



Carbon capture, use and storage in the power sector

C is the New Black

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2°C scenario

1.5°C scenario

CO₂ emissions [tons/sec]

1'268

time since CO₂ budget exhausted

year month day hour min sec

0 1 6 17 12 59 15

CO₂ budget left [tons]

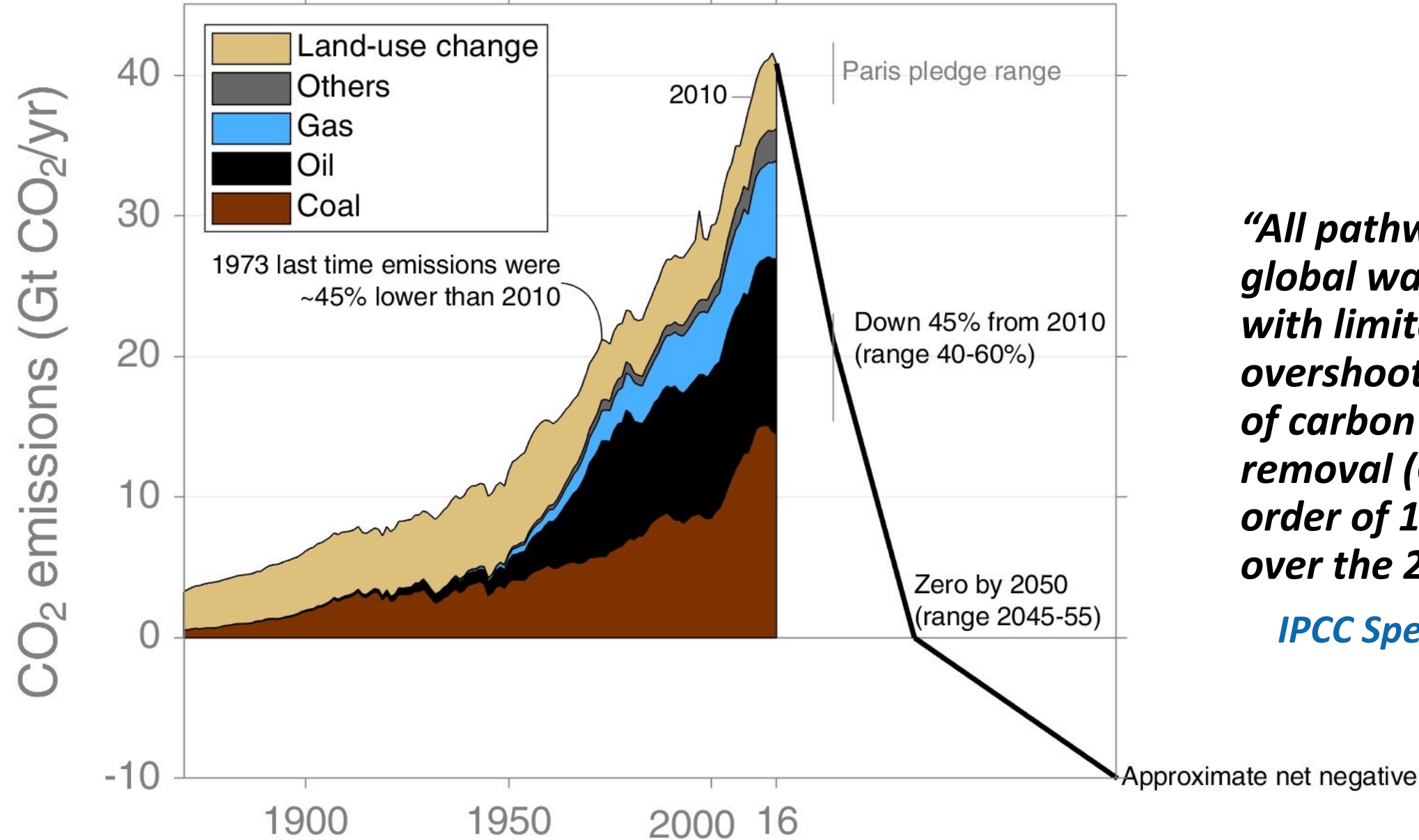
exhausted by: 4'020'988'922

upper estimate

medium estimate

lower estimate



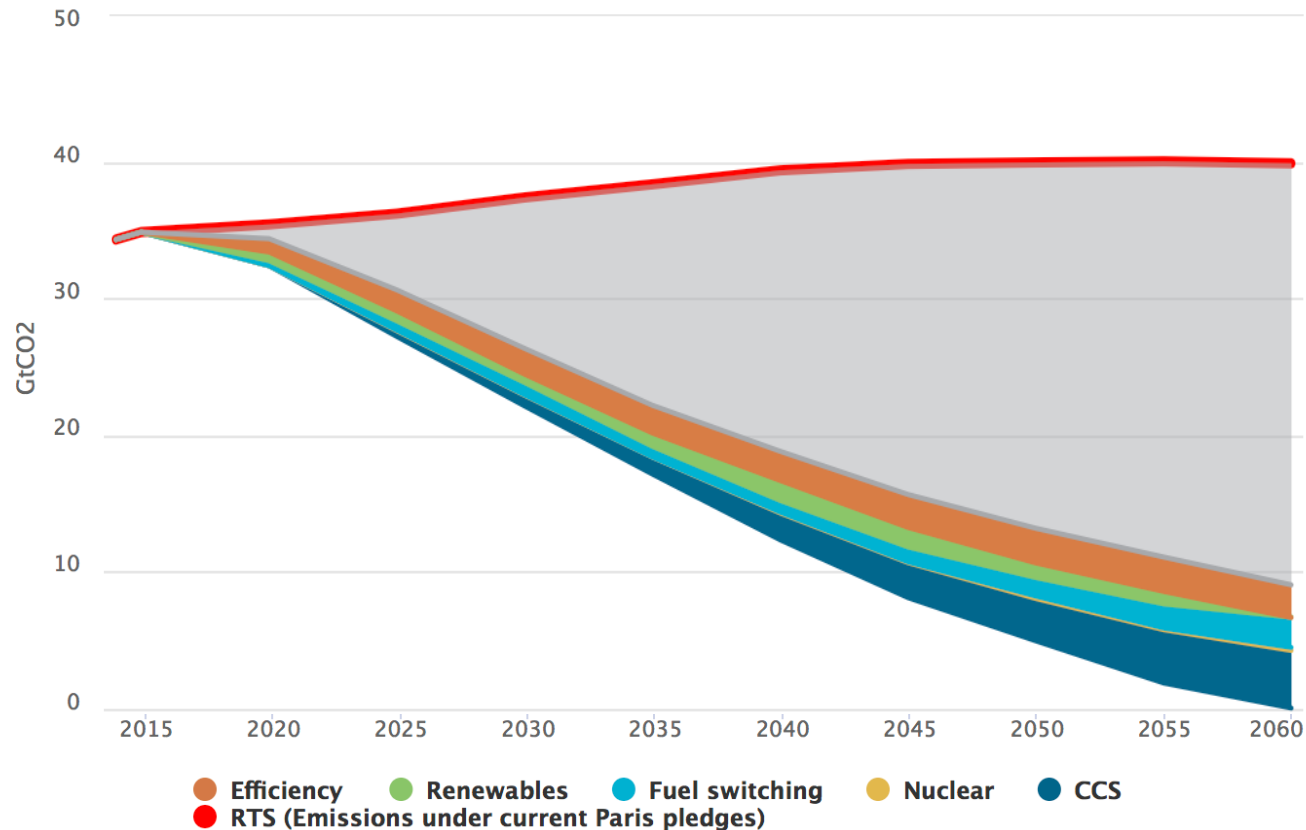


“All pathways that limit global warming to 1.5°C with limited or no overshoot project the use of carbon dioxide removal (CDR) on the order of 100–1000 GtCO₂ over the 21st century.”

