
CampusEnergy2021
BRIDGE TO THE FUTURE
Feb. 16-18 | CONNECTING VIRTUALLY
WORKSHOPS | Thermal Distribution: March 2 | Microgrid: March 16

Geothermal Deep Direct-Use for Decarbonizing Heating and Cooling:

Techno-Economic Analysis of Six Feasibility Studies Using Scenarios

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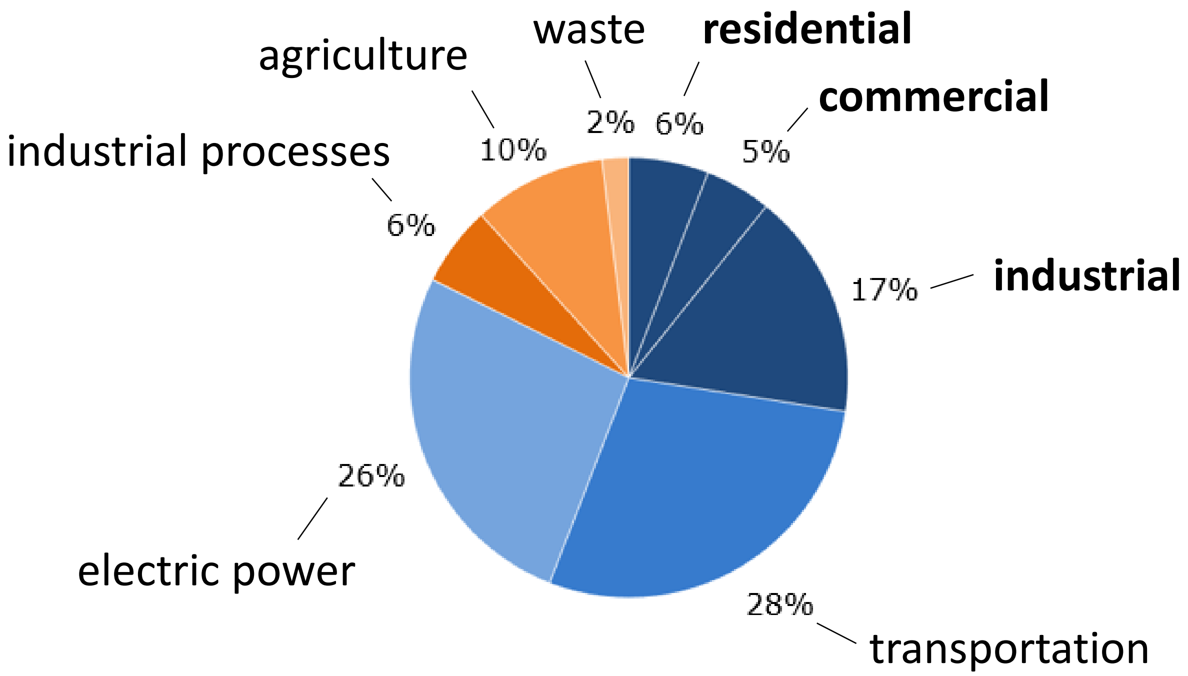
Q&A Will Not Be Answered Live

Please submit questions in the Q&A box.
The presenters will respond to questions off-line.

Heating and Cooling Significantly Contributes to U.S. Greenhouse Gas Inventory

- 25% of U.S. primary energy is used for heating (<120°C) and cooling
- 28% of total U.S. greenhouse gas emissions are from direct fuel combustion in residential, commercial, and industrial sectors
- Can geothermal energy help with decarbonizing heating and cooling?

U.S. Greenhouse Gas Emissions Inventory

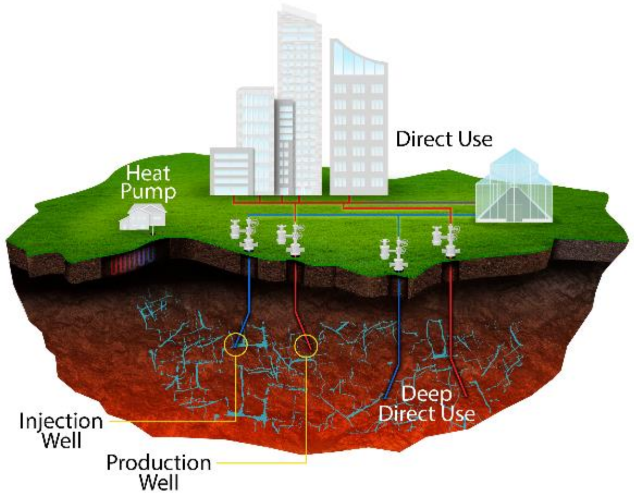


Source: EPA (2020), Inventory of U.S. Greenhouse gas Emission and Sinks: 1990-2018, 430-R-20-002.EPA

