Sabancı Üniversitesi

IICEC SABANCI UNIVERSITY ISTANBUL INTERNATIONAL CENTER FOR ENERGY AND CLIMATE

Exploring Rapidly Changing Energy System

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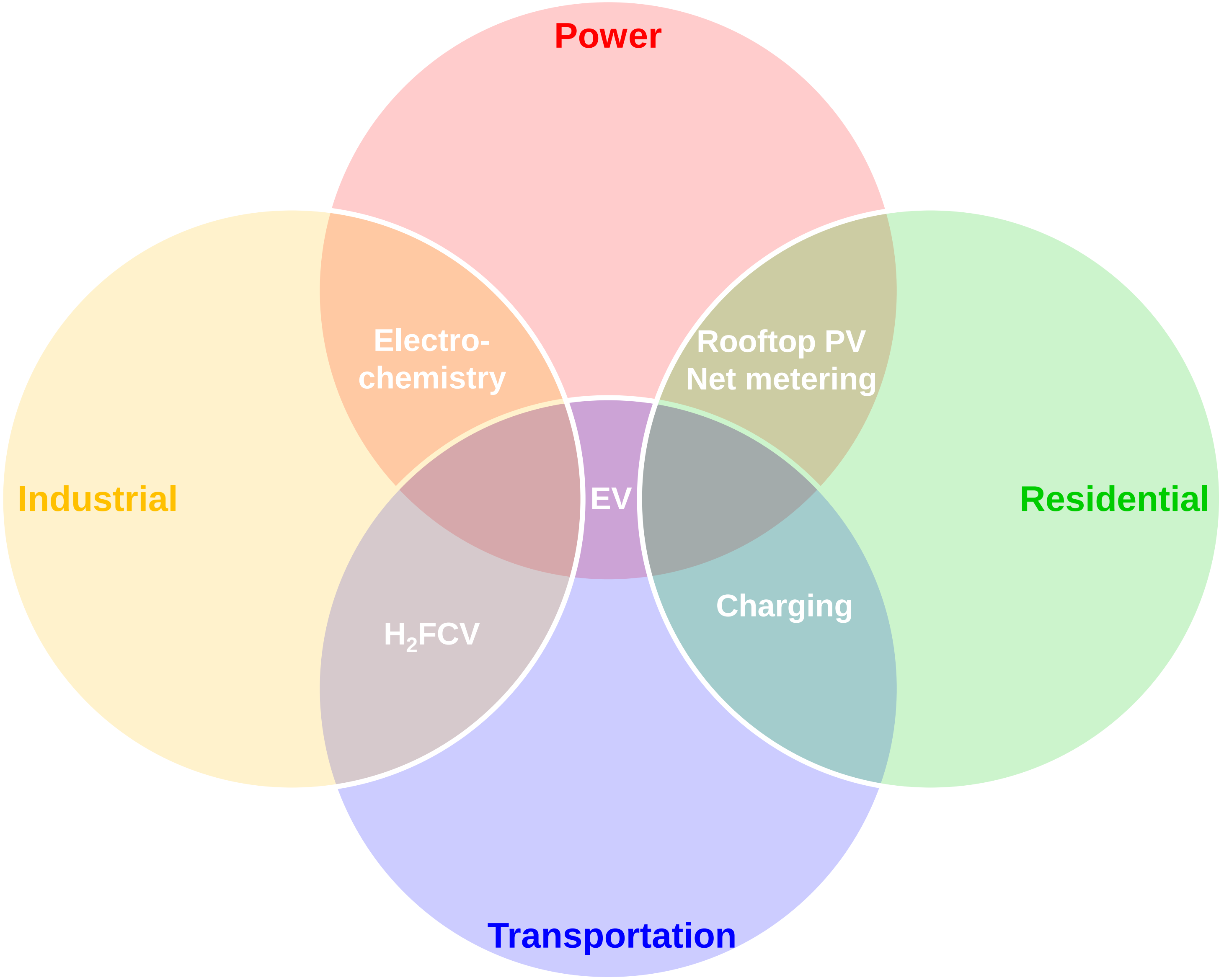
Outline

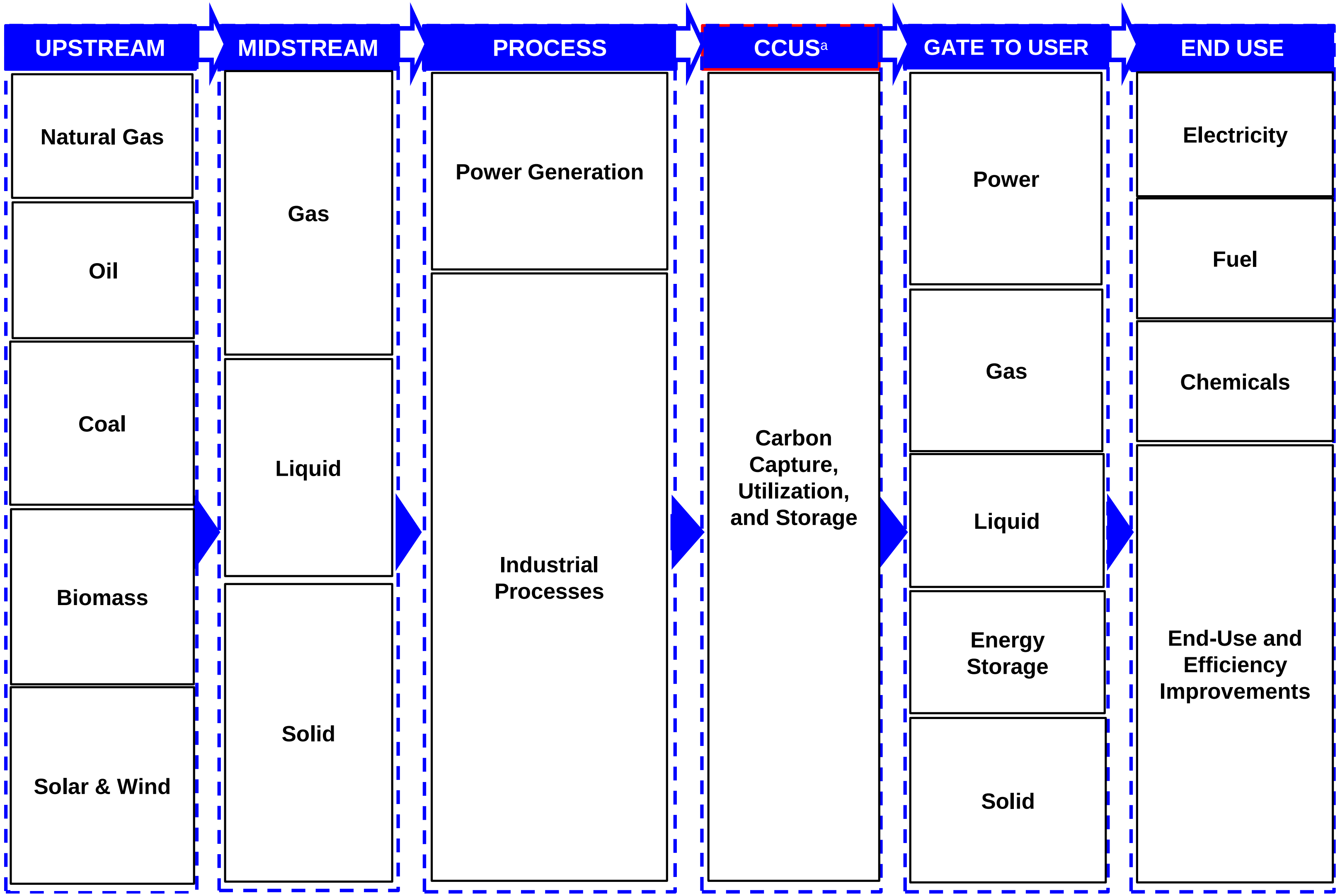
- Energy Transition
- Incorporating Systems Approach
- Environmental Impact of Renewables
    - Examples from California: Operational changes of existing NG plants
- Status of Carbon Capture, Utilization, and Storage
- Hydrogen for Deep Decarbonization

Energy Transition: Meeting growing demand while reducing carbon emissions

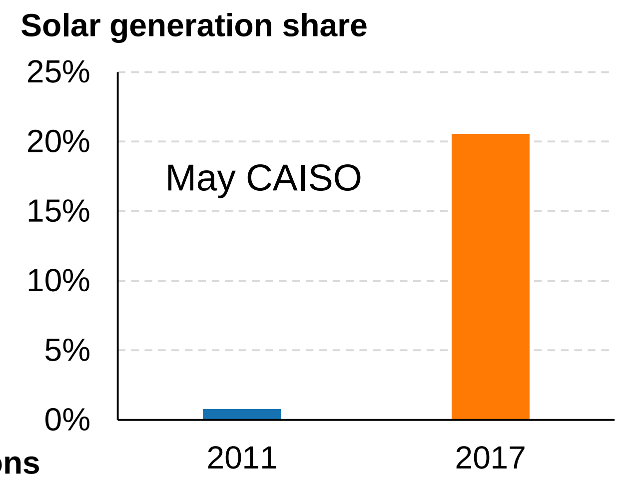
Today's energy systems are undergoing major transformations, which are leading towards greater convergence and inter-sectoral integration – Understanding the implications of these dynamics requires novel tools that provide deep systems-level insights

