incentives for homeowners to install home batteries with their solar panels[68].

California's Low Carbon Transportation program includes market pull initiatives as an important component of the program's goal to accelerate deployment of clean vehicle technologies. $770 million invested in consumer rebates for zero-emission vehicles (ZEVs) create a strong market pull for ZEVs with one in 10 new car sales in California being plug-in electric cars[69].

Californian market pull initiatives include more narrowly targeted initiatives as well. The Clean Energy Jobs Act K-12 program sets aside $1,7 billion over five years for schools to install energy efficiency upgrades and clean energy generation measures[70]. Another program sets aside $94 million to replace old diesel school buses in disadvantaged and low-income communities throughout California[71].

2.2.3 Examples of Massachusetts' government support

Regional Greenhouse Gas Initiative (RGGI)

To cap CO2 emissions the North Eastern States have developed the RGGI program over several years. The initiative was established in 2005 and administered its first auction of CO2 emissions allowances in 2008. The program was the first mandatory program to reduce emissions of CO2 from power generation in the US, which has been largely fossil fuel based.

To reduce the emissions of CO2 the program introduced a "cap-and-trade" market for the emission of CO2. The partnering states agree how many "allowances" of CO2 each state gets quarterly. Each state will auction the allowances to the power producers, the surplus from the auctions gets reinvested into the state in a variety of state programs, hereby energy efficiency incentives, fuel assistance programs, and electric vehicle rebates. California's cap-and-trade program operates in a similar way.

Lowering of CO2 emissions is achieved by lowering the quantity of allowances issued each year. In 2009, 188 million allowances (one allowance equals on ton of CO2) were available, and in 2015 88.7 million allowances were available[72]. Massachusetts joined the program in January of 2007 and is currently working on expanding the "cap-and-trade" model beyond the power sector, in programs such as the Transportation & Climate Initiative (TCI).

Comprehensive Energy Plan

17 percent of Massachusetts' energy consumption was from the power sector, where transportation uses 44 percent of the energy and buildings (thermal) uses 39 percent[73]. To further lower their emissions, Massachusetts Department of Energy prepared the Comprehensive Energy Plan. On transportation, the plan relies on the advice from The Commission of the Future Transport. In the Commission's report it is proposed to improve the electric charging infrastructure, to establish a goal that would require all transport vehicles sold from 2040 and onwards to be electric, and to establish a "cap-and-trade" system for transportation[74]. This is what later has become Transportation & Climate Initiative. For buildings it has been proposed to switch fuels to natural gas. However, a significant portion of the buildings must get better insulation, frequent testing, upgrading of broilers and smarter building because it is not likely that the entire thermal load will be carbon neutral, therefore Massachusetts needs to lower their overall demand for heating[75].

Renewable Energy Portfolio Standard (RPS)

The Renewable Energy Portfolio Standard is a regulatory mandate to increase production of power from renewable sources. The program makes it obligatory for the electricity supplier to deliver a specified percentage of clean energy[76]. In 2018 the required percentage was 13 percent[77], and each year the percentage has increased 1 percent – until 2020 were it will begin increasing 2 percent per year[78].

Solar Massachusetts Renewable Target (SMART)

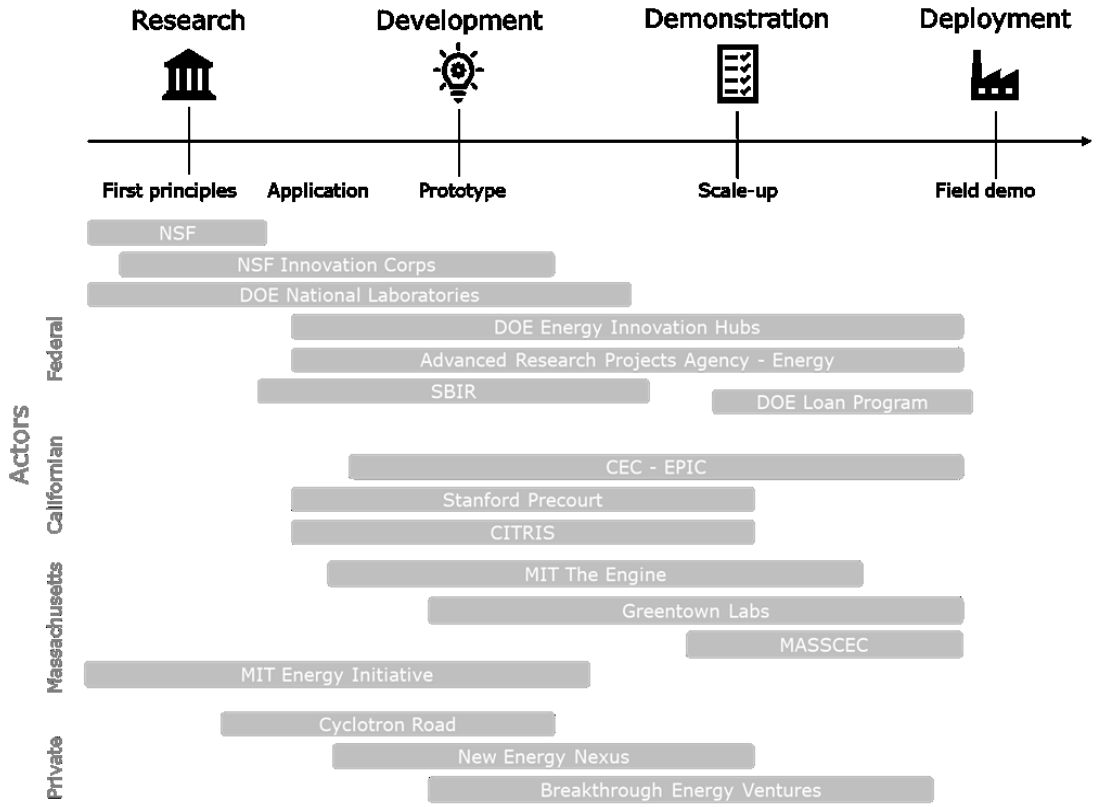
To expand renewable energy such a solar energy, the Department of Energy Resources (DOER) established the Solar Massachusetts Renewable Target program. Through the incentive program it is possible to earn a monthly rebate on both solar panels and battery storage for 10 years[79]. The program has the potential to bring Massachusetts to the frontline of US solar powered states[80].

3. Actors

This section will present a selection of important actors in the US, California and Massachusetts' research, development and demonstration of green technologies and bringing these to market, as well as the potentials for collaborations with these actors. The section is divided into government agencies, universities, and private actors (accelerators and incubators, corporates, and other financing models). The chosen examples of universities and private actors focuses on California and Massachusetts.

3.1 Examples of significant actors

The figure below provides an overview of selected actors that will be elaborated in this section – and of which part of the research and innovation process each actor engage.