IPCC Special Report, 1.5°C

Large-Scale C Management Required

There are very few pathways to 2°C or <2°C without large-scale C management

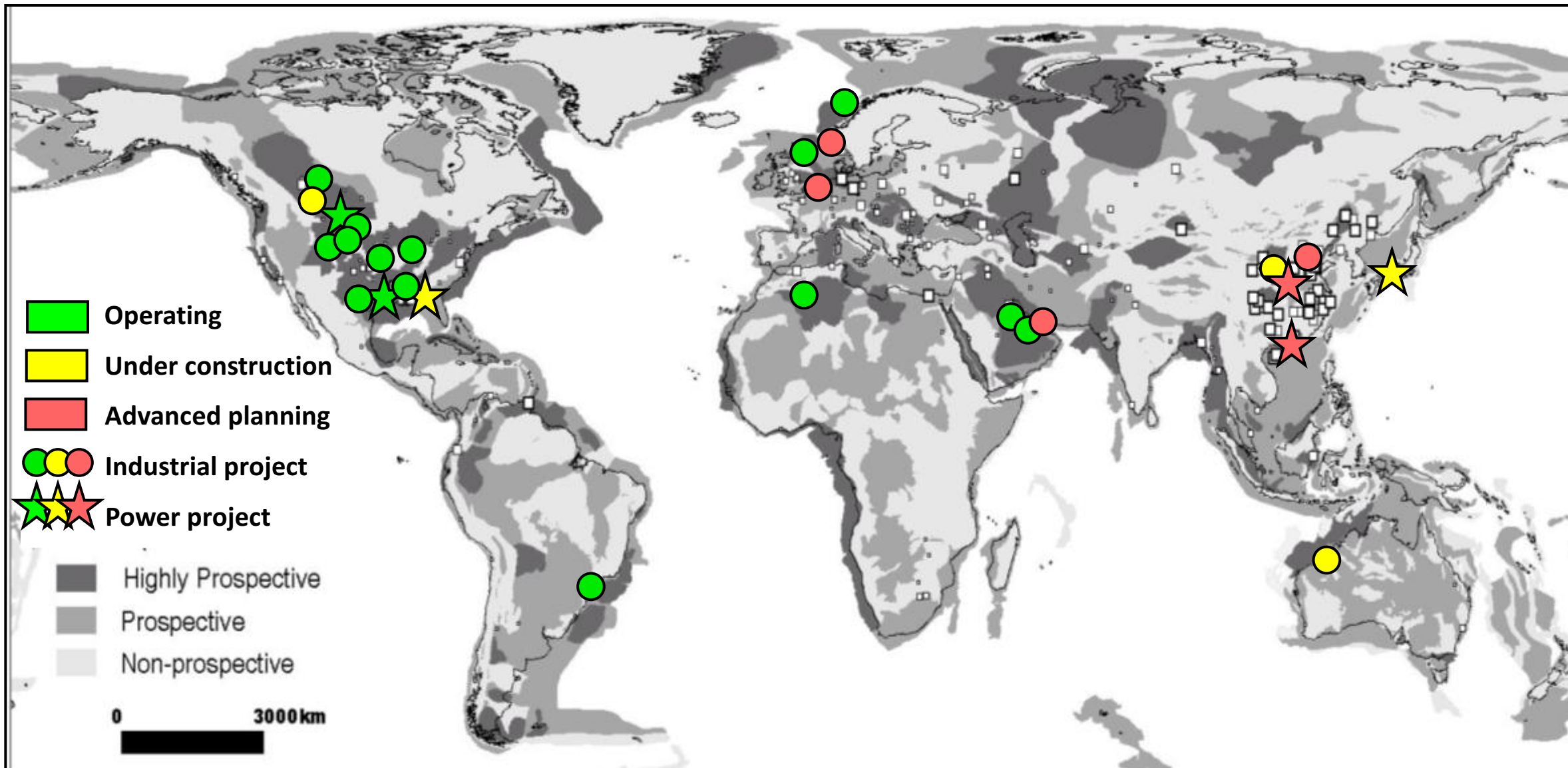


7 of 11 IPCC models require CCS for 2°C

- ~14% of solution
- 33% of next increment for 1.5 °C

© OECD/IEA

A key component to deep decarbonization



18 operating plants, storing ~30 Mtons CO₂ each year

Estimated storage worldwide: ~10 trillion tons

W.A. Parrish, TX
NRG/PetraNova project



**Fully operational Jan 2017. 1.4M tons/year, 90% capture
\$100/ton CO₂ costs; next plant 30% less**

Shell Quest Project

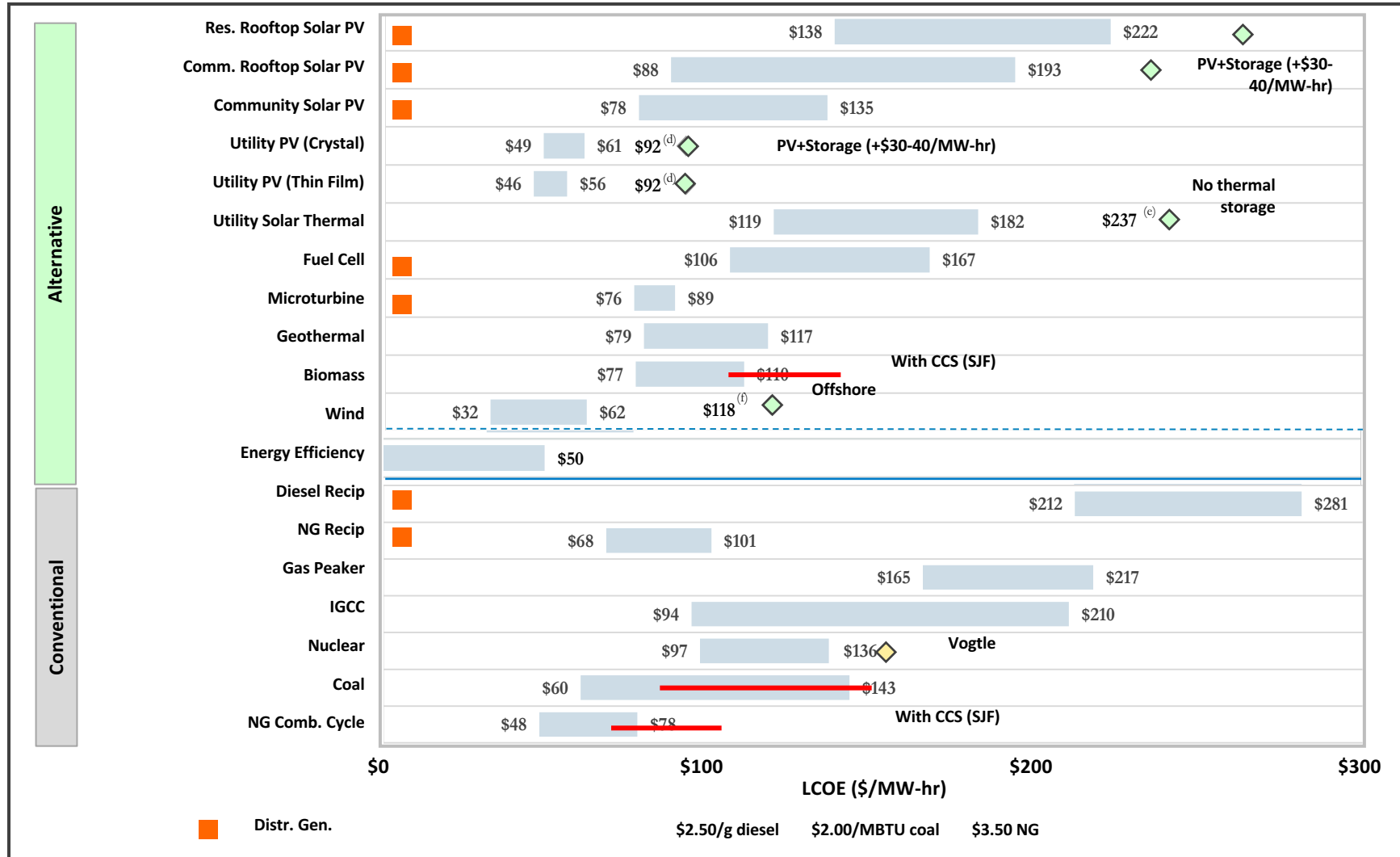
Scottsford Upgrader, Alberta



Fully operational Sept. 2015

Over 2 Million tons/y into saline formations

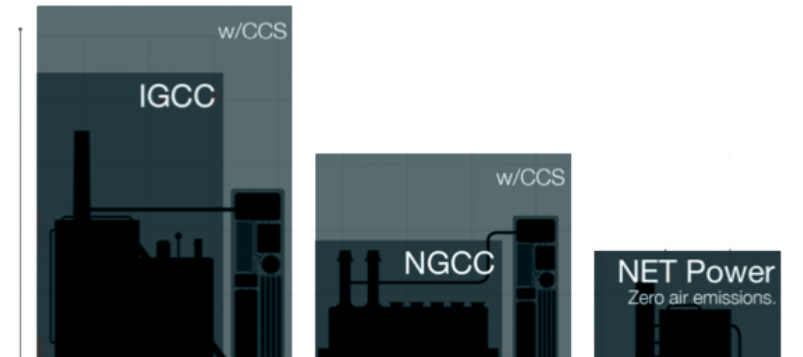
The market today (Unsubsidized LCOE – Lazard 2016)



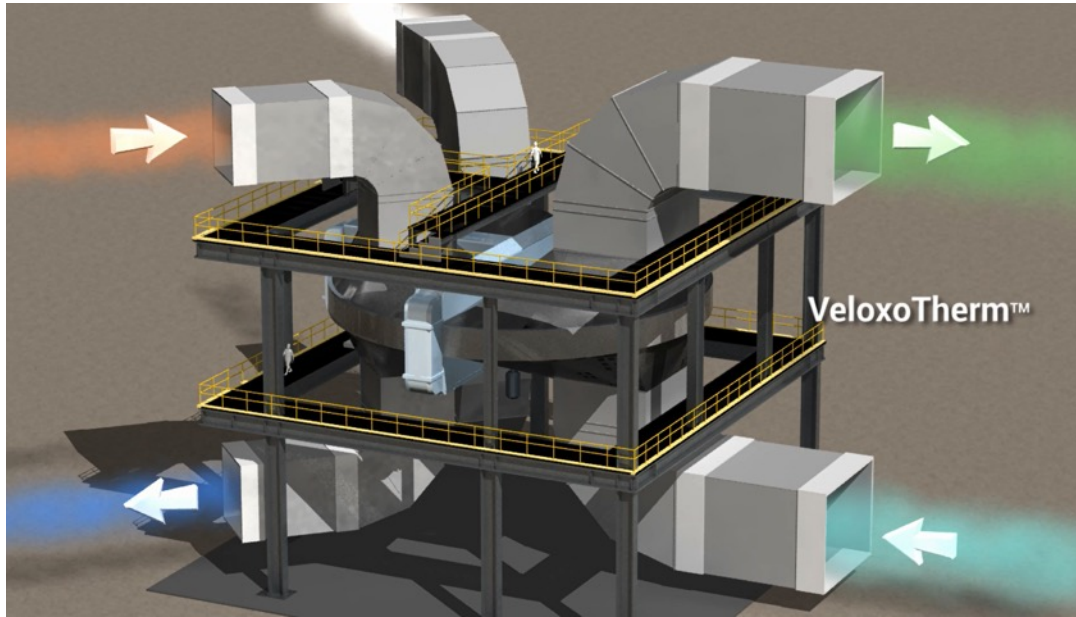
New Tech: NetPower



- **100% CO₂ stream, at pressure**
- **Produces water**
- **Nth plant: ~price parity to NGCC**
- **Can ramp up & down**
- **Addl. potential revenues**



New Tech: Inventys & Fuel Cell Energy (both NG focus)



- Solid sorbent + 3D printing
- Very low capital costs
- Nth plant: ~\$30/t CO₂
- Modular design
- New CEO
- Can ramp up and down



- Molten carbonate “afterburner”
- Produces extra power
- Nth plant: unclear
- High efficiency, modular design
- Partnership with ExxonMobil & Southern Co.
- Can ramp up & down



FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

Policy aperture must expand

Incentives (carrots)

- Tax credits, feed-in tariffs, contract for differences, trading schemes, etc.
- Direct grants (AEIC& PCAST recommend x4 increase)
- State-sponsored “strategic” projects (China’s 5-year plan)
- Broader clean financing mechanisms (CEPS vs. RPS; LCFS vs. RFS)

Disincentives (sticks)

- Carbon tax (e.g., Norway)
- Regulatory caps (e.g., CPP, California’s SB 1368)
- Border adjustable carbon tariffs

***No low-C MW left behind; More shots on goal
We need more***

FUTURE Act is now law (45Q tax credit reform)