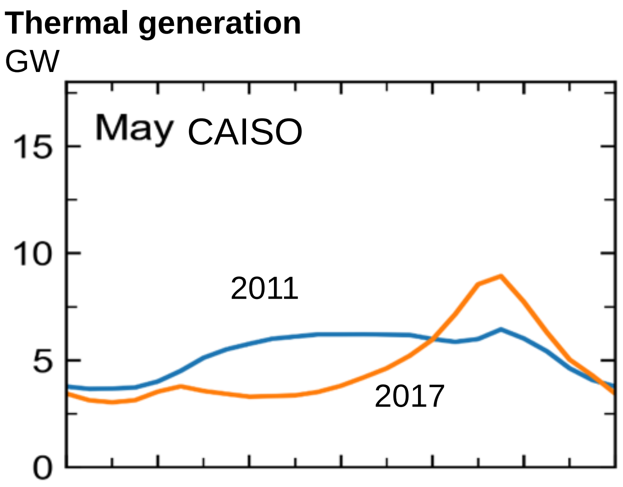


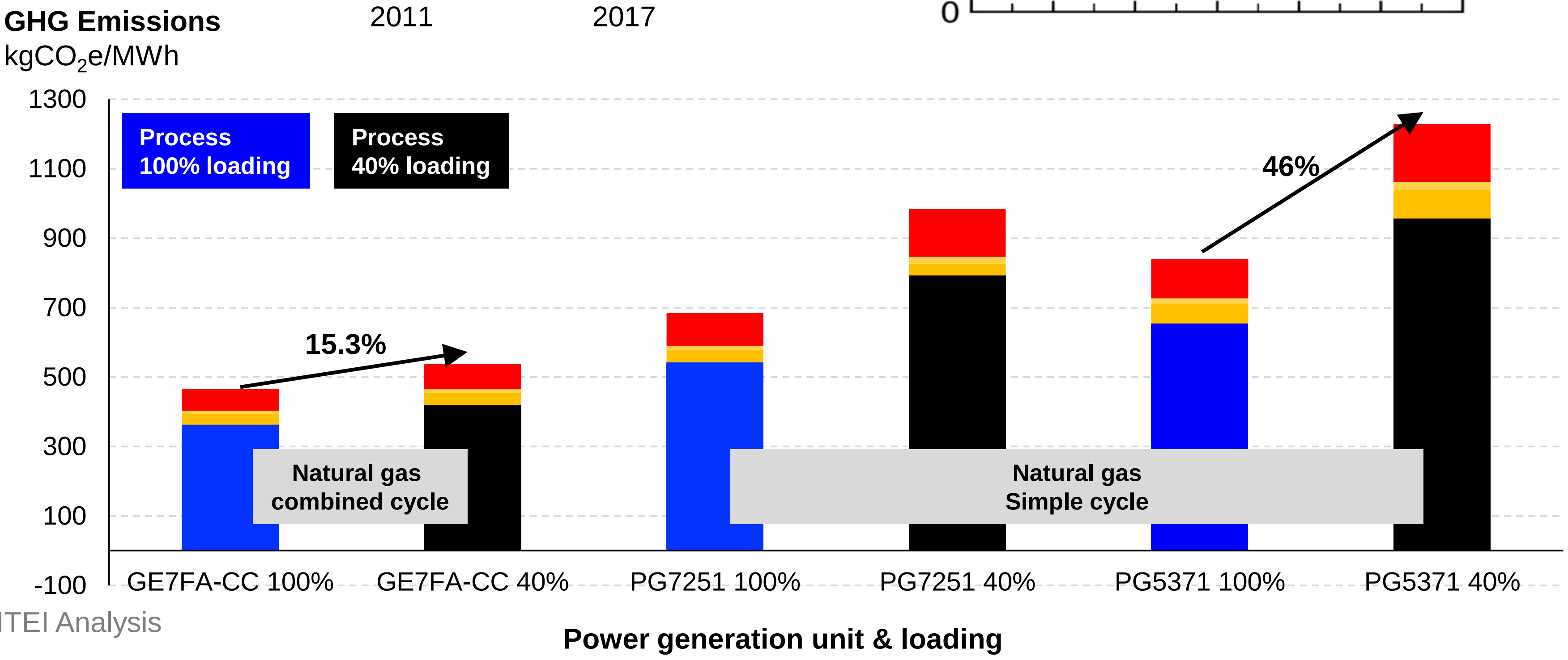
To address this pressing need, we have developed a novel systems-level technology assessment tool to understand the impact of all relevant technological, operational, temporal and geospatial variables to the evolving energy system



The growing penetration of renewable resources like solar PV on the power system significantly impacts plant-level operations – These dynamics have a range of complex consequence that our tool can help quantify







Bringing clarity to the real carbon footprint of renewable power technologies is also increasingly important

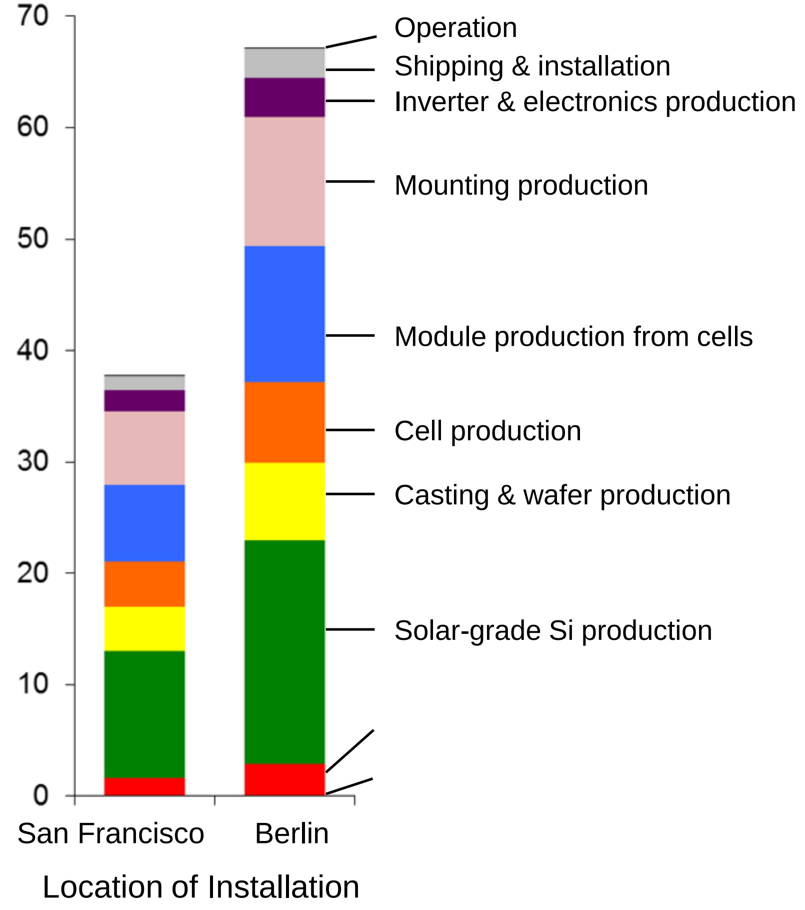
Example snapshot of our PV LCA tool

User Interface

What would you like to compare?		
Input	**Scenario 1**	**Scenario 2**
Location of installation	US (San Francisco)	Germany (Berlin)
Cell type	multi crystal Si	multi crystal Si
Installation type	rooftop, typical tilt	rooftop, optimal tilt
Shading losses	2.5%	2.5%
Lifetime (yr)	30	30
Efficiency, STC* rated	16.0%	16.0%
Degradation rate (/yr)	0.7%	0.7%
Inverter loading ratio	1	1
GHG emissions of electricity used to make panels (g-CO_2-e / kWh)	660	660
GHG emissions of electricity used to make BOS** (g-CO_2-e / kWh)	310	480
If multi-Si, panel prod. typical of:	China	China
Shipping distance from panel production to installation (km)	8690	17300
Output, lifetime average	**Scenario 1**	**Scenario 2**
Life cycle GHG emissions (g-CO_2-e /kWh)	39.6	66.7
Capacity factor, AC	15.2%	9.1%
AC power per panel area (W/m²)	24.4	14.6
Incident irradiance (kWh/m²/yr)	1803	1071
Panel prod. typical of:	China	China