3.2 Government agencies

3.2.1 Federal government agencies

The most important federal government agencies supporting research and development of green technologies are DOE, ARPA-E, DARPA, and NSF.

DOE is the lead federal agency promoting energy R&D[81]. DOE has a large R&D budget, as DOE's office of science have received $7,000 million in FY2020 and their six offices for applied energy R&D have received $5,862 million in FY2020, with Office

of Energy Efficiency and Renewable Energy receiving almost half of this[82]. DOE supports energy R&D with the different offices' programs, by directly supporting researchers at universities, with their National Laboratories, with their Energy Innovation Hubs, through ARPA-E, and through the SBIR and STTR programs.

DOE's 17 national laboratories cover both basic research and translating basic science to applied research. They partner with universities, research institutions and industry to do basic science and share it with private partners to spur technological breakthroughs[83]. There are several ways to partner with national laboratories for both nationals and internationals[84]. Generally, it is possible to partner with the national labs if you bring your own funding from your own institution or a fund, and in some cases, it is possible to get DOE funding. E.g. Lawrence Berkeley Lab has an International Energy Studies Group Visiting Scholar program[85]. Partnering with national labs is not uncommon, as Lawrence Berkeley National Lab has 2065 publications in collaboration with Denmark within the last 10 years.[e]

DOE's Energy Innovation Hubs are central in their R&D effort as well. The Energy Innovation Hubs are multi-institutional research teams with partners from national laboratories, universities and industry. They are advancing energy science from early stage research to point of commercialization[86], and they attract start-up companies seeking to commercialize green energy technologies[87]. Some of the hubs, e.g. the Energy Storage Hub, the Critical Materials Institute, and the Artificial Photosynthesis Innovation Hub partners with international universities[88].

ARPA-E is an important sub department of DOE. ARPA-E is designed to push new innovations to market with a budget of $425 million in 2020[89] and supports the energy innovation ecosystem by funding projects that are too early for private investments[90]. One example is ARPA-E's scaleup program that funds technologies reading for scaling to reach market[91]. ARPA-E's funding opportunities are generally targeted to US companies and universities.

DARPA (Defense Advanced Research Projects Agency) aims to invest in breakthrough technologies for national security, e.g. renewable jet fuels that can reduce military's dependence on petroleum-derived fuels[92]. Apart from providing grants[93], DARPA also promote research innovation by hosting innovation challenges with cash prizes, where teams from the entire world can participate. The best-known example is the Grand Challenge from 2004 that offered a prize of $1 million for designing a driverless car that could be the first to successfully complete a desert course. The prize was never awarded. However, the challenge succeeded in generating attention in the research community on the potential of driverless technology[94].

NSF (National Science Foundation) supports basic research in all fields except medical with an annual budget of $8.3 billion[95]. Grants are given based on a competitive application process. NSF's innovation efforts are centered in their Innovation Corps, that provides entrepreneurial training to scientists and engineers working on commercializing federally funded projects[96]. NSF is constrained as it cannot normally send substantial funds overseas, but among that grants that are allocated outside the US, Denmark is one of the top countries receiving grants[97]. International programs include AccelNet that supports international research networks and PIRE that supports international partnerships and is expected reopened in 2020[98]. These are the best-known opportunities for international collaborations with NSF.

[e] Scopus

3.2.2 California's government agencies

The most important government agencies in California supporting research and development of green technologies are CEC, CARB, and the State Treasurer.

CEC supports clean energy R&D with programs that provide more than $200 million each year[99]. CEC's two main research funding programs are EPIC (Electric Program Investment Charge) and the Natural Gas Research Program, and beyond these CEC has a range of programs aimed at helping bringing technologies to market[100]. One example is their Roadmaps for New Technologies that help advance commercialization of new technologies within energy storage, microgrids and vehicle-grid integration by providing roadmaps for path to market[101]. CEC is the administering agency of the two Memoranda of Understanding on energy efficiency and offshore wind energy that Denmark has with California, providing opportunity for further collaboration with CEC via the established relations.

CARB administers the aforementioned Low Carbon Fuel Standard Program and the Low Carbon Transportation Program, that advances deployment of clean vehicle technologies. Regarding research CARB sponsors a research program that investigates air pollution's causes, effects and solutions[102]. CARB has recently begun focusing on negative greenhouse gas emissions for California to reach the goal of carbon neutrality in 2045[103].

The State Treasurer manages the mentioned PACE program as well as the Sales and Use Tax Exclusion, that gives a tax exclusion for manufactures promoting alternative energy and advanced transportation deployment.

3.2.3 Massachusetts' government agencies

Most policies and regulation regarding energy and climate are handled by State department of Energy and Environmental Affairs, with various sub departments.

Massachusetts Department of Energy Resources (DOER) develops and implements policies and programs to ensure adequacy and cost-effectiveness of Massachusetts energy supply. DOER strives to maximize the development of clean energy and employment within Massachusetts' clean energy companies[104]. DOER is an agency of the Executive Office of Energy and Environmental Affairs (EEA).

Renewable Energy Division is a part of DOER. The Renewable Energy Division collaborates with other DOER divisions and related state and federal agencies to enhance renewable energy, by developing programs, incentives, and installation assistance to spur the implementation of clean energy[105].

Massachusetts Clean Energy Center (MassCEC) is a state agency dedicated to accelerate the growth of cleantech in Massachusetts and to deliver statewide environmental benefits while still securing economic growth in the state. This is done through investing in incentives that promote clean energy adoption, by helping business connect with the required talent, as well as investing in programs that enhances innovation[106].

3.3 Universities

Many American universities conduct research within the green area and clean energy, and many American universities have an entrepreneurial focus on this as

well[107]. This section provides examples of universities from California and Massachusetts.

3.3.1 Universities in California

At Innovation Centre Denmark Silicon Valley, we have partnerships with UC Berkeley and Stanford University making Danish collaborations more likely, and therefore making it the most relevant to describe their efforts in research and development of green technologies. Besides Stanford and the UC-system, Caltech is one of California's leading universities within research and development of green technologies and their efforts will be described as well.

At Stanford, the Precourt Institute for Energy is the focal point of energy research. Precourt integrates energy research from basic science and technology to policy and business. Research efforts span across renewables, storage and grid, policy and market, end use, transportation, nuclear and environmental impact and has more than 200 researchers affiliated from different disciplines. Precourt engages with industry in an academic-private sector program focused on accelerating clean energy development, deployment, scale-up and finance[108]. Besides engaging with industry, Precourt builds collaborations globally with other research institutions, government and civic organizations in pursuit of sustainable, affordable, secure energy[109]. Precourt's own funding opportunities are targeted Stanford faculty and students[110]. ICDK has a standing partnership with SUNCAT at Stanford, a center which focusses on converting sustainable energy into liquid fuels.