Senate: FUTURE ACT (Heitkamp, Capito, Whitehouse, Barrasso) 25 sponsors

House: Carbon Capture Act (Conaway) 44 sponsors

- UNCAPPED
- \$50/ton CO₂ for storage; \$35/ton CO₂ for EOR & CO₂U; \$35 for direct air capture
- Non-refundable tax credit, transferable along chain of custody
- Projects qualify at 500,000 tons/y (power) or 100,000 tons/y (industrial) storage & EOR
- CO₂U projects qualify at >25,000 tons CO₂/y
- Monitoring required to receive credit
- Active for 12 years for any project initiated within 7 years of enactment (+ inflation adjusted)

New opportunities for projects and financing

Well assessed sites will allow rapid project development

FUTURE Act is now law (45Q tax credit reform)

Minimum Size of Eligible Carbon Capture Plant by Type (ktCO ₂ /yr)				Relevant Level of Tax Credit in a Given Operational Year										
		Power Plant	Other Industrial Facility	Direct Air Capture	2018	2019	2020	2021	2022	2023	2024	2025	2026	Beyond 2026
Type of CO ₂ Storage/Use	Dedicated Geological Storage	500	100	100	28	31	34	36	39	42	45	47	50	Indexed to Inflation
	Storage via EOR	500	100	100	17	19	22	24	26	28	31	33	35	
	Other Utilization Processes ¹	25	25	25	17 ²	19	22	24	26	28	31	33	35	

¹ Each CO₂ source cannot be greater than 500 ktCO₂/yr

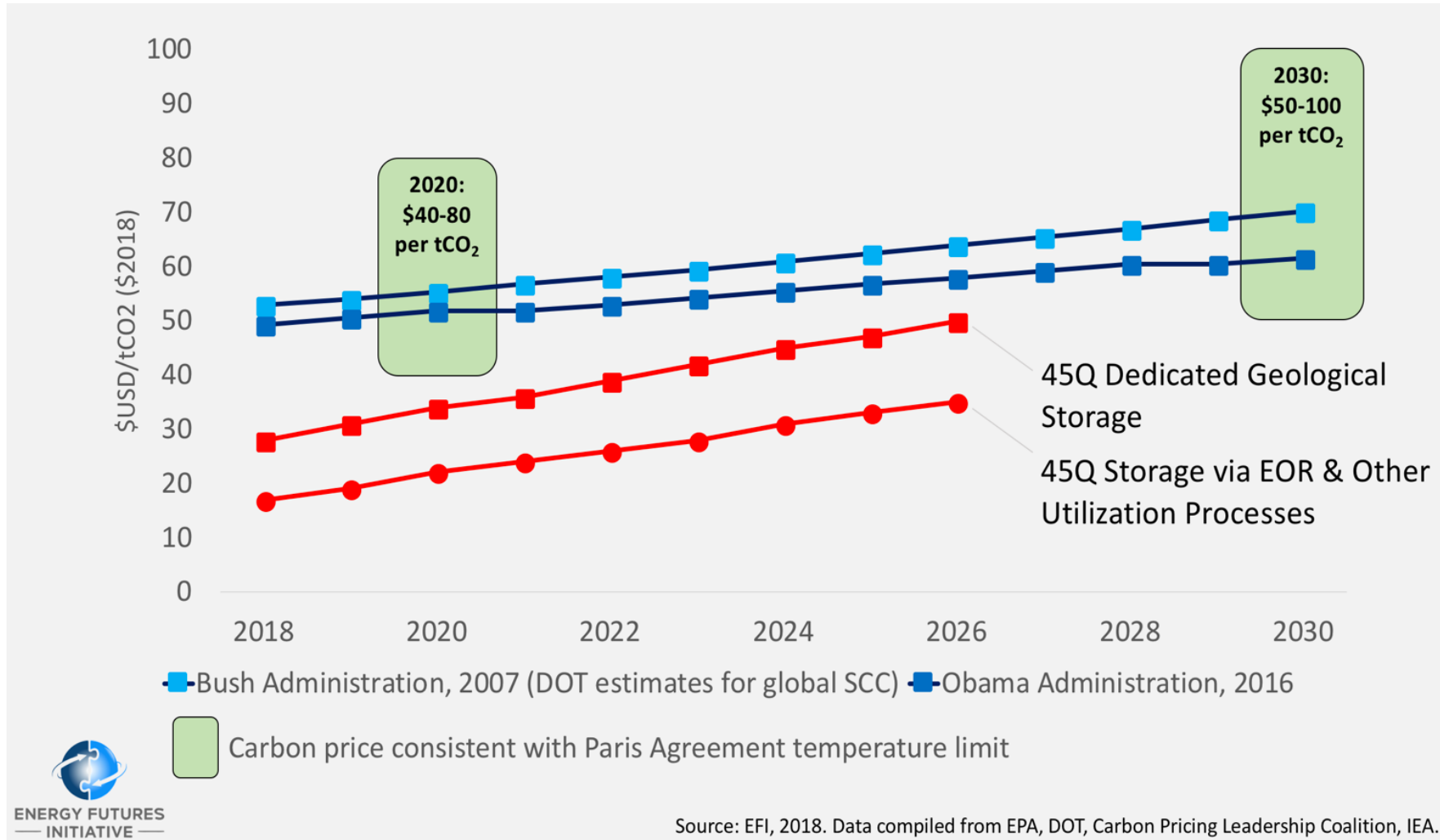
² Any credit will only apply to the portion of the converted CO₂ that can be shown to reduce overall emissions