Decarbonizing District Energy with Geothermal Deep Direct-Use (DDU)

What is geothermal DDU?

- DDU draws on lower-temperature (<150°C) geothermal resources for multiple uses:
  - District heating and cooling
  - Commercial and residential applications
  - Industrial processes and agricultural uses
- Includes subsurface thermal energy storage (TES).

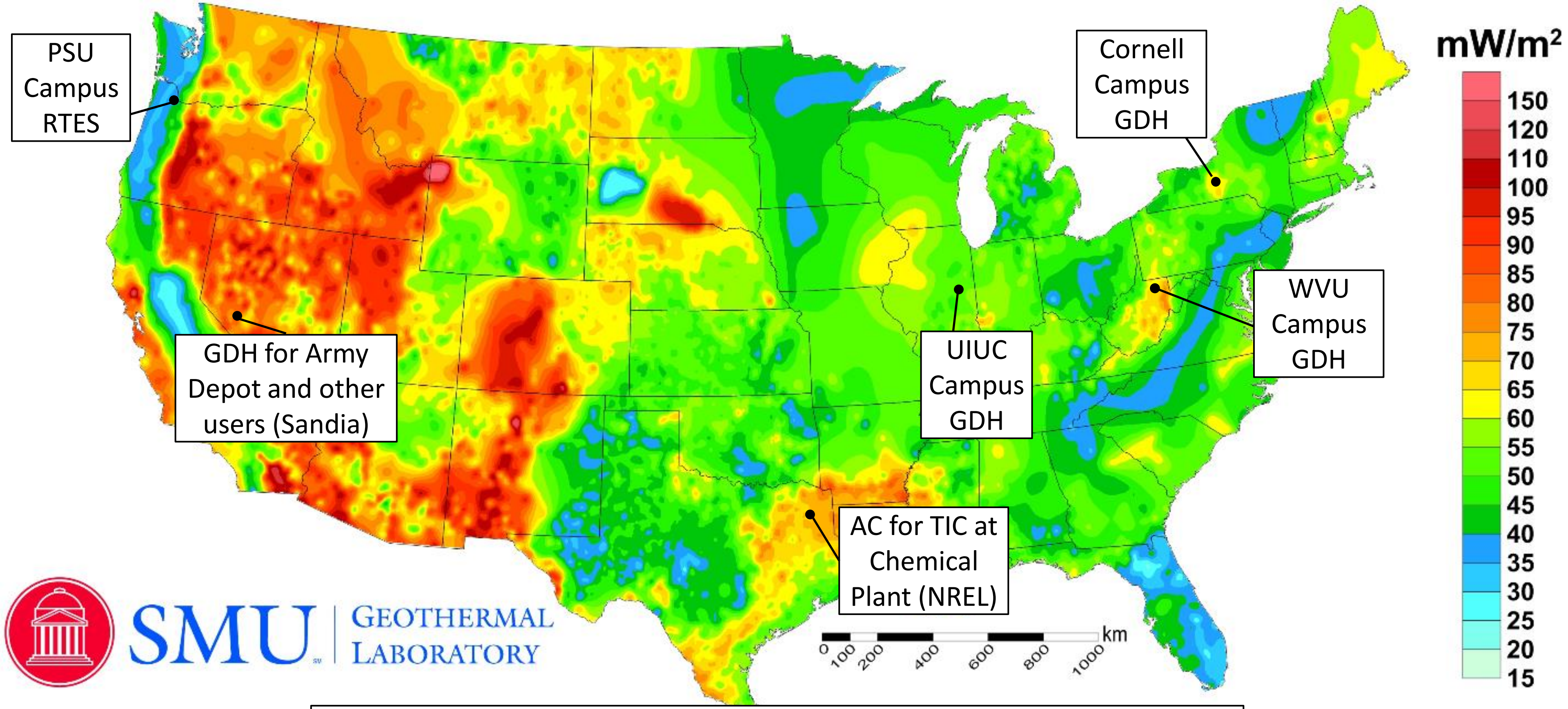


6 DDU Case Studies

- DOE-funded feasibility studies for district-scale DDU projects (mostly for campuses) 2017–2019
- Awardees:
  - Team 1. Cornell University
  - Team 2. National Renewable Energy Lab (NREL) & partners
  - Team 3. Portland State University (PSU) & partners
  - Team 4. Sandia National Labs (Sandia) & partners
  - Team 5. University of Illinois Urbana-Champaign (UIUC) & partners
  - Team 6. West Virginia University (WVU) & partners.

DDU Case Study Locations