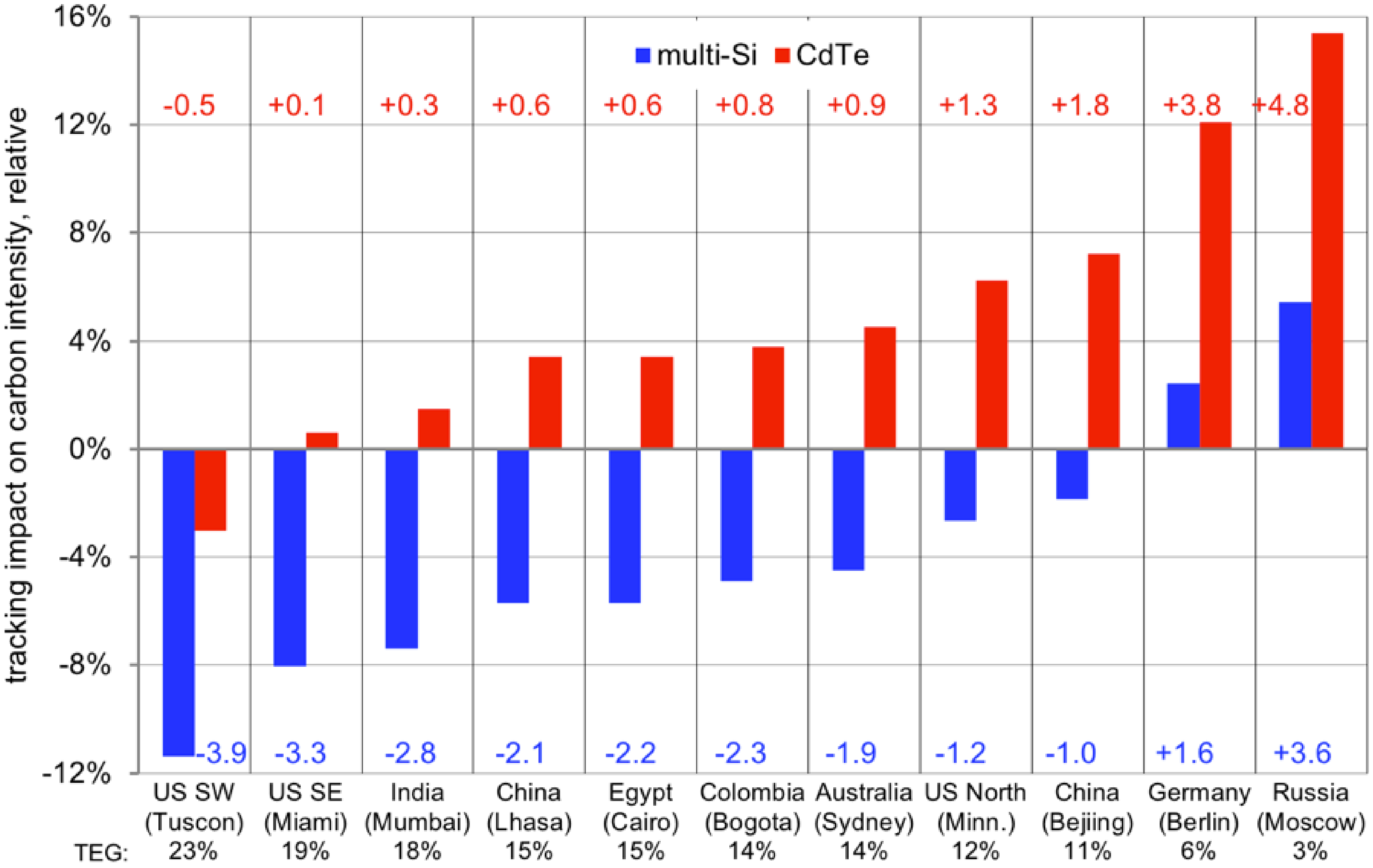
* Standard Test Condition
** Balance of system

Life cycle GHG emissions
kg CO_2e/MWh



Sources: MITEI Analysis

Tracking's impact on carbon intensity ranges from -12% to +12% - (1) Cloudier or higher latitude → more diffuse light → less power gain from tracking, (2) More module prod. emissions (mc-Si > CdTe) → greater reduction in carbon intensity

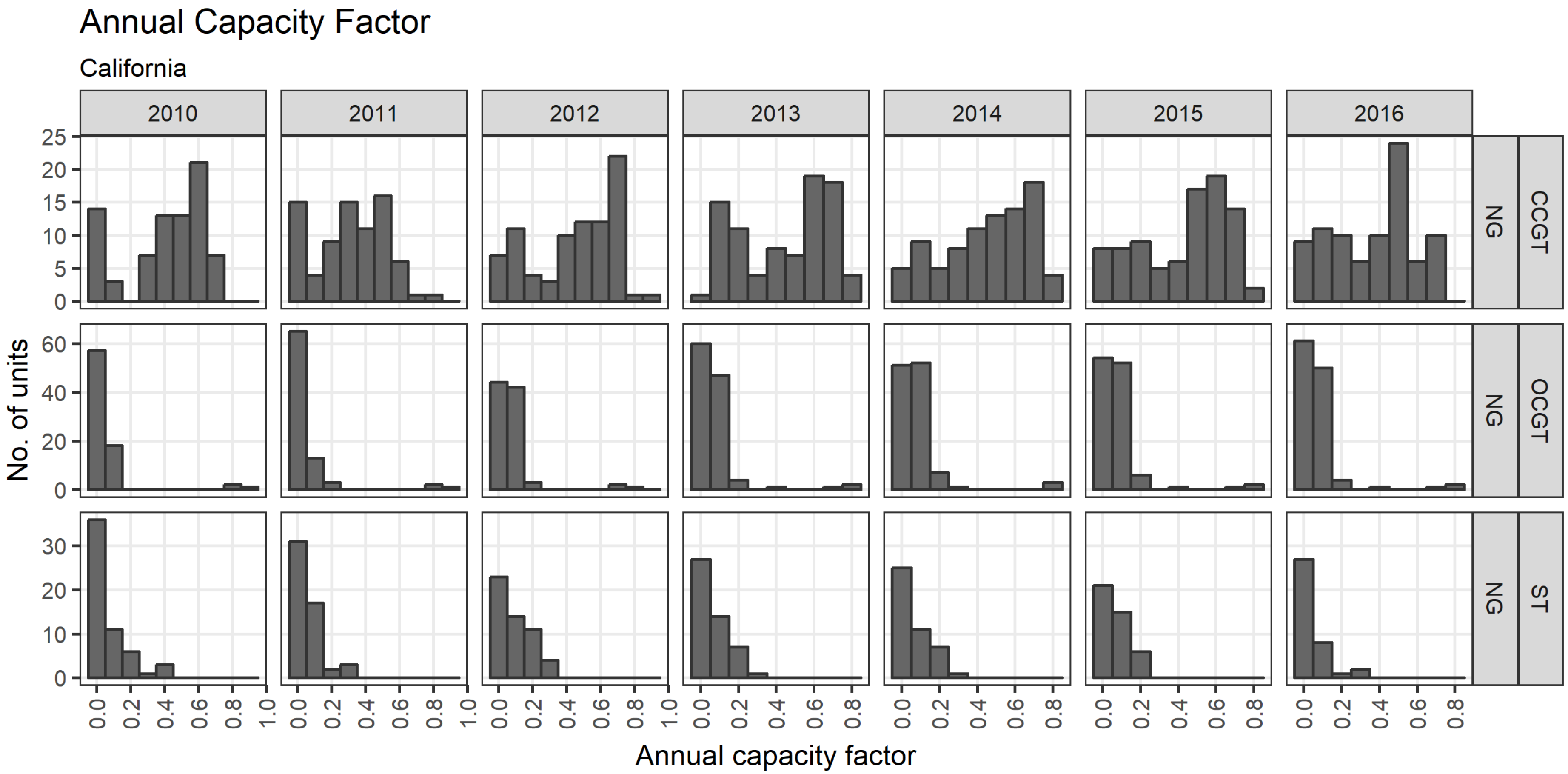


Sources: MITEI Analysis, Miller et. al. *Applied Energy* 2019.

Estimating the net impact of higher renewable power penetration is quite challenging – Has solar boom in California achieved its maximum emission reduction potential?

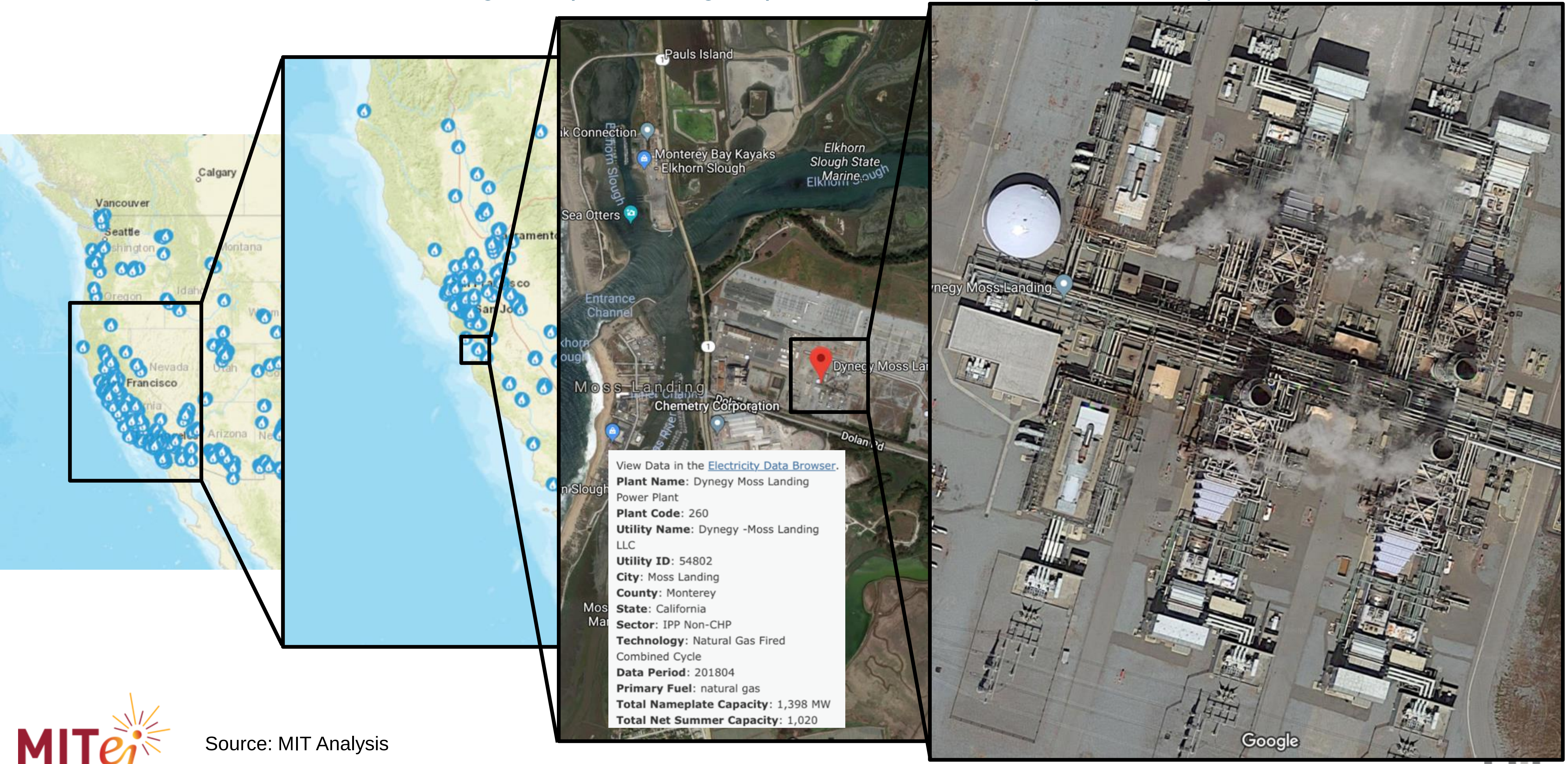
Sources: MITEI Analysis

There is a considerable alteration in how the natural gas power plants have been dispatched over the last decade