The UC Berkeley Energy Institute at Haas focuses its research on business and policy challenges to inform decisions within energy market and regulation[111]. The energy institute has visiting scholars, mostly from the US but also internationals. Besides that, the institute collaborates with businesses, government, and non-profit organizations to solve real-world problems[112]. The energy institute promotes cleantech with their cleantech accelerator – Cleantech to Market (C2M). C2M brings together students, entrepreneurs, researchers, and industry professionals to accelerate the commercialization of emerging clean technologies[113].

CITRIS (Center for Information Technology Research in the Interest of Society) is central to Berkeley's energy research efforts as well. CITRIS was created to shorten the pipeline from laboratory research to development of companies. From concept to prototype, the CITRIS invention ecosystem includes competitive seed funding, specialized testbeds, laboratories, and a startup accelerator[114]. One of the center's research areas is Energy and Environment[115]. Another is the sustainable infrastructures initiative that pursues information technology research in energy, water, and transportation as parts of the cyber-infrastructure of a sustainable society[116]. Collaboration with CITRIS is possible through the partnership agreement with Danish Agency for Science and Higher Education. The collaboration covers all four CITRIS campuses (UC Berkeley, UC Davis, UC Merced, and UC Santa Cruz).

Caltech, The Resnick Sustainability Institute is a hub for energy and sustainability research. With a new donation of $750 million the institute has backing to do sustainability research in their 4 core initiatives: sunlight to everything, climate science, water resources, global ecology and biosphere engineering[117]. The institute has a tradition for international research collaborations and visiting scholars[118].

Caltech, JCAP (Joint Center for Artificial Photosynthesis) is one of DOE's Energy Innovation Hubs, which is placed at Caltech. It is the nation's largest effort focused

on artificial photosynthesis. Its researchers aim at creating a low-cost generator that uses sunlight, carbon dioxide, and water to make fuels—after which they hope to hand that prototype off to private-sector companies to launch a new solar-fuels industry through their industrial partnership program[119]. Research collaborations with JCAP is possible[120].

3.3.2 Universities in Massachusetts and on the North East Coast

In Massachusetts, MIT, Harvard, and Tufts University are examples of universities with a strong focus on the green agenda. In addition to the universities based in Massachusetts, there are several other excellent universities working on the green agenda on the North East Coast, which this section also provides examples of.

Massachusetts Institute of Technology (MIT) has several departments and initiatives on the green agenda.

One is the *MIT Energy Initiative (MITEI),* which is one of five center initiatives across the five Schools at Massachusetts Institute of Technology (MIT). MITEI is MIT's hub for energy research, education, and outreach. MITEI connects faculty, students, and staff to develop technologies and solutions that help prosper clean energy. Within research, MITEI facilitates the collaborations between research teams from MIT with government entities, business, and NGO's[121]. MITEI oversees the energy education efforts at MIT and has sponsored numerous research opportunities for undergraduates, graduates, and postdoctoral students[122]. MITEI develop and administers the Energy Studies Minor for undergraduates at MIT, as well as the Undergraduate Research Opportunities Program in energy and the graduate Energy Fellow program, and online energy classes.

Another is, *MIT Sustainable Design Lab* is an interdisciplinary research group, focused on architecture that develops design work, planning tools, and metrics to evaluate the environmental performance of buildings[123].

Harvard University's focus on energy and climate stems both from a policy approach and an engineering approach. Harvard Kennedy School (HKS) is working on how government can create environmentally sustainable energy policies that are feasible both technologically and politically. Harvard School of Engineering and Applied Sciences (SEAS) has a specific research focus on Energy Resources and Energy Systems[124]. Besides this, Harvard has a variety of programs focusing on sustainability. One such program is their Student Grant program[125]. The grant is designed to provide students with seed funding to support new ideas and innovative projects that address global sustainability challenges. Harvard University Endowment has joined the Climate Action 100+, which is an investor-led initiative to ensure that the world's largest emitters act against climate change[126]. On a local scale Harvard University has developed a sustainability plan committed to become fossil fuel-free university by 2050 and fossil fuel-neutral by 2026[127].

Tufts University's Department of Engineering has for a long time been focusing on research in renewable energy and related technologies. The university has been one of the leading forces in Massachusetts Research Partnership (MRP) in Offshore Wind. Other partners in this initiative are The University of Massachusetts Lowell (UMASS), National Science Foundation (NSF), and Massachusetts Clean Energy Centre (MassCEC). In a recent white paper from MRP they are launching a nationwide network called Power-US (Partnership for Offshore Wind Energy Research). This is a framework for offshore wind research and innovation in the United States focusing

on established relationships in data, systems-level thinking, and strategic research approaches needed to advance the global off-shore wind industry[128].

New York University (NYU): In collaboration with Urban Future Lab, NYU has developed the Clean Start program, which is a one semester Certificate Program for students who want to transition into a career in cleantech[129]. In the program mid-career professionals from diverse industries acquire the knowledge and skills to work in a clean energy economy[130]. In addition to this, NYU currently has over 600 courses focused on sustainability and NYU awards $150.000 annually to innovative and entrepreneurial ideas within sustainability[131].

Columbia University: The Earth Institute at Columbia is an interdisciplinary approach to research within sustainability. Their research ranges from paleoclimatology to hands-on work with local governments to help improve their daily water supply. The institute offers numerous education programs that requires students to learn environmental science and social science along with applied policy and management analysis[132].

Yale University has in their science strategy laid out a strategic plan for STEM at Yale that will be implemented in the coming decade. Among the chosen scientific areas are environmental science and climate solutions. Research will be focused on climate change as a defining issue of our time and on carbon capture as one of the most overwhelming challenges within addressing climate change, as it is difficult to identify practical mechanisms to capture CO2 directly from the ambient atmosphere and to sequester it[133].

3.4 Private organizations in California

Privately funded corporate research play an important role in the research and innovation system of green technologies, and there is an endless number of interesting private organizations in the US and Californian green ecosystems. Broadly, some of the central private actors in California can be divided into accelerators and incubators, corporate ventures, and other financing models.

3.4.1 Examples of the different types of private actors

Accelerators/incubators	Corporates	Other financing models
Cyclotron Road	Oil and Gas Climate Initiative	Breakthrough Energy Ventures
New Energy Nexus	Energy Impact Partners	Bezoz' Earth Fund

3.4.2 Accelerators and incubators

Cyclotron Road and New Energy Nexus are examples of some of the most interesting accelerators and incubators relevant for the green transition in the Californian ecosystem. Cyclotron Road and New Energy Nexus are publicly co-founded and specialized in supporting clean energy startups. They will be described in detail. Other interesting accelerators and incubators in both the Californian ecosystem and beyond are e.g. The Wells Fargo Innovation Incubator, Elemental Accelerator, Powerhouse, Rocky Mountain Institute, and Clean Tech Open.