For DDU-related publications, go to https://gdr.openei.org and search "DDU"



Acronyms

GDH = Geothermal District Heating
RTES = Reservoir Thermal Energy Storage
AC = Absorption Chilling
TIC = Turbine Inlet Cooling

Range of Input Parameters Used in DDU Feasibility Studies

Model Input Parameter	Min	Max
Drilling depth	0.3 km	2.9 km
Reservoir temperature	45°C	~120°C
System size	0.6 MW	32 MW
Geothermal gradient	16.5°C/km	272°C/km
Number of wells	1 inj + 1 prod	5 inj + 10 prod
Well flow rate	11 kg/s	125 kg/s
Utilization factor	~45%	98%
Tax rate	0%	30%
Discount rate	0.8% (real)	7.5% (nominal)
Exploration costs	$0	$4.2M
Surface application	DH only	DH ± HP ± AC ± Solar TES
Surface capital costs	$381/kW	$6500/kW

GEOPHIRES Techno-Economic Analysis Simulator:

https://github.com/NREL/GEOPHIRES-v2

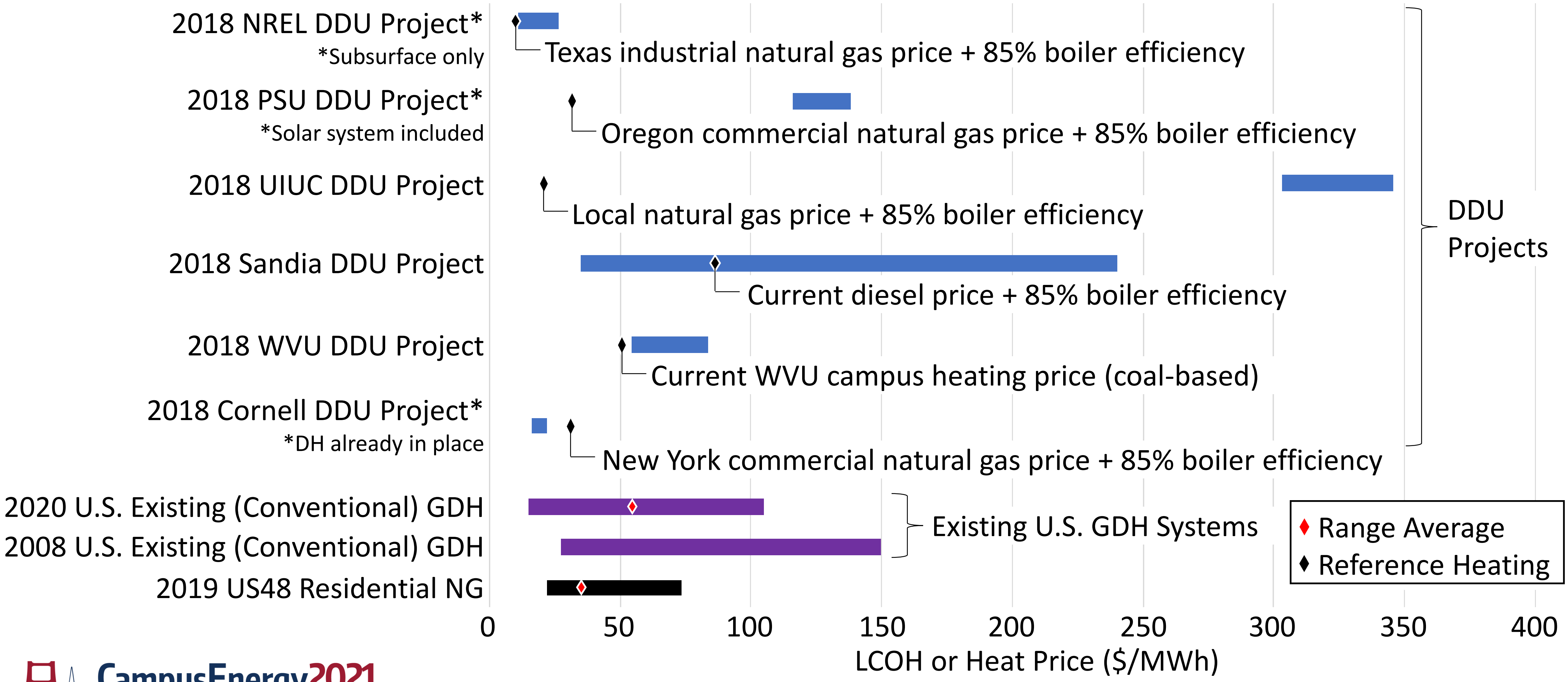
Capital Costs for Base-Case DDU Projects: Subsurface