Source: Simon Bennett and Tristan Stanley, Commentary: US budget bill may help carbon capture get back on track, International Energy Agency.

https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/5b0604f30e2e7287abb8f3c1/1527121150675/45Q_EFI_5.23.18.pdf

FUTURE Act is now law (45Q tax credit reform)



Federal R&D Programs: Unprecedented funding

Office of Fossil Energy: \$727M total

Clean Coal and Carbon Management

Maintains carbon capture and advanced cycle programs

Maintains carbon storage, including CarbonSAFE assessments

Maintains CO2 Utilization, possibly expands

Office of Energy Efficiency and Renewable Energy: \$2.3B

Bioenergy Technology Office (BETO)

- CO2 to products program (including algae and biochemicals)
- Engineered Carbon Reduction Report (Rewiring C Economy)

DOE Loan program Office

- Sustained current advanced fossil budget
- Added \$2B authorities for rural cooperatives



CA SB100: 100% Clean Energy Portfolio Standard by 2045

EO B-55-18: 100% decarbonized by 2045, net removal after



CA 100% CLEAN ENERGY

CALIFORNIA CAN LEAD THE NATION

PASS #SB100

100% CLEAN ENERGY BY 2045

VOTE SOLAR

Today's carbon prices in policy

Carbon Taxes (\$US/ton CO₂):

Sweden: \$167 Switzerland (2020): \$200 Norway: \$80-85 (on industry)

Canada: \$8, rising to \$40 in 2022 (Alberta: \$24; Manitoba: \$20; BC: \$10)

Carbon trading systems:

European Trading System: ~\$20-25 (last year, ~\$6-10). RGGI: \$3-4 CA: \$10-15

China Carbon Market: (Beijing: \$6-7; Shanghai \$4-6; Shenzhen, \$4-6)

CA Low-carbon fuel standard:

Emissions standards (LCFS): \$150-180

For Comparison (units in \$/ton eq. for CO₂ reduction)