Cyclotron Road is a so-called fellowship program and a comprehensive approach to technical company building providing a path for scientists and engineers from academia to entrepreneurship in the area of energy hardware technologies. It was

created by Lawrence Berkeley National Laboratory in conjunction with DOE. The program addresses the gap between federal grants dollars for research and traditional early-stage investment, that typically requires a prototype to attract VC investments. The program allows early-stage hardware innovators the time and resources to de-risk their technologies while determining a pathway to market in order to attract more traditional forms of capital. Once accepted, fellows are granted access to Lawrence Berkeley National Lab and UC Berkeley facilities for two years, while receiving a generous stipend, extensive mentorship, entrepreneurial training, and networking opportunities. The program also leans on Berkeley's Haas School of Business for some business development of the Cyclotron Road projects. DOE and Activate recently expanded the Cyclotron Road commercialization model to two more national labs, making it a series of lab-embedded entrepreneurship program called LEEP nodes[134]. One of these new locations is in Boston in partnership with MIT Lincoln Laboratory. This is a step to scale the fellowship model to support a greater number of scientists and engineers within energy and climate. Traditionally MIT Lincoln Lab is working in the area of sensitive defense related research which to a certain extent makes international collaboration difficult but that remains to be seen, as the initiative is still very new[135].

New Energy Nexus is a California based global network of clean energy accelerators and incubators supported by CEC. They are focused on knowledge sharing, best practices and connections. They partner with and help organizations and governments build thriving startup ecosystems building on Californian experience[136]. New Energy Nexus runs accelerator programs, seed funds, and demonstration and pilot programs. New Energy Nexus runs the seed fund and accelerator CalSEED on behalf of California Energy Commission. CalSEED funds early-stage startups and entrepreneurs developing innovative clean technology solutions. In addition to funding, CalSEED provides access to technical expertise, test-facilities, mentoring, and business development training through its network of companies, nonprofits, universities, and clean energy incubators. Since 2017 CalSEED has granted $15 million[137]. CalCEF is the venture arm of New Energy Nexus, that finances clean energy solutions. CalCEF engages as a mission-aligned implementing partner to pilot clean energy solution financing[138]. New Energy Nexus runs programs in various countries and is open to international collaboration.

3.4.3 Corporates

Currently, we are witnessing some of the major tech, oil and gas, and utility companies driving developments in the green field[139]. Due to the size and global reach of these companies, their efforts can act as a catalyst for transition and emissions reductions in other industries, which are integrated in their supply chains.

Many tech companies are setting ambitious goals for clean energy consumption etc. within their business and are investing in and collaborating with green startups. Companies doing this are e.g. Amazon, Facebook, Apple, Salesforce, Microsoft, and Google. As an example, Amazon has signed the Climate Pledge, a commitment to meet the Paris Agreement 10 years early, and have invested in green startups, e.g. to develop an electric delivery van[140]. When tech companies adopt a green agenda, they become relevant green partners for Denmark – and Denmark becomes interesting for them, as we have seen with Google and Apple placing datacenters in Denmark where there's access to renewable energy and a cooler climate. The green policies of major tech companies also bring opportunities for Danish cleantech startups, as demonstrated by e.g. Googles recent collaboration with a Danish greentech company on maximizing use of renewable energy[141].

Oil majors are investing in clean energy as well. One example is Chevron Technology Ventures, that is highly visible in California. Since 1999, they have invested in six focus areas including e.g. water management, emerging materials, and power systems[142]. Many European oil companies are present in the US and California – one example is Shell. Shell has the Shell Gamechanger Accelerator in collaboration with National Renewable Energy Laboratory in Colorado[143]. This accelerator focuses on energy storage technologies to enable the grid of the future and will grant up to $250,000 in funding[144]. The gamechanger program works as a public-private partnership, leveraging the technical expertise and facilities at National Renewable Energy Lab. The Oil and Gas Climate Initiative is an example of major oil and gas companies gathering in a consortium to accelerate industry response to climate change. The initiative has a $1 billion fund investing in solutions to decarbonize oil and gas, industrials and commercial transport[145].

Utility companies are also investing in clean energy. E.g. Energy Impact Partners gathers 14 utility companies to back cutting-edge energy technology companies, and the fund has raised $681 million currently. In addition to alliances like Energy Impact Partners, utility companies are also launching their own corporate venture funds dedicated to clean energy innovation[146].

3.4.4 Other financing models

Green technologies often require 'patient capital' and benefit from different types of financing. In addition to government grants, strategic and venture capital investors, other types of funding are emerging. These include funds which specialize in investments with climate impact, such as Breakthrough Energy Ventures, founded by Bill Gates and other high net worth individuals, and philanthropic funds such as the new Earth Fund, established by Amazon founder Jeff Bezos.

Breakthrough Energy Ventures (BEV) is noteworthy in its size of $1 billion initial funding, its long 20 year investment horizon, its limited partners including Bill Gates, Jeff Bezos, and several other notable individuals, and its focus on technologies with the potential to reduce more than half a gigaton of annual CO2 emissions if deployed at scale. BEV is among top three investors in clean energy technologies in Silicon Valley within the last two years[147]. The longer time horizon allows BEV to invest in transformational technologies still in their nascency, while the size of the fund allows BEV to place many bets across sectors and levels of development. Their investment strategy links government-funded research to their patient, risk-tolerant capital. BEV has announced five grand challenges – in electricity, transportation, agriculture, manufacturing, and buildings – that jointly capture nearly all sources of greenhouse gas.

BEV-Europe was created in 2019 as a partnership between BEV and the European Commission. It is a £100 million pilot fund that invests in groundbreaking decarbonizing technologies. The partnership connects patient, flexible private-sector investors with a public sector committed to research and development to support Europe's clean energy innovators[148].

Bezos' Earth Fund was created on February 17th, 2020, when Amazon CEO Jeff Bezos pledged $10 billion to fight climate change. The fund is significant in the amount pledged. The fund will work to amplify known ways and to explore new ways of fighting impacts of climate change. The global initiative will fund scientists, activists, and NGO's with grants, that will begin being issued this summer[149].

Founded in 2001, **Angeleno Group** (AG) is a VC focusing on clean energy and climate solutions companies. AG invests in a range of deal types, with a strategy that is sector-focused and research-driven[150]. AG has become one of the largest dedicated clean energy growth equity investment firms in US and has specifically expressed an interest in the Nordic and Danish market both for lead generation for potential investment cases and for partners in the ongoing fundraising from Nordic players to a next fund of VC investment.

3.5 Private organizations in Massachusetts and on the North East Coast

Examples of central private actors in Massachusetts' and the North East Coast's research and innovation of green technologies can be divided into accelerators and incubators, and funds.