Project parameter	University of Illinois at Urbana-Champaign	Sandia National Laboratories	Cornell University	West Virginia University	National Renewable Energy Laboratory	Portland State University
HEAT						
Source	Earth	Earth	Earth	Earth	Earth	Solar array
Cost	N/A	N/A	N/A	N/A	N/A	$6,100/kW
GEOTHERMAL SYSTEM						
Exploration costs	$0	$1.02 million	$0	$4.2 million	$3.4 million	$0
Drilling depth	1.9 km	0.3 km	2.5 km	2.9 km	2.7 km	0.3 km
Reservoir temperature	45 C	~100 C	~72 C	~88 C	~120 C	~12.5 C (stored heat: up to 80 C)
Geothermal gradient	16.5 C/km	272 C/km	27.5 C/km	25.8 C/km	37.5 C/km	N/A
Number of wells	1 injection + 1 production	1 injection + 1 production	1 injection + 1 production	5 injection + 10 production	1 injection + 1 production	1 injection + 1 production
Well flow rate	11 kg/s	36 kg/s	50 kg/s	40 kg/s per well	125 kg/s	50 kg/s
Utilization factor	~45%	48%	98%	95%	90%	N/A
Stimulation costs	$0	$0	$1.25 million	$0	$0	$0
Subsurface capital cost ($/MMBtu)	$91.8	$3.7	$4.1	$5.8	$2.4	$1.3