Sources: MITEI Analysis

Aggregate fleet wide studies are incapable of capturing the real world dynamics – For accurate characterization, high temporal and geospatial resolution analysis must be performed

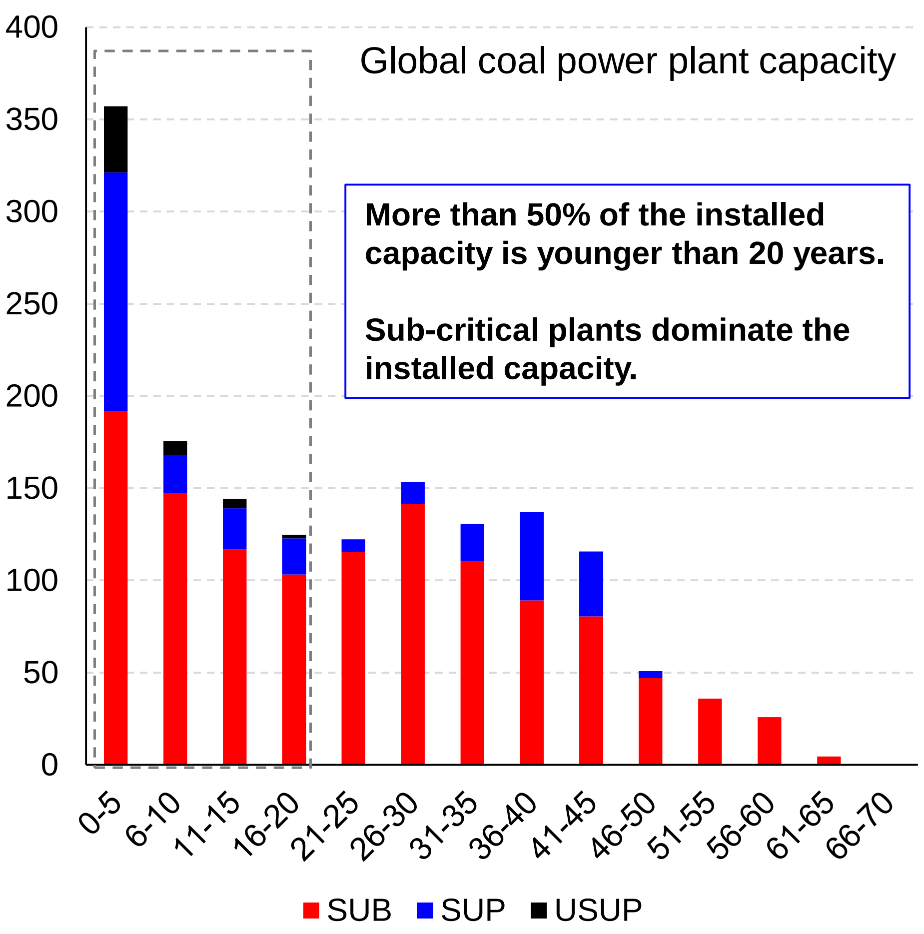


Source: MIT Analysis

By executing the analysis at hourly generator level resolution the main causes of the deviation from the optimum performance of the units are identified - Higher number of start-ups and more frequent cycling with a profile shift in time of the day are

Although we are seeing real growth in low carbon capacity, the global coal fleet remains large and relatively young – Today, coal supplies ~40% of total electricity from a fleet made up of ~1,600 GWs

Installed new capacity per age segment
GW



Installed new capacity per age segment
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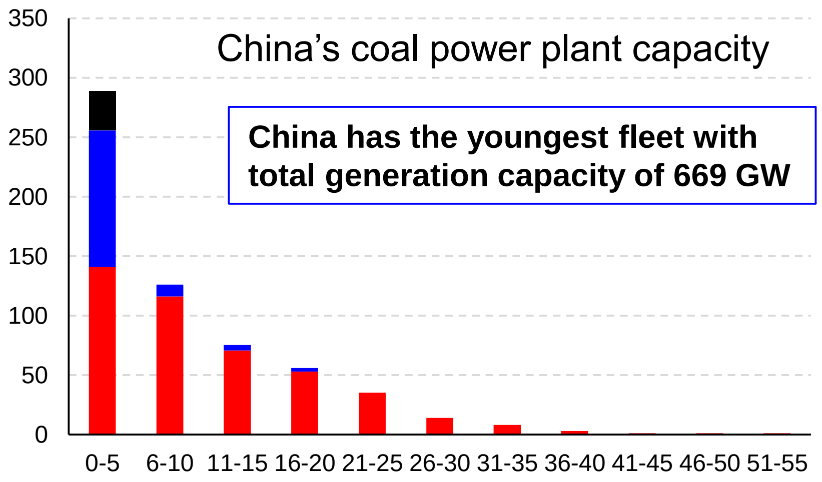
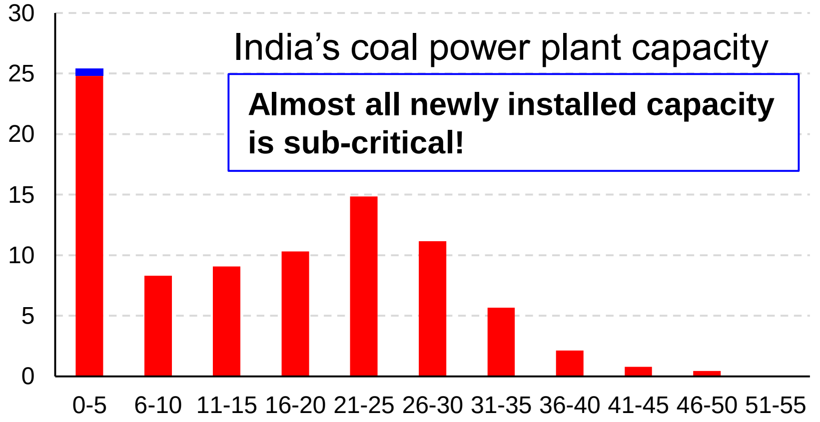




Source: IEA, CCS Retrofit, 2012.

Relative to the profound growth witnessed with renewables deployment, CCS has really struggled to gain any momentum – Today's deployment reality vastly deviates from targets

Current

32 $MtCO_2$/year

\$60/ton CO_2 captured[3]

25%-35% (HHV)[4]

Total planned

74 $MtCO_2$/year

Target

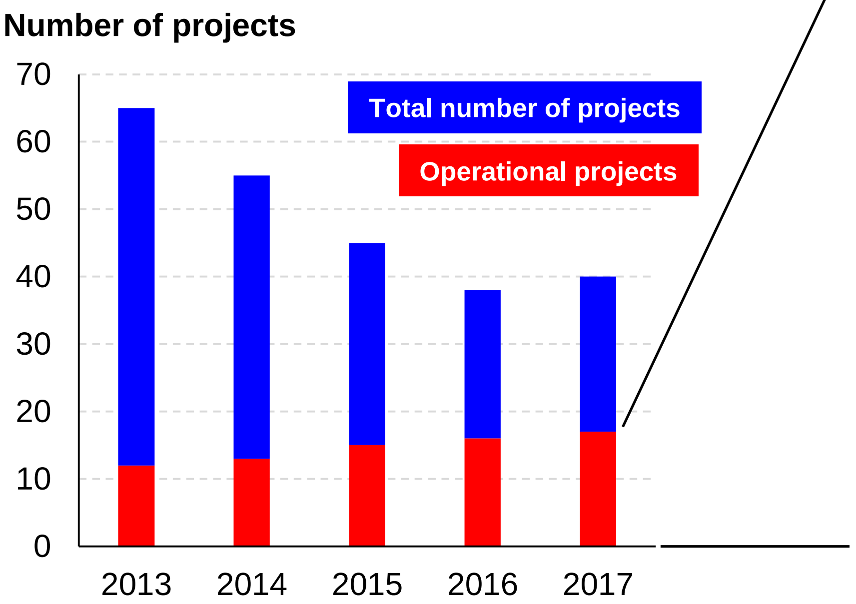
4 $GtCO_2$/y by 2040[2]

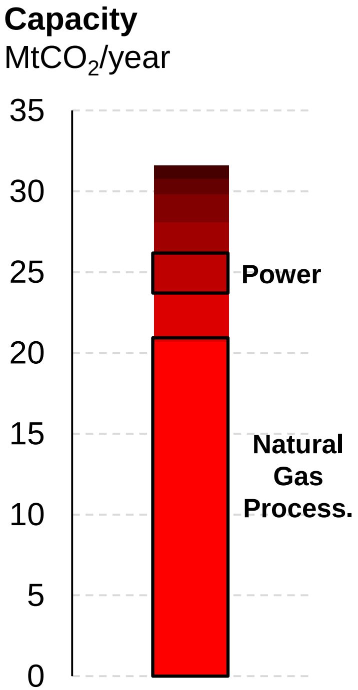
\$10/ton CO_2 capt. by 2035

43%-56% (HHV) in 2035

Missed Targets

2.6-4.9 $GtCO_2$/y by 2020[1]





Target: 125x capacity increase in 20 years!