3.5.1 Accelerators and incubators

The Engine at MIT is an accelerator aimed at bridging the gap between discovery and commercialization for startups in tough science. Like Cyclotron Road in California, The Engine at MIT bridges the gap between federal research dollars and traditional capital. The Engine's model acknowledges that tough science and disruptive technologies need long-term capital, and that though tech companies have lacked funding from traditional VC's, as their technologies' road to market doesn't fit the traditional VC model. The Engine focuses exclusively on founders in the tough science areas including areas such as energy producing, energy conversion and storage[151]. The Engine launched in 2017 with investments in seven tough tech companies. It has since invested in 12 additional tough tech founding teams[152]. Together, these companies have raised approximately $285 million in capital and employ more than 200 people[153].

Greentown Labs is the largest clean technology incubator in North America, founded in 2010. Greentown Labs offers all the traditional services of an incubator such as space and equipment – they provide space for prototyping, offices, event space, a wet lab, electronics lab, and machine shop. In addition to this comes services for startups on an equity-free basis within legal, information technology, marketing and sales support, and a coveted network of corporations and industry investors[154]. Since its inception, Greentown has incubated more than 200 startups. MIT has played a pivotal role in starting Greentown 's success. About 60 percent of all the companies that have come through Greentown have direct ties to MIT[155].

The business model is payment and not taking equity, but Greentown Labs has developed Greentown Launch for Corporates to establish an accelerator model aimed at a specific technology areas or industry. The corporate partnerships accelerator enables corporates to engage with startups in the cleantech ecosystem to advance their sustainability goals, their external innovation strategies, and forge partnerships with industry-disrupting startups. Currently two Greentown Launch program are running in 2020 including a program sponsored by Vineyard Wind which is 50 owned by Copenhagen Infrastructure Partner (CIP). The accelerator program is called Offshore Wind Challenge and focused on advances in marine mammal monitoring, specifically for data collection and real-time transmission and data analysis.

Danish Cleantech Hub New York (DCH) is a public-private partnership, led by the Confederation of Danish Industry and State of Green. Since 2014 DCH has supported Danish cleantech solutions in New York through their network in New York. DCK organizes conferences, assist with collaboration agreements, and workshops to create awareness of Danish Cleantech solutions[156].

Urban Future Lab (UFL) is New York City's hub for smart cities, smart grid, and clean energy. UFL currently has incubated 58 companies and has raised $670M[157]. UFL has programs ranging from ACRE, a business incubation program for pre-seed to series A startups. PowerBridgeNY, a proof-of-concept center, helps identify early stage clean energy technology from institutional research labs and invests in commercializing the technology[158].

Nexus-NY is an accelerator program that helps startups at their earliest stages. The program aims to accelerate clean energy in startups in New York State. They help move research derived innovations from labs to the market. Nexus-NY is a 9-month program split in 2 phases[159]. The 1st phase consists of approximately 10 Business Discovery Teams that will develop and test numerous business hypotheses trough interaction with customers and industry participants. The 2nd phase consists of the teams building prototype while continuing building a relationship with potential customers and develop their go-to-market plans. Depending on the startups progress and availability of funds, Nexus-NY may offer seed investing.

3.5.2 Funds

Prime Coalition is a public charity based in Boston. Prime coalition mobilizes philanthropic dollars and invests as an early-stage, highly risk-tolerant VC fund with focus solely on technologies with potential to mitigate gigaton-scale CO2-equivalent emissions. The aim is to support cleantech startups in the process of de-risking technologies – in the gap between funding of scientific research and commercial technological development. This is accomplished through recoverable grants and program-related investments[160].

Clean Energy Venture Group (CEVG) is an investment group that provides seed capital and management expertise to early stage clean energy companies. CEVG covers New England and New York, where the New England group regularly meets in Cambridge[161]. They have a close cooperation with Clean Energy Ventures (CEV), who are responsible for their investments in early stage cleantech startups[162]. Many of the CEVG members are investors and venture partners in CEV. CEVG and CEV are working closely together in assessing deals.

ENI Next – the Italian oil giant Eni have established a venture capital firm in Boston, to take part of the green transition. In 2008 ENI engaged in a strategic collaboration with MIT, involving 100 researchers working on 40 energy transition-related projects[163]. In same year ENI spent $50 million to become a founding member of the MIT Energy Initiative[164]. They currently have invested in two companies from the Engine at MIT.

4. International organizations

This section will describe some of the most important international organizations and agreements that the US federal government, California and Massachusetts are part of regarding international energy technology cooperation.

4.1 US Science and Technology Agreements – an overview

The US has active umbrella science and technology agreements in force with 54 countries or regions[165]. One is the Science and Technology agreement with EU that has been in place since 1998 and is currently extended to 2023, with among others environment and non-nuclear energy as cooperation areas[166]. Individual agreements exist with 15 EU member countries, including Denmark. These agreements provide frameworks for science and technology cooperation, intellectual property protection, research access, and related topics but usually do not indicate explicit fields for cooperation. The most common area in these agreements is environmental and climate change, followed by energy, health, agriculture, and basic research[167].

4.2 US Federal participation in international organizations

The US government are part of several organizations on climate and energy cooperation. Important international organizations that Denmark also participate in (either directly or through the EU) are International Energy Agency (IEA), G7, G20, the Carbon Sequestration Leadership Forum (CSLF), the Clean Energy Ministerial (CEM) and Mission Innovation (MI)[168]. These are described more thoroughly below. Besides these that Denmark also participates in, the US also collaborate internationally on energy through the International Forum for Nuclear Energy Cooperation, Asia-Pacific Economic Cooperation, North American Energy Cooperation, and US-China Nuclear Energy Collaboration among others[169].

IEA (International Energy Agency) is an international energy forum with 30 countries and 8 associated countries, that among other foster multinational energy technology cooperation as both public and private partnerships. Both Denmark and the US are member countries[170]. IEA also hosts "The Energy Efficiency Hub" – a new platform for collaboration on energy efficiency[171].

CSLF (Carbon Sequestration Leadership Forum) is an international climate change initiative focused on development and deployment of cost-effective technologies for carbon capture and storage (CCS). CSLF's goal is to foster collaboration on R&D projects reflecting members' priorities and identifying areas of multilateral collaborations on CSS technologies among other. Denmark participates through the European Commission[172].

CEM (Clean Energy Ministerial) is a partnership of the world's leading economies

working together to accelerate the deployment of clean energy technologies by sharing best practices and promoting policies and programs that encourage clean energy. Both Denmark and the US are members[173].

MI (Mission Innovation) is an intergovernmental initiative working to accelerate clean energy innovation. Both Denmark and the US are members. Member countries have committed to double their public investments in clean energy R&D over five years from 2015. MI hosts Innovation Challenges that brings together interested member countries in international collaborations. The challenges cover the entire research spectrum from early-stage to demonstration projects[174].

The US-EU Energy Council is the primary forum regarding bilateral energy cooperation between EU and the US. It was launched in 2009 to deepen coordination on strategic energy issues of mutual interest and R&D cooperation. Collaboration activities concentrate on four priority areas: smart grids and energy storage, critical raw materials including for energy, fuel cell and hydrogen and nuclear fusion. In addition, the US and EU have dialogue on energy issues in international fora, such as IEA, CEM, CSLF, IRENA and Generation IV International Framework (GIF)[175].