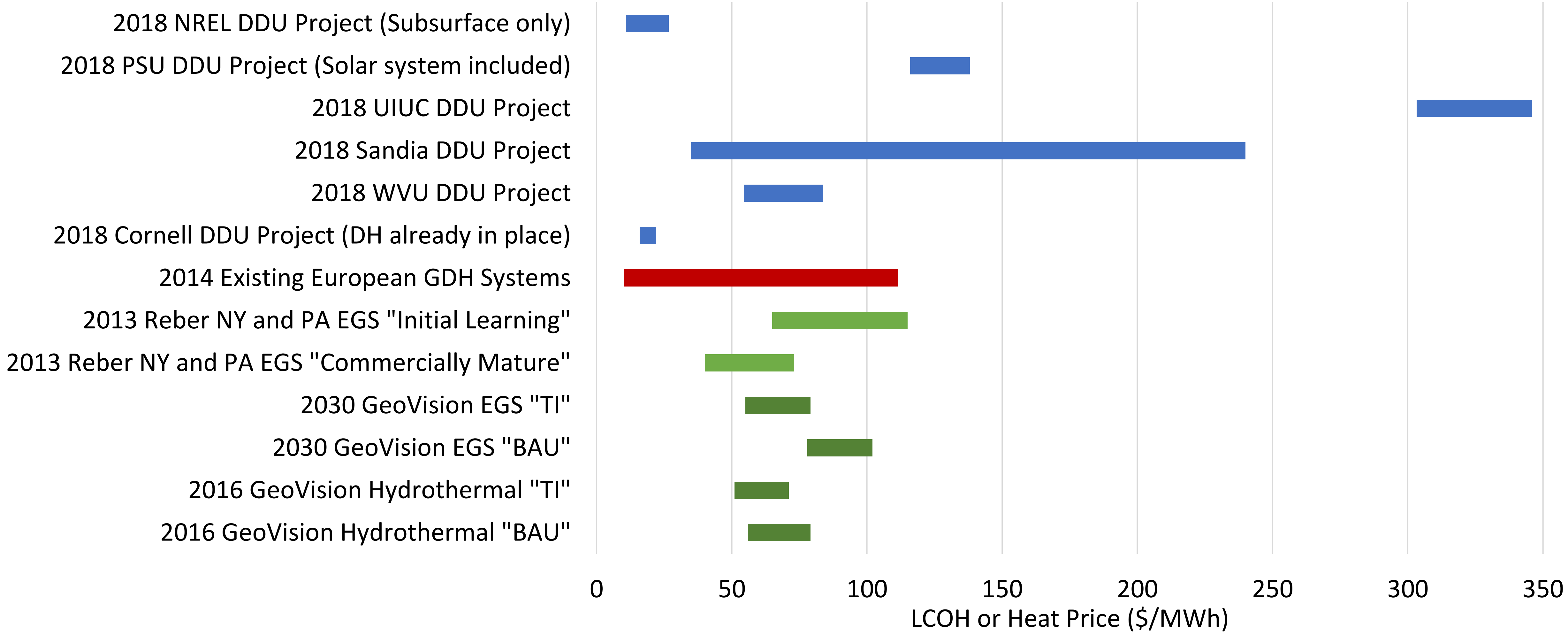
Levelized Costs (LCOH) for Base-Case DDU Projects

Project parameter	University of Illinois at Urbana-Champaign	Sandia National Laboratories	Cornell University	West Virginia University	National Renewable Energy Laboratory	Portland State University
SURFACE APPLICATION						
System size	0.6 MW	6.2 MW	13 MW (including heat pumps)	32 MW (including heat pumps)	15 MW	0.5 MW
Surface equipment	District heat + electric heat	District heat	District heat (+ heat pumps)	District heat + absorption cooling	Absorption cooling	District heat (using solar thermal energy reservoir storage)
Surface capital cost	$5,000/kW	$785/kW	$560/kW	$1,300/kW	$381/kW	$400/kW
Surface capital cost inclusions	Piping + district heat system	Piping + district heat system	Heat pumps + district heat connection	Piping + district heat retrofit	Piping + absorption cooling system	Piping + building heat system
GEOTHERMAL SYSTEM						
Subsurface capital cost ($/MMBtu)	$91.8	$3.7	$4.1	$5.8	$2.4	$1.3
TOTAL PROJECT						
Tax rate	0%	0%	0%	30%	0%	0%
Discount rate	5%	7%	2.5%	7.5%	5%	0.8%
Project lifetime	50 years	30 years	30 years	30 years	30 years	30 years
Base case LCOH ($/MMBtu)	$101	$12	$5	$18	$3.7	$34