Plan: 2.3x capacity increase in 8 years!

Sources: [1]EIA, International Energy Outlook, 2005. [2]IEA, Energy Technology Perspective, 2015. [3]DOE-NETL, Carbon Capture Tech. Program Plan, 2013. [4]IEA, Emission Reduction Thru Upgrade of Coal-Fired Power Plants, 2014. Global CCS Institute Project Database, 2017

The majority of today's operational CCS facilities are linked to gas processing and this accounts for 20 $MtCO_2$/year of the capacity – Only two power plants have an operational CCS element

Val Verde
Natural gas processing
EOR
1972

Enid
Fertilizer production
EOR
1982

Shute Creek
Natural gas processing
EOR
1986

Sleipner
Natural gas processing
Dedicated
1996

Great Plains
Synthetic gas production
EOR
2000

In Salah
Natural gas processing
Dedicated
2004

Snøhvit
Natural gas processing
Dedicated
2008

Century Plant
Natural gas processing
EOR
2010

Coffeyville
Fertilizer production
EOR
2013

Lost Cabin
Natural gas processing
EOR
2013

Petrobas Lula
Natural gas processing
EOR
2013

Air Products
Hydrogen production
EOR
2013

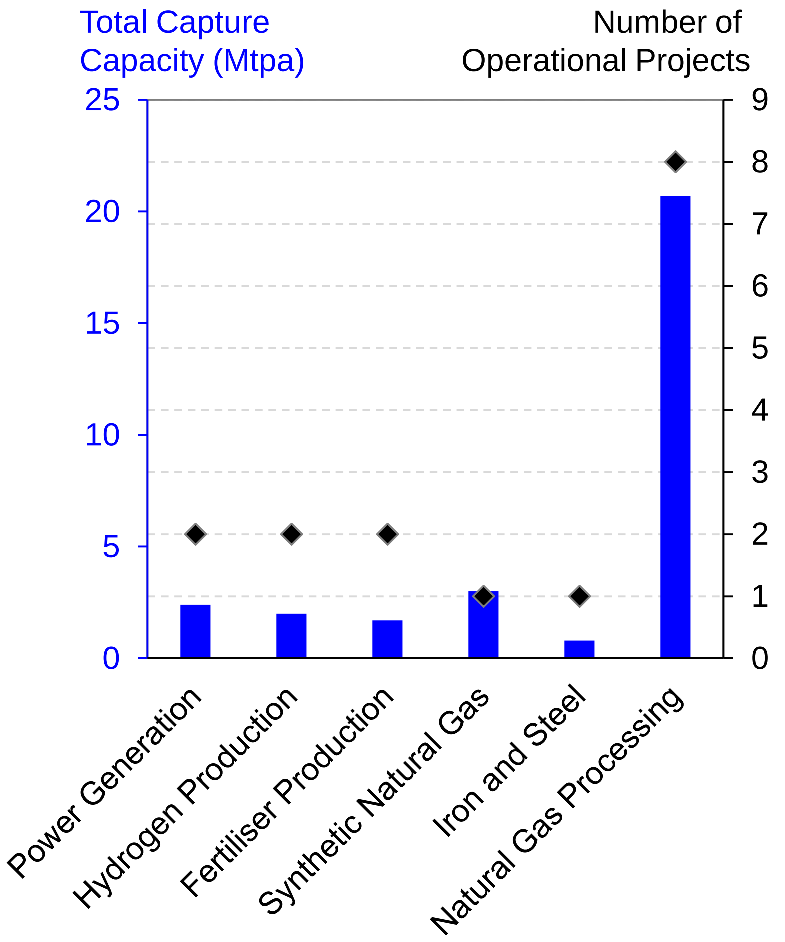
Boundary Dam
Power generation
EOR
2014

Quest
Hydrogen production
Dedicated
2015

Uthmaniyah
Natural gas processing
EOR
2015

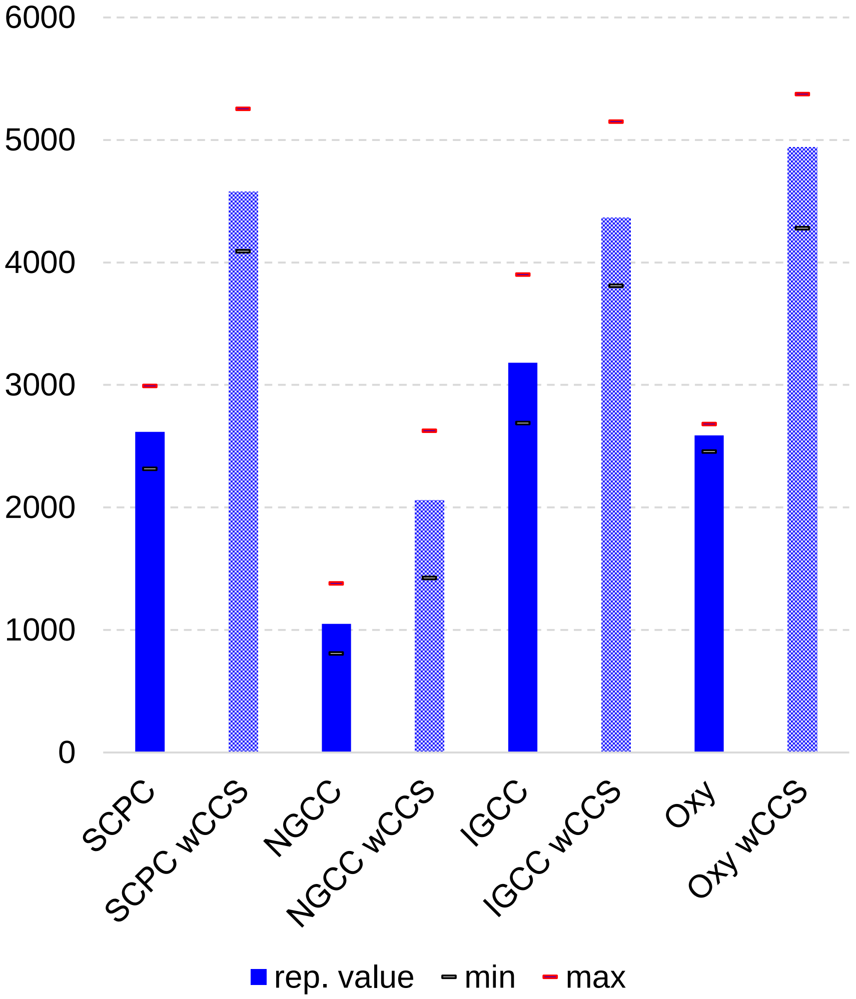
Abu Dhabi
Iron and Steel production
EOR
2016

Petro Nova
Power generation
EOR
2017

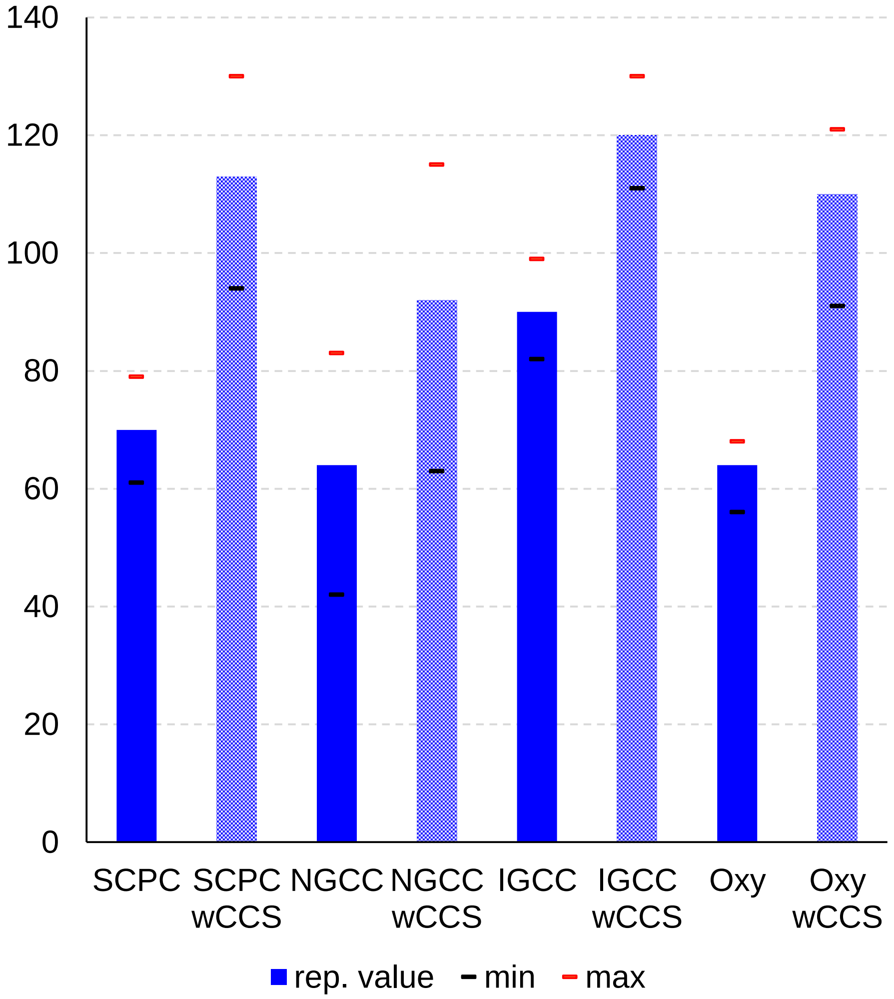


The relative cost of integrating CCS remains an enormous hurdle for the technology