4.3 California and Massachusetts' participation in international organizations

Being two of the more progressive states when it comes to renewable energy and climate, California and Massachusetts are members of some of the same organizations. These are the Under 2 MoU[176], the International ZEV Alliance[177], and United States Climate Alliance[178]. Denmark is not a member in any of these.

The Under 2 MoU is a global community of 118 state and regional governments that have signed a memorandum of understanding committing them to uphold the Paris Agreement. The group's work includes sharing policy initiatives and providing technical support to assist governments in developing long-term emission reduction plans. California is a founding member and Massachusetts was the 10th state to sign the under 2 MoU. Denmark endorses the initiative.

The International ZEV Alliance focuses on accelerating zero-emission vehicle (ZEV) deployment by expanding the global ZEV market and enhancing government cooperation on ZEV policies. California is a founding member and Massachusetts is a member. Other members are primarily from North America however a few European countries are members.

The United States Climate Alliance is a bipartisan coalition of 24 governors, including California and Massachusetts, committed to reduce emissions.
The alliance was founded by California, Washington and New York in the light of the current administration decision to withdraw the US from the Paris Agreement. The alliance's members commit to uphold the Paris Agreement and build state-to-state cooperation through the alliance to accelerate the deployment of climate solutions.

Besides the international organizations, California has signed several bilateral agreements and memorandums of understanding with other governments on climate change, including China (23 agreements), Mexico (12), Japan (4), the Netherlands

(4), Denmark (3), and others[179]. The three Danish agreements are elaborated in the next section (see 5.2.2).

Besides the international organizations, Massachusetts has bilateral MoU's within cleantech with Japan and Colombia. MoU's is a model for cooperation with Massachusetts and the MoU with Japan e.g. focuses on expanding the collaborations within life science, big data, clean energy, robotics and health care information technology. Massachusetts Life Sciences Center (MLSC), the Massachusetts Technology Collaborative (MassTech), and the Massachusetts Clean Energy Center (MassCEC) will be involved fulfilling the mission[180]. The agreement also allows for an increase in academic exchanges.

Lastly, it is worth mentioning that San Francisco, Los Angeles (and Copenhagen) are part of C40 that connects 94 of the world's cities to collaborate effectively and share knowledge that can drive climate action[181]. This illustrates that action not only happen at federal or state level – but cities and local utilities drive changes as well.

5. Opportunities for collaborations

This report has shown the breadth and strength of the US, California and Massachusetts' initiatives and programs working to promote clean energy research and innovation. This last section will present selected opportunities for research collaboration between Denmark and the US in the broad field of climate/energy technology. Firstly, we point out thematic areas with special potential for collaborations with California and Massachusetts. Secondly, we point out opportunities for collaborations in the US, in Denmark and through international organizations.

5.1 Thematic areas with collaboration potential in the US

Carbon capture, power-2-x, energy efficiency, and offshore wind – including system integration and workforce development – are four thematic areas with collaboration potentials based on the mutual interests from both Danish and American research and innovation actors as well as Danish private sector strongholds.

Carbon capture, utilization, and storage (CCUS) is receiving much attention in California. California's goal of carbon neutrality in 2045 has led to a focus on negative emissions – and thereby carbon capture, utilization, and storage. Many universities in the area research on CCUS, investors as Breakthrough Energy Ventures and Oil and Gas Climate Initiative invest in CCUS, and several projects and companies develop carbon capture technology throughout California. One example is Elk Hills Power that is developing a large carbon capture project in connection to a natural gas plant to remove approximately 1.5 million mt/year from the natural gas plant starting in 2024. This specific natural gas plant accounts for more than half of California's natural gas production[182]. California is an attractive place for carbon capture projects with policies[f] providing additional revenue sources[183]. While there are interesting initiatives under development in Denmark, carbon capture is today not a strength in the Danish research community. It is an important area in the discussion of negative emissions in relation to reduction of greenhouse gas emissions and is very likely to gain a broad interest going forward, not least in the light of the Danish Climate Council's recommendations. California could be an interesting collaboration partner on carbon capture.

Green hydrogen and power-2-X is another area receiving much attention in California as well as Denmark. Danish stakeholders in academia (DTU, AAU and AU) as well as stakeholders in industry have specialized in a range of technologies based on electrolysis over decades. California is also quite far advanced when it comes to energy storage and conversion. An example of California's ambitions within green

[f] Policies providing additional revenue sources for carbon capture projects are the Cap-and-Trade program and the Low Carbon Fuel Standard in California. These are in addition to the federal carbon capture tax credit (45Q).

hydrogen is Los Angeles' municipal utility, that is converting a power plant from coal to natural gas, to 100 percent hydrogen by 2045. Operations will begin in 2025 with 30 percent hydrogen on day one of operations. This will be the first power plant in the world to run on 100 percent green hydrogen produced through electrolysis[184] and could be of interest for Danish companies. Aarhus University and Haldor Topsøe are also building a demonstration project of CO2 neutral methanol from Biogas and green electricity, which potentially could be exported to the USA[185].
Different end-applications of green hydrogen are interesting as well, e.g. also the production of ammonia. Demonstration of a large-scale ammonia production facility (which is not a feasible business case in Denmark due to too little demand for the end product) could potentially be relevant in California due to the large agriculture sector and thus large number of potential end users.

Energy efficiency is a priority in both Danish and Californian research and innovation of green technologies, and Massachusetts and California rank 1st and 2nd of US states on energy efficiency[186]. UC Davis currently has centers for energy efficiency and water technologies, and they are planning to expand with a center focusing on decarbonization of industries. The new center is seeking international collaboration; in both exchange of students and researchers as well as more strategic collaborations/joint funding. The center will do both applied research and demonstration projects focused on reducing the carbon footprint of industrial processes, e.g. through heat regeneration, efficient cooling systems, energy management systems, process management, and electrification of industrial processes. The Danish Energy Agency is currently collaborating with CEC on energy efficiency in tandem with Trade Council efforts to promote Danish cleantech solutions and increased research collaborations in the area could support these joint efforts.

Offshore wind is a focus in Massachusetts and California. In Californian the potential for offshore wind energy likely depends on the development of floating foundations for wind turbines[187]. Whereas offshore wind along the US East Coast is being installed with the use of fixed foundations because of the shallower waters. Denmark already has a strong presence in the US offshore wind sector and that role could be expanded in the development of offshore wind in the US in four areas especially; 1) modelling and forecasting, 2) marine biology and ocean bottom, 3) system integration, and 4) workforce development. On modelling and forecasting models e.g. DTU has competences, on marine biology experience from The North Sea can be applied, and Danish researchers have significant experience in simulating integration of large wind farms on the electric grid. Increased research collaboration in this area can support The Danish Energy Agency's work with California's Energy Commission on offshore wind, which in collaboration with Trade Council Denmark also serves to pave the way for Danish exports.