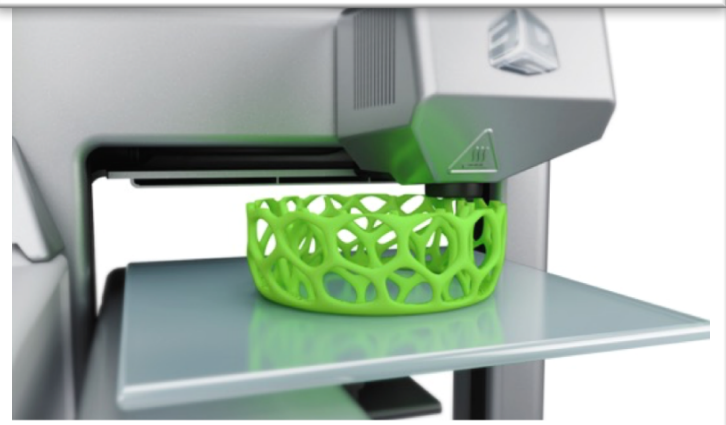
EV subsidy, CA: ~\$1000

EnergieWende, GER: \$300

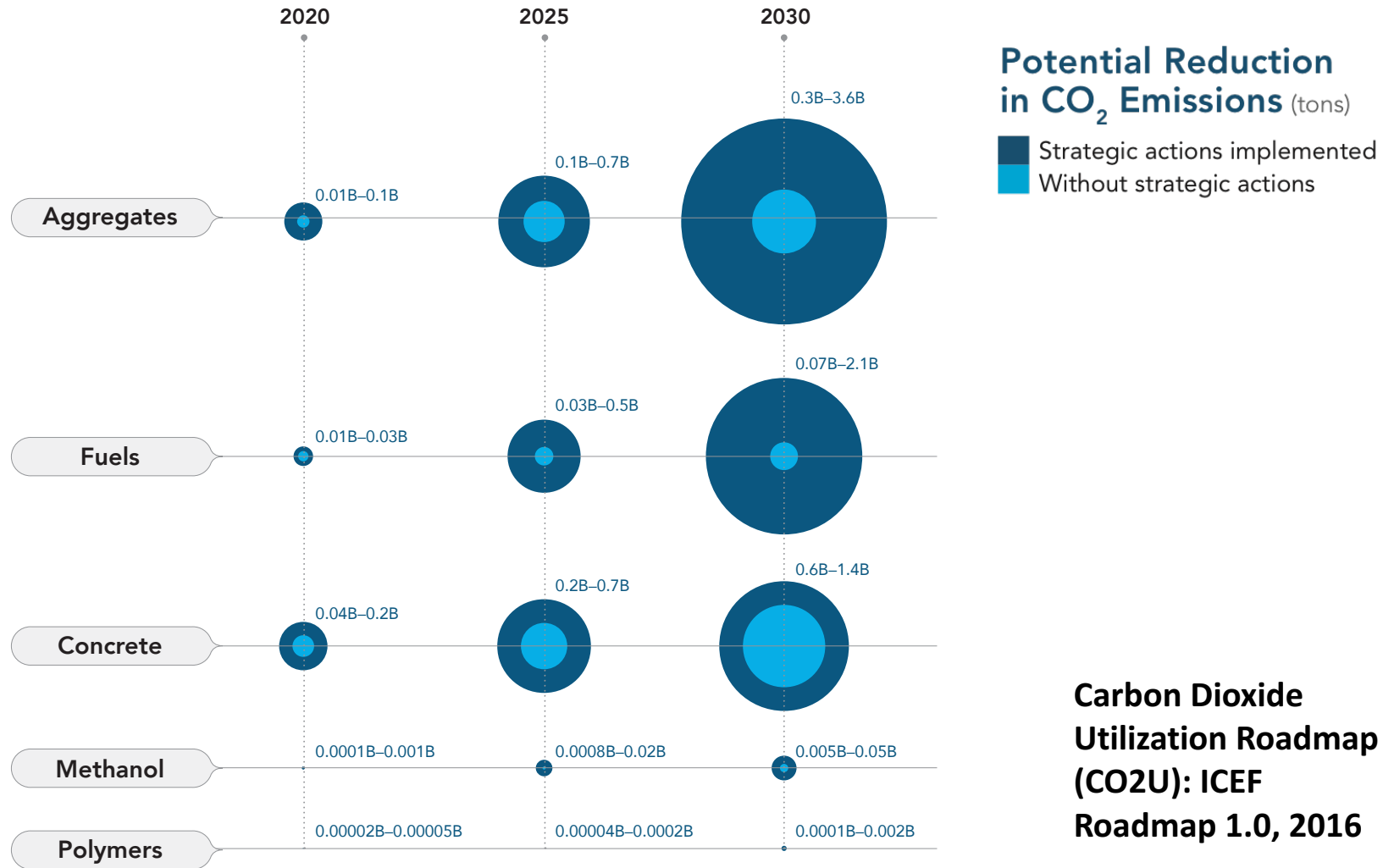
Wind Prod. Tax Credit: \$60-120

Est. current CA RPS system costs: \$120-160

Projected CA RPS system costs (50%): \$400-1200

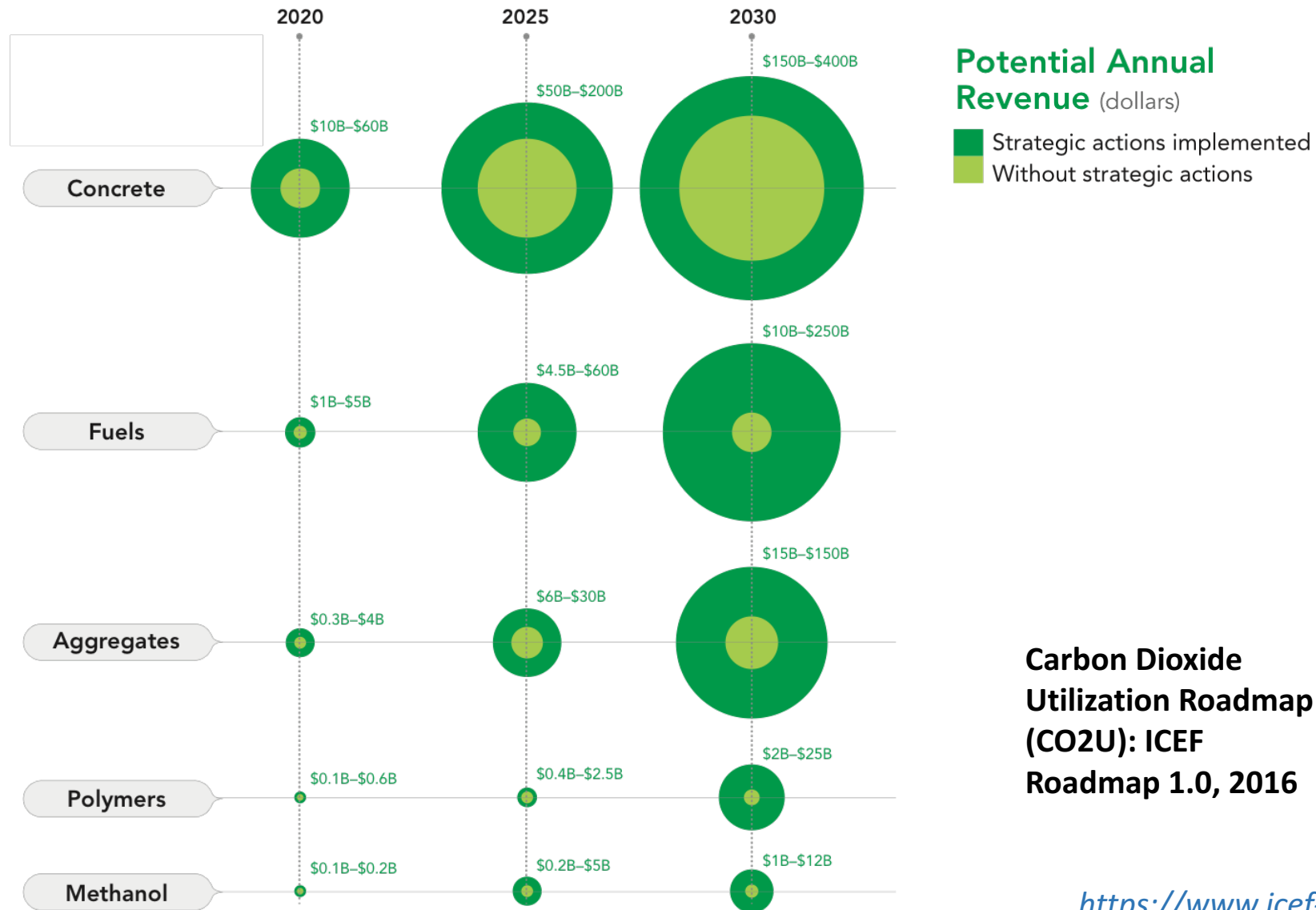


New C Economy: Thriving economy that consumes more than emits



**Carbon Dioxide
Utilization Roadmap
(CO₂U): ICEF
Roadmap 1.0, 2016**

New C Economy: Thriving economy that consumes more than emits



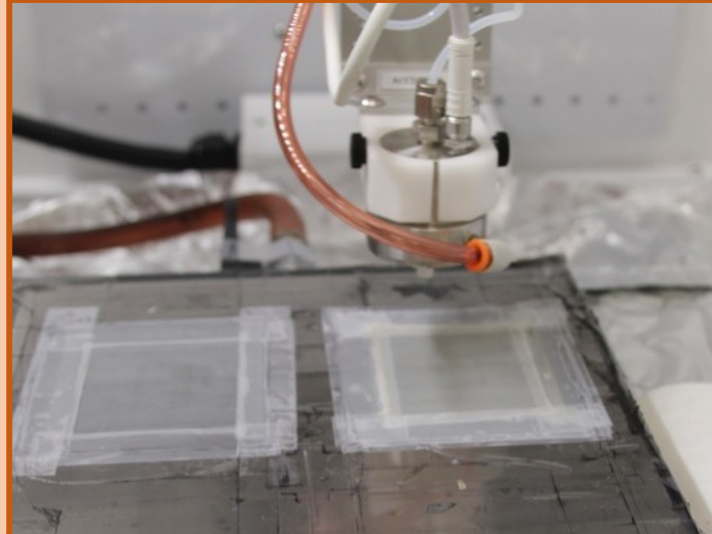
**Carbon Dioxide
Utilization Roadmap
(CO2U): ICEF
Roadmap 1.0, 2016**

Circular Economy pioneers

Cement & Concrete



Fuels & Chemicals



Durable carbon



The world's first commercial direct air capture plant