Total capital requirement
USD/kW

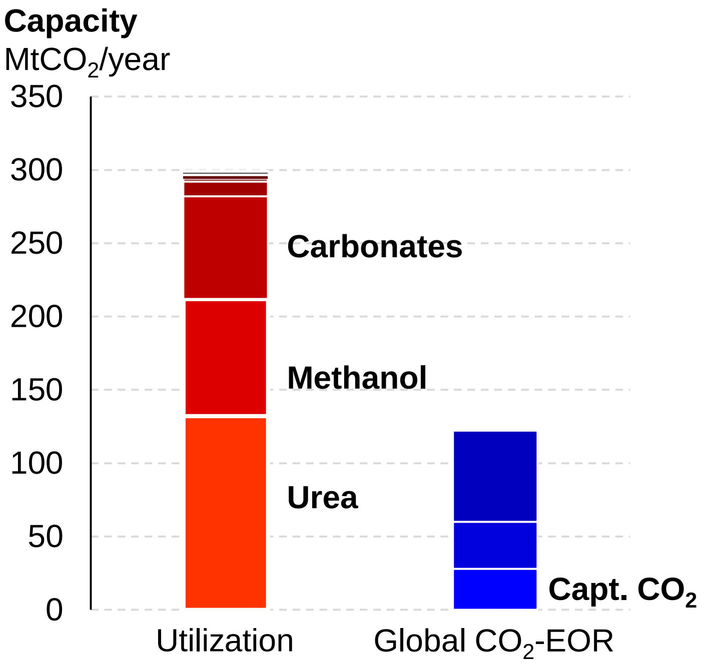


Levelized Cost of Electricity
USD/MWh



Sources: Rubin, Davison and Herzog, IJGGC, 2015.

Value capture via CO_2 utilization has the potential to provide some impetus for deployment of capacity over the medium term – For it to be useful from a climate perspective though the utilization will have to support a closed loop



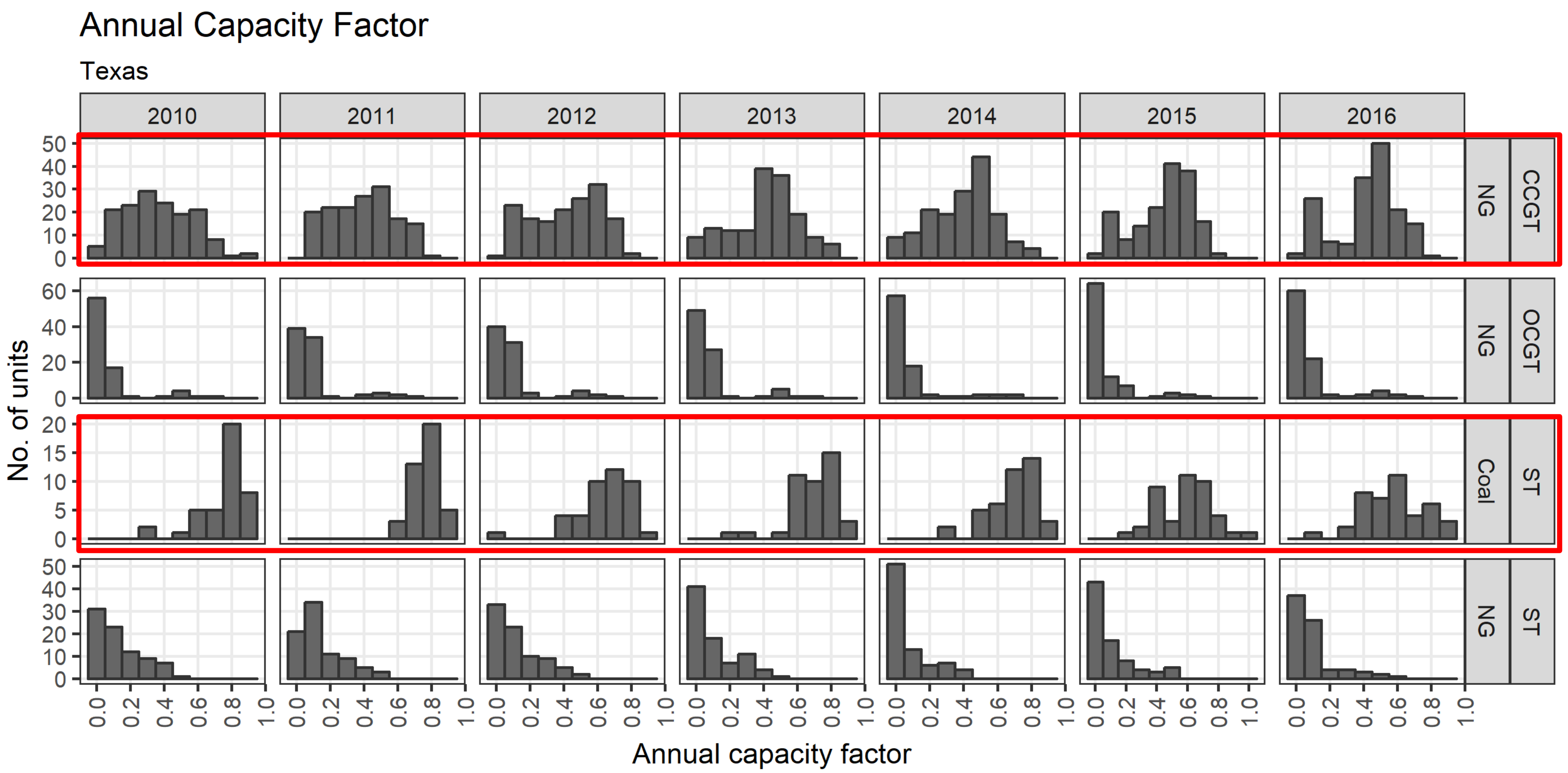
Achieving current carbon mitigation targets will require utilization with long term storage at the gigatonne scale.

Other than utilization for EOR, the permanent storage with utilization options is questionable.

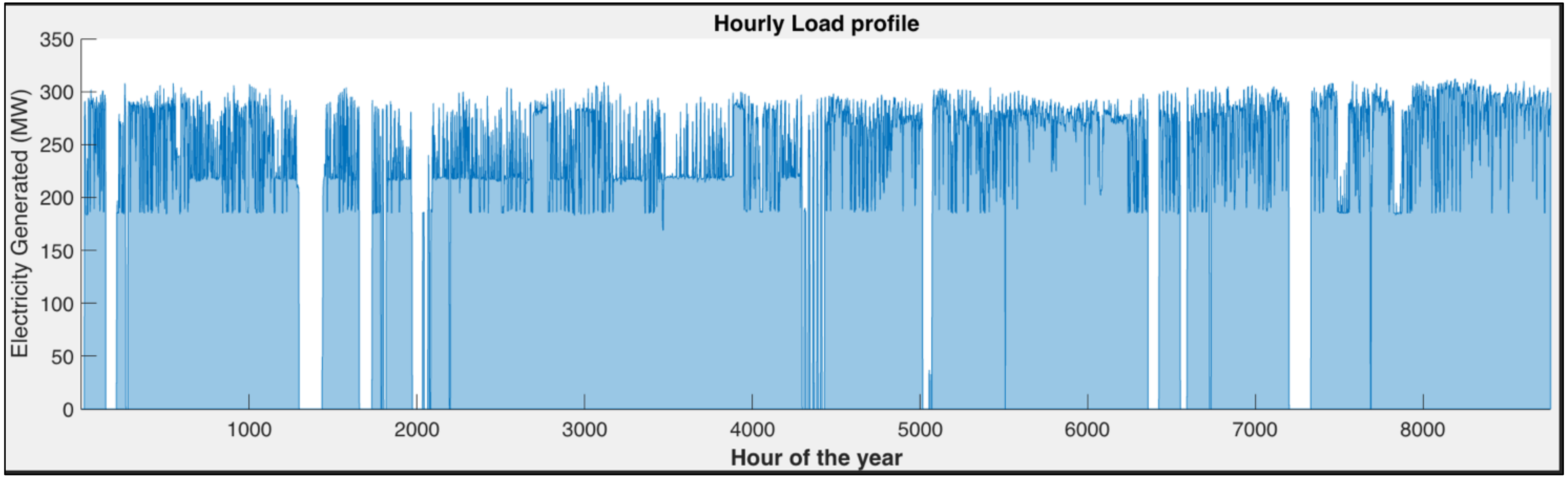
There is still potential to expand CO_2 use in EOR, but in reality that application is limited in scale.