On the US North East Coast, the main research and industry partners are concentrated in Boston, New York, and Virginia. Laboratories are concentrated in Maine (floating), Boston (blades), Woods Hole (air-sea interaction), Rhode Island (jacket support structures), Virginia (monopiles), and Charleston, SC (drive trains and electricity grids). All along the US North East Coast, offshore wind energy has emerged as a promising alternative to traditional onshore wind farming. Massachusetts has been the pioneer in the offering large scale offshore wind project to developer and currently the is a vast number of planned projects along the East Coast from Maine, Massachusetts, Rhode Island, Connecticut, New York and New Jersey. Many of these

projects one way or the other have Danish players involved, either as developers, Wind Turbine manufactures or subcontractors.

Like all large scale fluctuating renewable generation offshore wind also comes with challenges, which also creates possibilities for collaboration in system integration and workforce development.

System integration. Unprecedented challenges and opportunities are arising in the US with the increasing penetration of Distributed Energy Resources (DER) connected to the power grid, particularly in terms of better understanding modelling and assessing their interaction with distribution and transmission grids as well as new market arrangements. As conventional power generation is displaced by cheaper renewable generation, there is often a concern about how to incentivize and enable the necessary services and flexibility to maintain power system security. The grid integration of variable renewable energy resources involves different aspects of power system planning and operation, which starts from long-term energy systems planning to power-2-X, sector coupling and energy storage solutions.

Digitalization, Flexibility and AI will play a major role on coping with the challenges that will arise from increasing share of renewable energy in the grid. Danish researchers have significant knowledge regarding the challenges and opportunities for the development and operation of clean, competitive and secure energy systems with significant share of renewable energy sources. A knowledge that can be deployed several places in US which undergo a significant shift in the energy mix like e.g. New England.

Workforce development The offshore wind industry is a new industry in New England and it demands a significant skilled and trained workforce; especially during the years of wind farm installations it requires skills ranging from vessels and cranes operators, and wind technicians with mechanical or electrical qualifications to engineers specializing in construction and grid maintenance and operation. Other parts of US can to a certain degree attract workforce from other offshore industries (like oil and gas) but these are not relevant in the North East of US. Consequently, a large share of the work is done with European labor force. The North East Coast states are increasingly looking at the potential for building up a new industry and has in several cases made it a prerequisite for an offshore wind turbine project that a specific share of the work must be done using US workforce. This opens for a potential in training and education by Danish educational institutions that have a long experience in setting up such courses and programs.

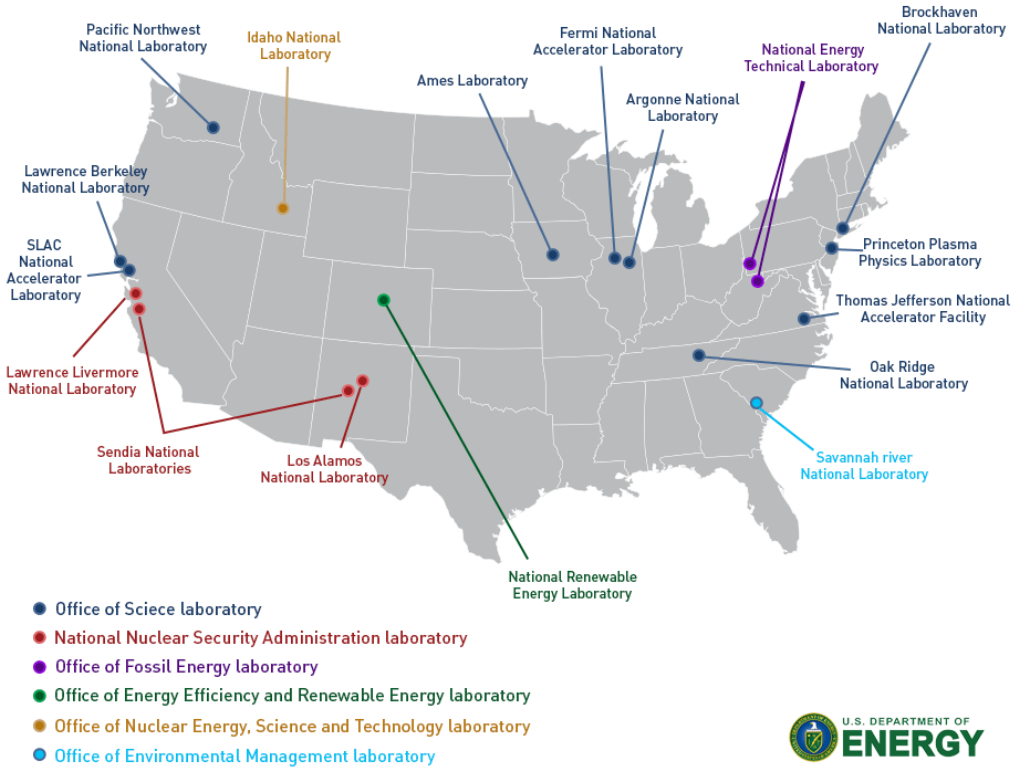
5.2 Opportunities for collaborations in the US

5.2.1 Federal opportunities for collaborations

There is an ongoing dialogue with DOE about modes of collaboration. These could include collaboration with ARPA-E or EERE (Office of Energy and Efficiency and Renewable Energy) on e.g. joint funding schemes or collaboration with the national labs such as National Renewable Energy Laboratory (NREL) and /or Lawrence Berkeley National Lab. A collaboration with DOE could potentially engage with the above-mentioned thematic areas. Another concrete idea is to establish joint funding mechanisms for DOE grants (for the US side) and EUDP grants (for the Danish side), which could support research collaborations.

DOE's national labs have a range of facilities making them relevant for collaborations from a Danish perspective. It is possible to collaborate with DOE's 17 national laboratories both regarding research and development. There are a variety of ways to partner with the labs and access their facilities when the participant pays the costs. One is through a cooperative research and development agreement (CRADA), where you partner with the lab and share the results of a jointly conducted research and development project[188]. In California, there is Lawrence Livermore National Lab, SLAC National Accelerator Lab and Lawrence Berkeley National Lab. Within climate, Lawrence Berkeley National Lab focusses on earth and environmental sciences, energy sciences and energy technology[189], and has many activities, including e.g. partnering with Activate to run Cyclotron Road and leading a DOE energy innovation hub for water innovation[190]. Besides the three in California, a highly relevant national lab is National Renewable Energy Lab, that focusses on renewable energy, energy efficiency technologies, sustainable transportation, and energy system integration[191]. NSF's AccelNet and PIRE programs could potentially fund these collaborations with national labs or energy innovation hubs.