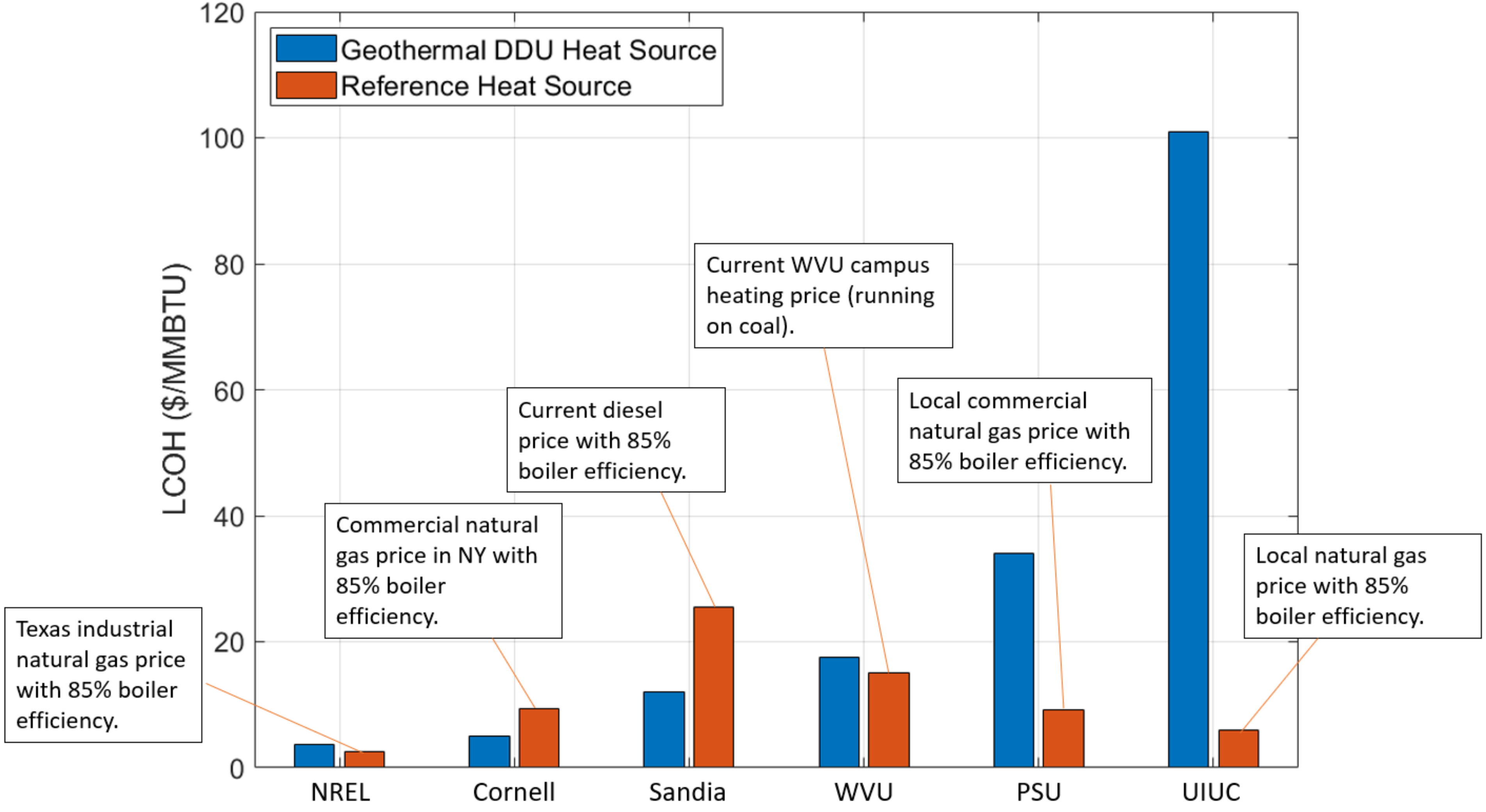
Feasibility of DDU: LCOH Ranges



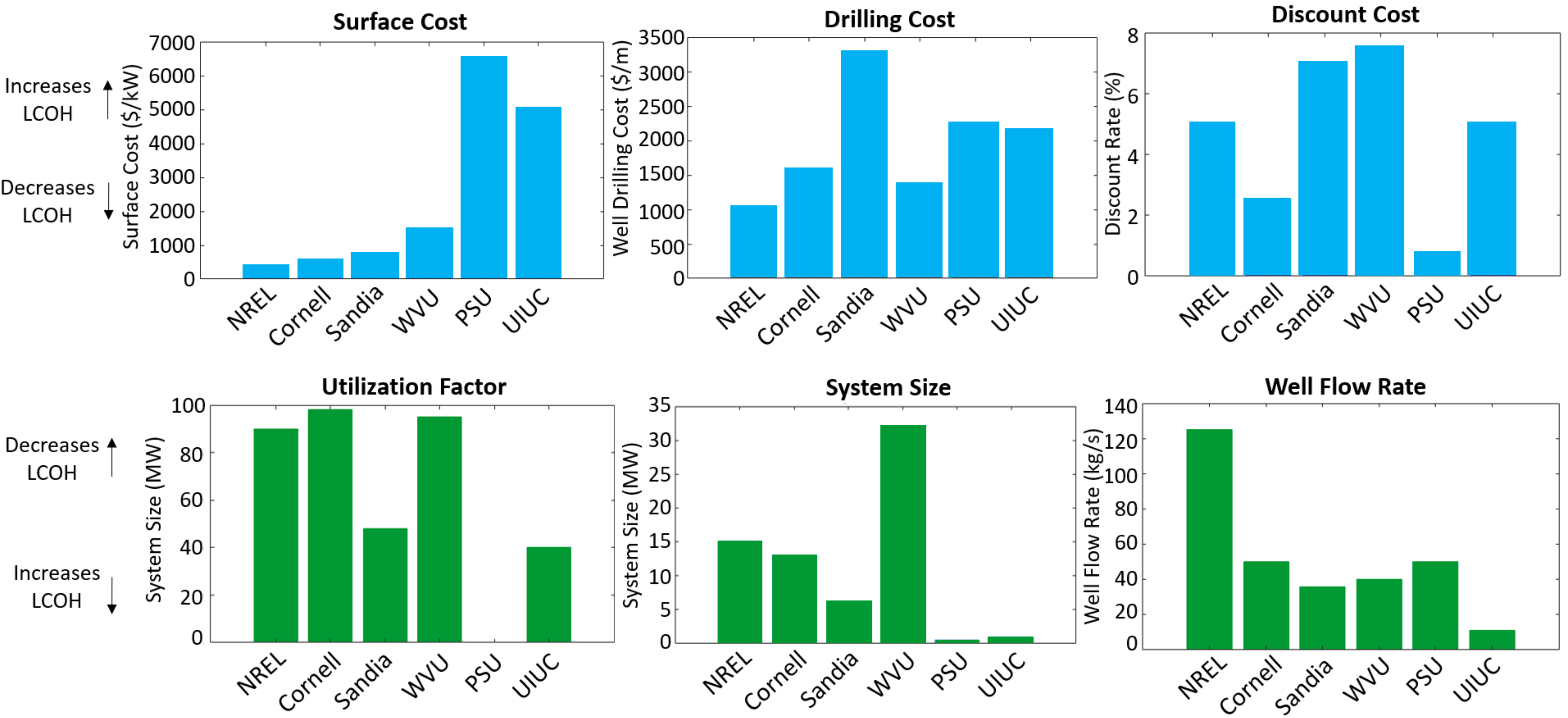
DDU vs. European and *GeoVision* LCOH



DDU LCOH vs. Reference Fuel Cost



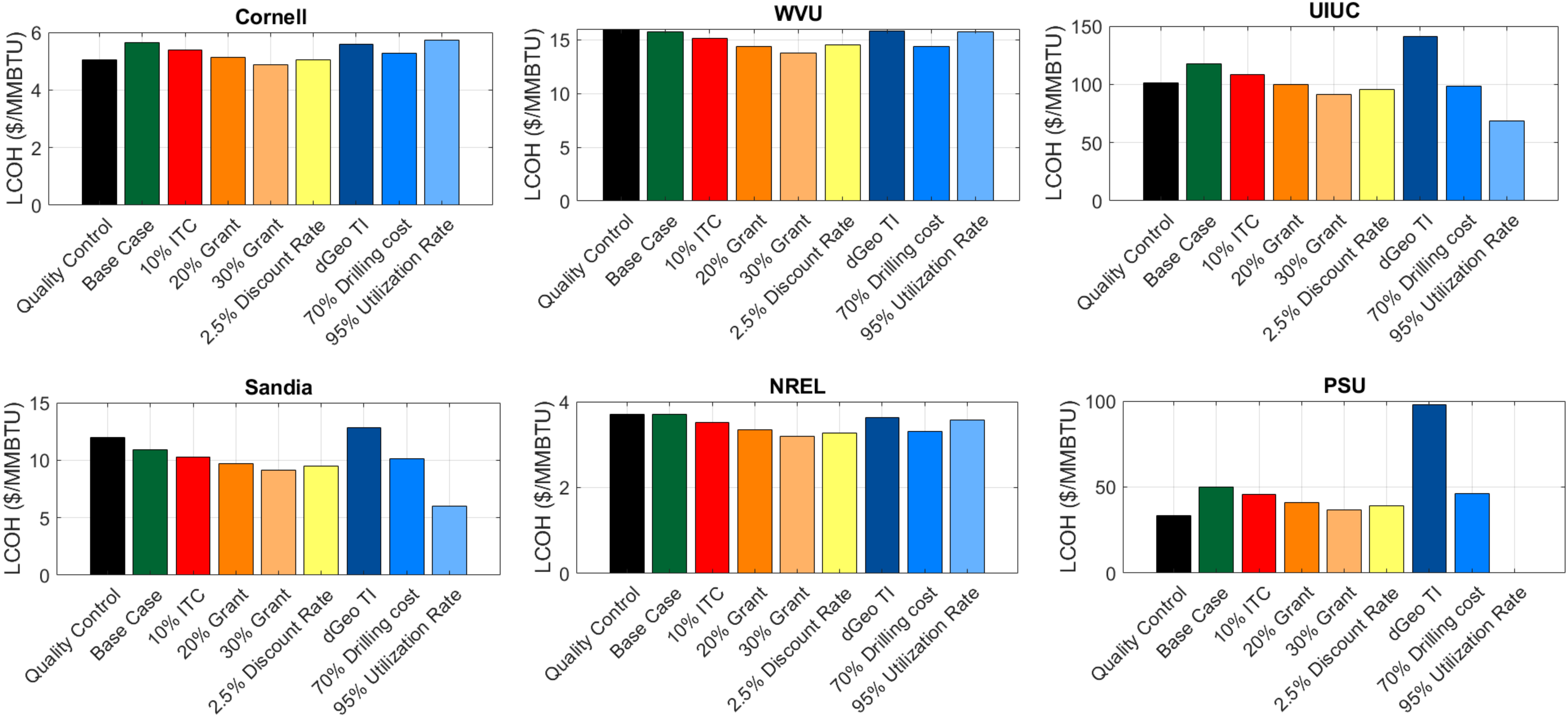
Impact of Key Parameters on DDU LCOH



Scenario Analysis of DDU LCOH

GEOPHIRES Scenario	Discount Rate	Project Lifetime	Tax Rate	Exploration Cost	Drilling Cost	Surface CAPEX and OPEX	Surface Equipment	Utilization Factor	
Scenario 1 (QC)	As is	As is	As is	As is	As is	As is	As is	As is	*Objective: Streamline inputs to better compare projects*
Scenario 2 (Default Financing)	**5%**	**30 years**	**0%**	As is	As is	As is	As is	As is	