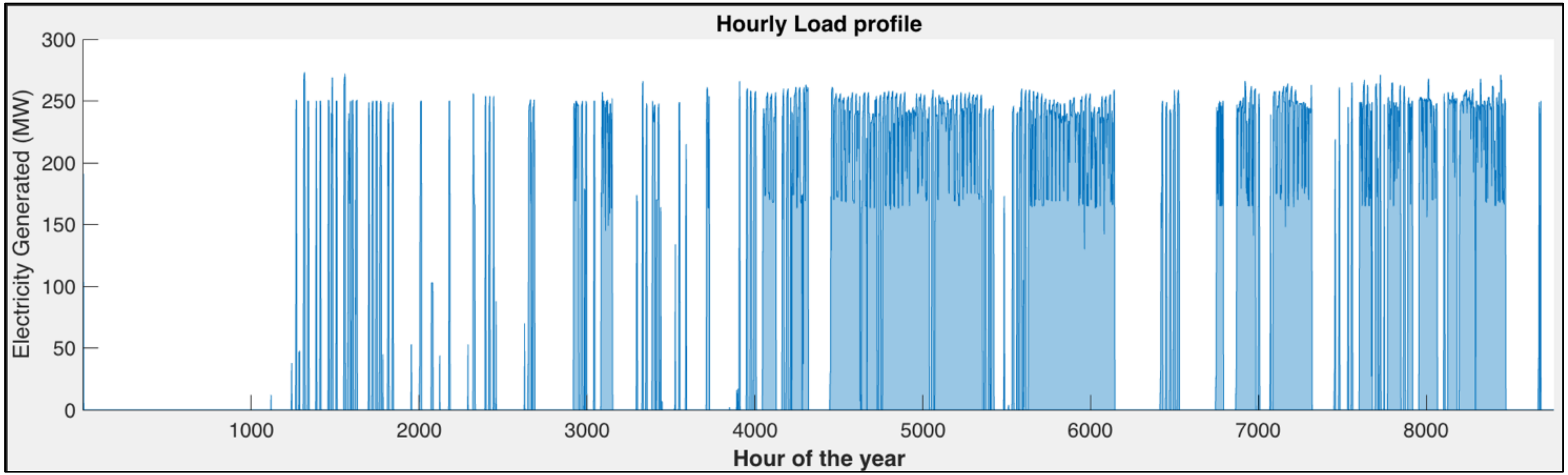
Sources: IPCC SRCCS, 2005. Aresta, et. al, 2007. Dowell et al. Nature Climate Change, 2017. Wallace & Kuuskra, NETL, 2014.

The integration of renewable power has led to considerable changes in how the fossil-fired power plant fleet is being dispatched relative to a decade ago

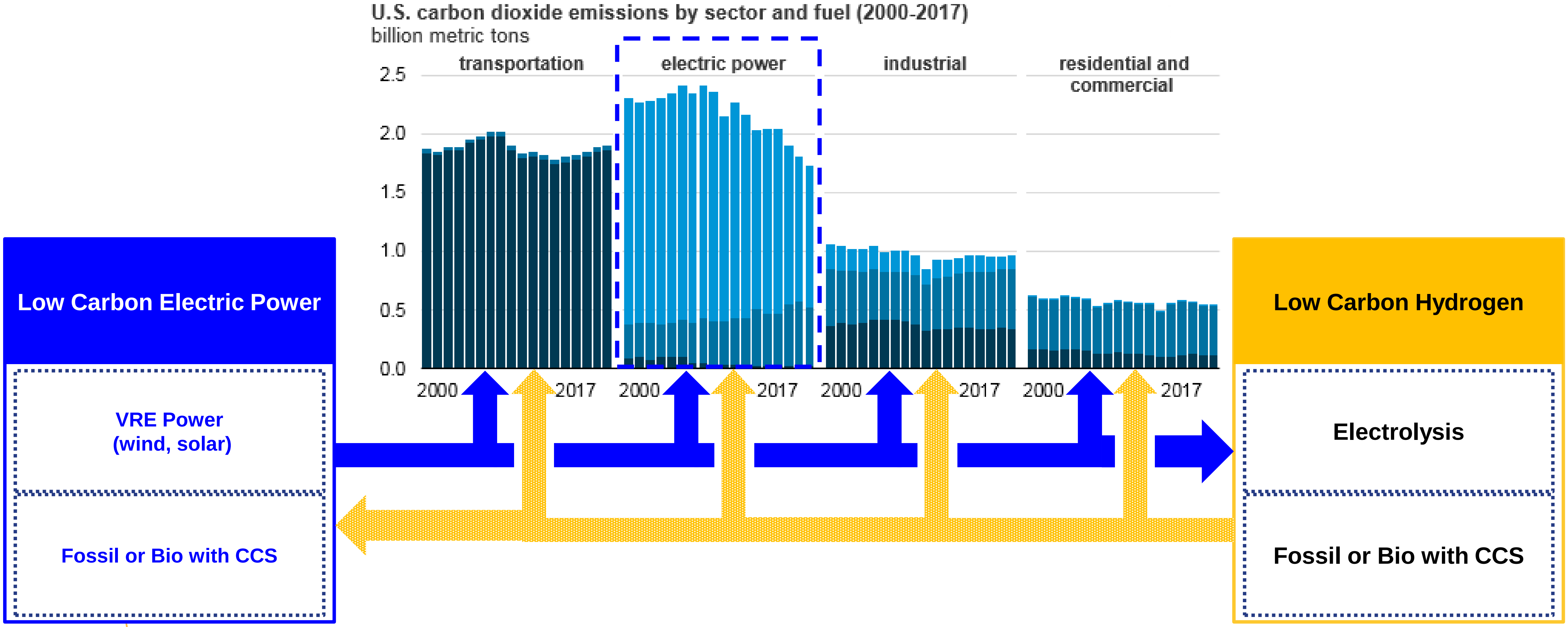


Cycling and a shift from baseload to peaking capacity in combined cycle units are some of the operational changes we will increasingly observe





The role of CCUS in delivering low-carbon electricity remains unclear, however deep economy-wide decarbonization will likely need other energy carriers (*e.g.* Hydrogen)



Sources: EIA, 2018

The exact integration of hydrogen into the energy system is uncertain but numerous opportunities exist both on the supply and demand side

Sources: MITEI

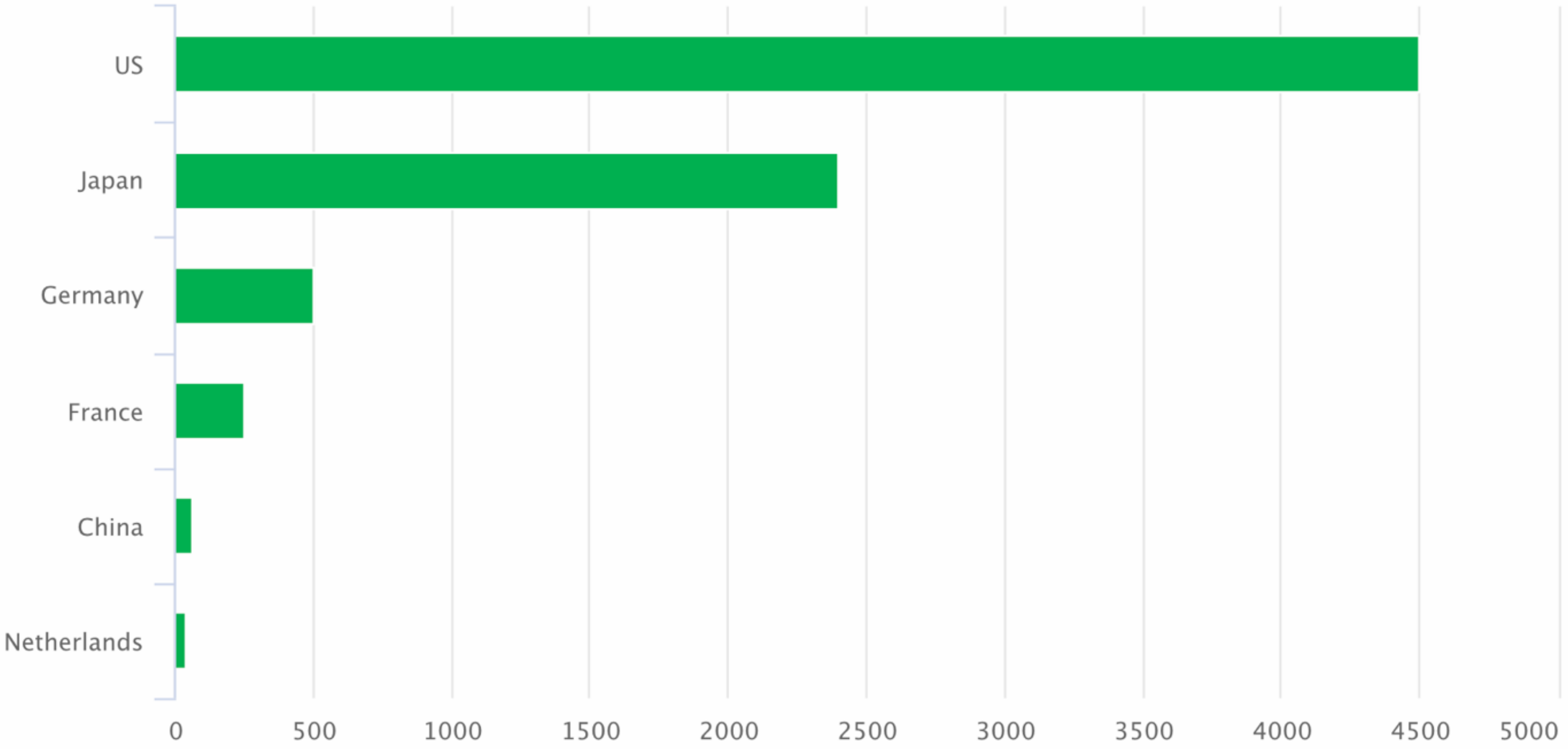
Not all hydrogen are created equal – The role of hydrogen in economy-wide deep decarbonization is dependent on how hydrogen is produced

Sources: MITEI

The global fuel cell electric vehicle (FCEV) car stock reached 8 000 units in April 2018. The United States represents the largest fleet with 4 500 FCEV