DOE national labs



[g]

Partnership with ARPA-E could be relevant for Denmark as well. Internationals can apply for ARPA-E funding through project teams or consortiums, but funding of projects is restricted to projects carried out in the US[192]. Danish stakeholders can participate in their annual Energy Innovation Summits. They bring together entrepreneurs, media, government, academia, industry, and investors from different countries to think about energy challenges in new ways. 2019 included keynote speakers

[g] Photo from https://clearpath.org/policy/innovation/

from e.g. MIT, National Renewable Energy Laboratory, and several corporates[193].

5.2.2 Opportunities for collaborations in California

Denmark has three Memoranda of Understanding with California within water technology, offshore wind, and energy efficiency respectively. These are platforms for combining technical/regulatory, export and research collaboration, as all three have potential research collaboration written into the agreements. The MoU on energy efficiency further mentions sharing best-practices for e.g. market-based approaches to stimulate the adoption of new technology in housing units[194]. The current MoU in offshore wind is open to include other areas in the collaboration, e.g. R&D in marine biology, birdlife, windmill foundations, grid-connection and integration, wind forecasting, etc.

An example of a collaboration originating from our MoUs with California is GAP – California, a three-year groundwater architecture project, where Stanford University partners with leading Danish companies and three water agencies in California to develop a template for an optimal workflow using airborne electromagnetic (AEM) data as the foundation for developing hydrogeological conceptual models[195]. This collaboration has supported the successful work of the Trade Council to promote Danish water solutions in California.

Californian and US universities present opportunities for collaboration as well. Firstly, much research collaboration happens informally between researchers. Within the last 10 years, there have been more than 3000 US-DK co-publications in the field of Environmental Science, almost 2000 in material science and more than 1000 in energy[h]. Besides these informal collaborations, there are possibilities for formal research collaborations. The existing collaboration with CITRIS provides access to UC Berkeley, UC Davis, UC Santa Cruz, and UC Merced that all work with energy and environment[196]. The collaboration with SUNCAT at Stanford also gives access for Danish researchers. At Stanford University, Precourt (mentioned earlier) runs a project on the Sustainable Campus, which also could be of interest to Danish universities who are reducing the carbon footprint of campuses. Furthermore, Precourt researchers are also interested in collaboration on energy systems integration research as well as research on second life batteries (reuse and rejuvenation of batteries; designing for reuse and circular economy of batteries).

The Californian ecosystem offers many opportunities for cooperation, learning fro best practices, and potentially attracting investments, which could strengthen Danish efforts to establish Denmark as a global green hub with strong international links. For example, the California based Cyclotron Road, which offers access to ressources, lab space, training, and key Silicon Valley investors, is interesting from a Danish perspective[197]. The 2018 cohort of Cyclotron Road included a startup, Noon Energy, which is based on technology developed at DTU[198]. Cyclotron Road is interested in deploying the method in Europe, and it could be considered to establish the model in Denmark. In general, there is ample opportunities for leveraging Danish economic diplomacy and research collaboration combined with Danish innovation and growth funding programs to assist in commercialization and scaling of Danish cleantech research and startups via the ecosystem in Silicon Valley. Danish instruments, such as EUDP, could likewise be leveraged for joint demonstration projects, which could also

[h] Search on SCOPUS for publications affiliated to US and Denmark since 2010.

pave the way for exports of Danish cleantech solutions.

5.2.3 East Coast opportunities for collaborations

Several Massachusetts research institutions with complementary expertise has established the Massachusetts Research Partnership in Offshore Wind (MRP) in the summer of 2016. Two factors that led to the creation of the MRP were the presence of important offshore wind research assets in Massachusetts—such as the Wind Technology Testing Center and the timing of Massachusetts' emerging commercial-scale offshore wind market.

The MRP consists of seven Massachusetts research institutions: Northeastern University; Tufts University; the University of Massachusetts Amherst, Boston, Dartmouth, and Lowell; and the Woods Hole Oceanographic Institution. The state financed MassCEC provided funding to the MRP to consider and articulate the role of the research sector in achieving state and national clean energy goals, and to develop a multidisciplinary framework for offshore wind energy research and innovation.

In order to develop a multidisciplinary framework, the MRP has engaged in discussions with institutions throughout the United States, Europe, and Asia. In particular, MRP has expressed interest in forming a closer contact with Danish research institutions and Danish Wind industry. Potential areas of interest from US side are land-based and offshore wind; civil infrastructure; ocean and atmospheric science; and fisheries, policy, and economics. The discussion with US partners has initiated the Partnership for Offshore Wind Energy Research (POWER-US). For more see 3.4.

5.3 Two examples of what Denmark has to offer in terms of unique research infrastructure and knowledge

In certain areas Denmark attract attention from US actors – two examples are the new ESS facility and sustainable energy islands. This provides opportunities for collaborations.

An new opportunity for Danish collaborations with the US is introduced with the new European Spallation Source (ESS) facility in Lund and the Data Management and Software Center in Copenhagen, that is expected to attract international researchers, and is already on the radar of many US research groups in the energy field. The ESS facility will enable new knowledge about the structure and dynamic properties of materials, which play a key role in finding new climate, energy and transport solutions. It is expected to attract researchers in the field of material technology etc. to Sweden and Denmark[199]. The US often participate in large-scale research infrastructure programs like this, as they did with their contribution to CERN and the international space station[200], why it is likely that US researchers will be interested in participating in projects at ESS.

Another opportunity for Danish collaborations with the US arises from Danish expertise on sustainable energy islands. Bornholm and Samsø came in 1st and 2nd in EU's Horizon 2020 "Responsible Island Prize", and through Bornholm and Samsø Denmark possess substantial knowledge on sustainable energy islands[201]. This knowledge can be exported to other areas, as seen with the current successful Danish collaboration with Indonesia[202]. Besides Indonesia's islands, the knowledge on sustainable microgrids from Danish islands could be transferred to remote areas in the US, as

remote areas are similar to islands regarding energy infrastructure and have many of the same characteristics. Wildfires in California have resulted in increased interest in microgrids and resilience – in both remote areas and cities. Danish expertise can provide resilience in remote communities' microgrids.

5.4 International organizations facilitating collaborations

International Energy Agency (IEA) and Mission Innovation (MI) are two international organizations with potential to facilitate collaboration between the US and Denmark.

IEA facilitate extensive international collaborations between member countries on energy. IEA's platform for cooperation is a series of Technology Collaboration Programs. DOE and its national labs engage in multilateral science and technology cooperation through IEA, and the US participates in 37 of 40 TCPs[203]. EUDP can finance Danish businesses and knowledge institutions' participation in joint projects through IEA[204].

Collaborations between Denmark and the US is also possible through Mission Innovation's Innovation Challenges. Since 2015, Mission Innovation members have created 59 new international collaborations and delivered $1,3 billion funding for joint research projects – Denmark has participated in 6 international research activities[205].

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