Does the CO₂ work of 36,000 trees



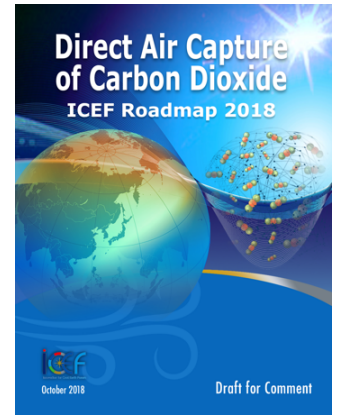
Generation Engine: turning CO₂ to fuel: Carbon Engineering & Greyrock
Squamish, British Columbia



Third new species: Air-CO₂ for fun and profit: Global Thermostat, Alabama



MANY APPROACHES TO CARBON DIOXIDE REMOVAL



Forestry/Land



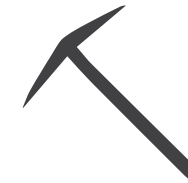
Agriculture



Energy



Manufacturing



Mining



Ecosystem Restoration



Biochar



Bioenergy + CCS



Enhanced Weathering



Timber



Land Management



Direct Air Capture



Carbon Negative Materials

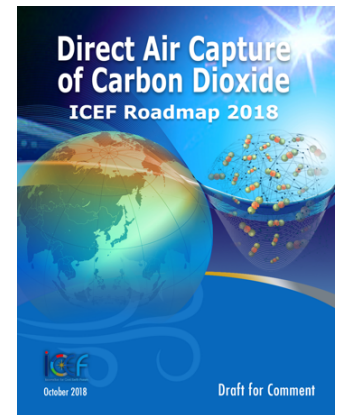
BIOLOGICAL

CHEMICAL

Center for Carbon Removal

<https://www.icef-forum.org/roadmap/>

ALL CDR APPROACHES HAVE BENEFITS & CHALLENGES



		Cost	Energy Requirements	Land Use	Water Consumption	Risk of Reversal	Verifiability	Implement. Readiness
 NATURAL	Reforestation & Enhanced Forest Management							
	Wetland & Coastal Restoration							
	Soil Carbon Restoration							
 TECHNOLOGICAL	DACS							
	Terrestrial Enhanced Weathering							
	Ocean Alkalinity Modification							
 HYBRID	Hybrid Bioenergy with CCS (BECCS)							
	Bioenergy with Biochar Sequestration (BEBCS)							

LEGEND

- Generally Acceptable/ Available
- Exercise Caution
- Potentially Unacceptable/ Unavailable

New carbon economy required



THE CENTER
FOR CARBON
REMOVAL



ENERGY FUTURES
— INITIATIVE —

Carbon180

BUILDING A NEW
CARBON ECONOMY

An Innovation Plan



ENERGY FUTURES
— INITIATIVE —