Toyota Mirai ($57,500)
Fuel Economy = 106 km/kg H_2
Tank ~ 5 kg
Range = 550 km (340 miles)

Total FCEV fleet



Japan has more than twice as many fueling stations relative to the US (100 vs. 38)

Sources: EIA 2019

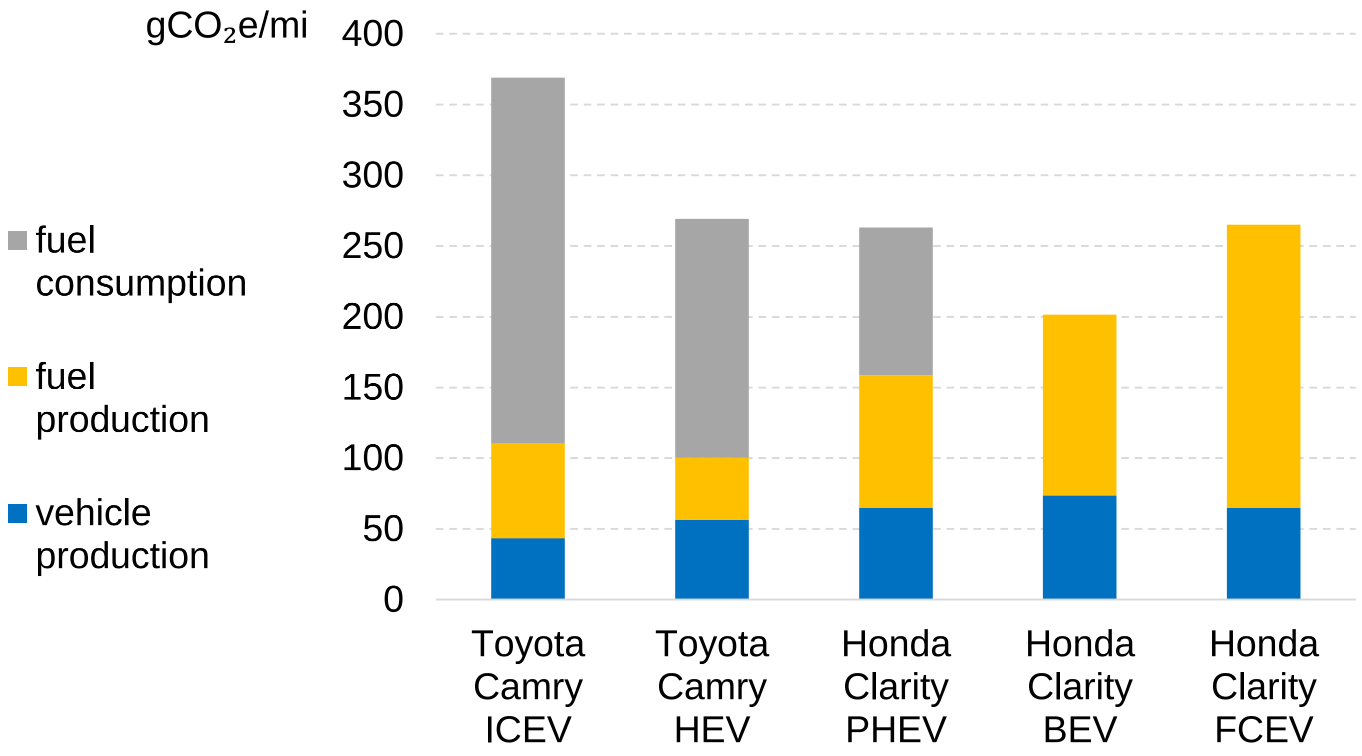
Exploring the life cycle greenhouse emissions of various hydrogen pathways relative to vehicle types

- Car models chosen to facilitate apples-apples comparisons—i.e., minimize differences in non-powertrain features.

	Toyota Camry ICEV	Toyota Camry HEV	Honda Clarity PHEV	Honda Clarity BEV	Honda Clarity FCEV
Interior volume (ft^3):	115	115	117	116	113

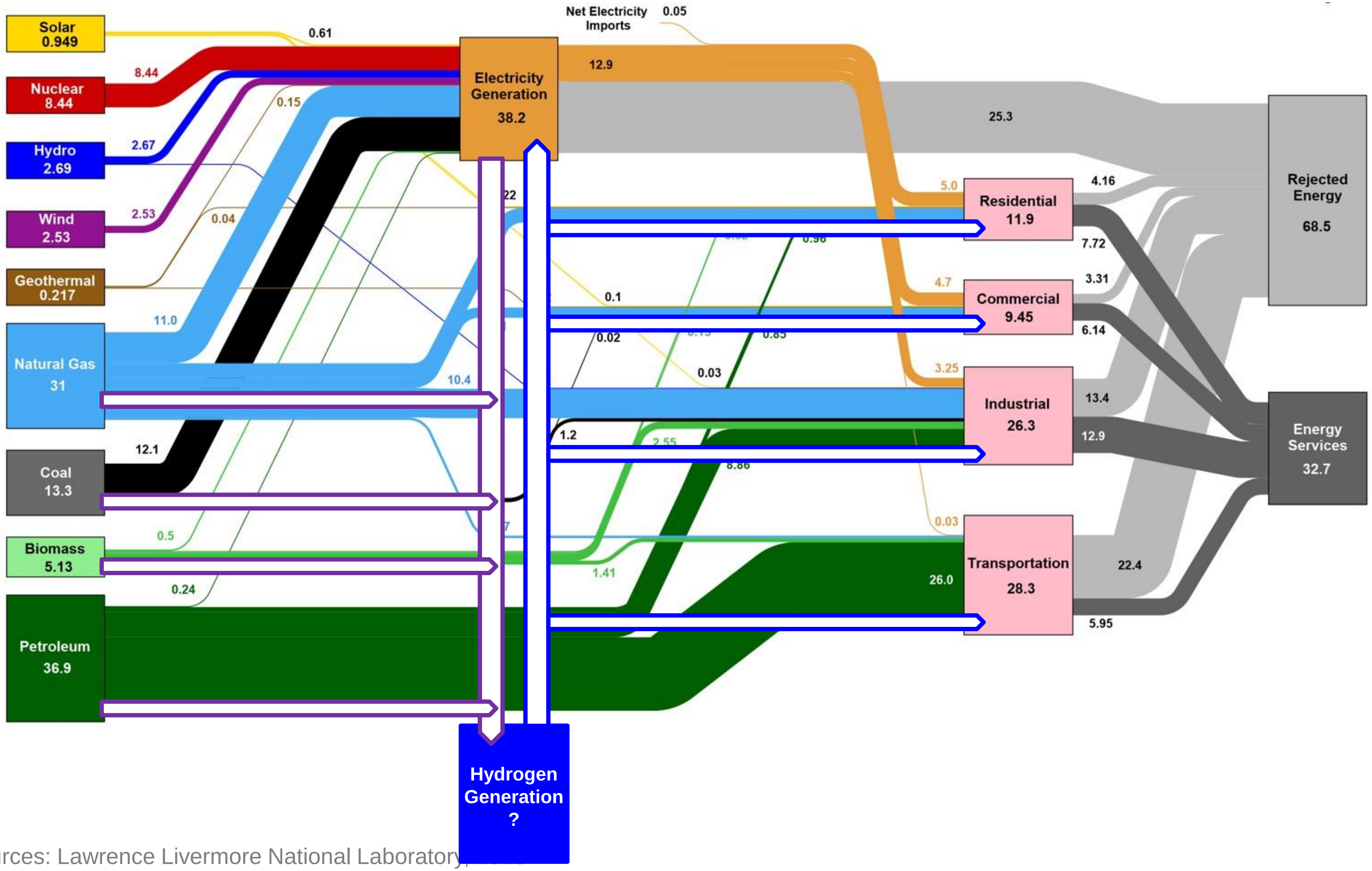
Sources: MITEI Analysis

GHG Emissions for Mid-size Sedans with Different Powertrains



1. BEV emissions per mile ~ 55% emissions of comparable ICEVs.
2. Increased emissions from battery & fuel (electricity) production are more than offset by increased powertrain efficiency (MPG).
3. HEV emissions per mile fall between ICEV and BEV emissions.
4. FCEVS: more later.

Hydrogen value chain should be significantly scaled-up to have an impact in the current energy system – 2018 H_2 production ~10 Mtons (1.2 EJ) vs. 2018 energy demand ~101.2 Quad (106.8 EJ)



Sources: Lawrence Livermore National Laboratory

Key Takeaways

- Understanding the evolving energy system requires new analytical methods and tools that allow exploration of system level interactions and perform cross sectoral comparisons.
- Impacts arising from standard vs. best practices can have a significant impact such as in California's natural gas fleet.
- The shift in energy system from isolated to integrated and from centralized to distributed is hard to characterize. High temporal and geospatial resolution is a must for any accurate analysis.
- CCUS is essential for deep decarbonization especially for sectors that are hard to electrify.
    - For electric power sector CCUS has a role to play as the global fossil power plant fleet is young.
    - The changes in how the fossil-fired power plant fleet is being dispatched will be a technical challenge for CCUS deployment
- Meaningful climate change mitigation efforts must target all sectors, not just power – the versatility of H_2 makes it an appealing energy carrier to serve traditionally difficult-to-electrify end uses.
    - For light duty transportation (FCEV), hydrogen production determine the ranking among other options. FCEV GHGs ~quadruple with H_2 from coal gasification vs. electrolysis + wind.
    - Due to growth of renewable power, there is a growing need for long-term/seasonal energy storage.

Thank you

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