Scenario 3 (Default Cost + Financing)	**5%**	**30 years**	**0%**	**$0**	**Corrected**	As is	As is	As is	
Scenario 4 (Subsurface LCOH)	**5%**	**30 years**	**0%**	**$0**	As is	**$0**	**No HPs, heaters, etc.**	As is	
Scenario 5 (Low Drilling Cost)	**5%**	**30 years**	**0%**	As is	**70%**	As is	As is	As is	*Objective: Evaluate key factors impacting DDU deployment*
Scenario 6–8 (Grants & Tax Credits 10, 20, 30%)	**5%**	**30 years**	**0%**	As is	As is	As is	As is	As is	
Scenario 9 (High Utilization Factor)	**5%**	**30 years**	**0%**	As is	As is	As is	As is	**95%**	
Scenario 10 (dGeo TI)	**5%**	**30 years**	**0%**	**$3.5M**	**50%**	As is	**80% end-use efficiency**	As is	
Scenario 11 (Low Discount Rate)	**2.5%**	**30 years**	**0%**	As is	As is	As is	As is	As is	

Scenario Analysis of DDU LCOH *(cont.)*



Takeaways from Scenario Analysis

Key project parameters drive overall LCOH, including:

- ✓Resource depth and temperature
- ✓Surface application
- ✓Well flow rate
- ✓Drilling cost
- ✓Utilization factor
- ✓Discount rate

Other factors can lower LCOH:

- ✓ Larger vs. smaller systems
- ✓ Retrofit of existing surface equipment vs. new installations
- ✓ Limit surface piping lengths: locate thermal demand close to geothermal resource
- ✓ Grants and incentives

Beyond LCOH: DDU Feasibility by Other Metrics

	Cornell	UIUC	NREL	WVU	Sandia	PSU
Environmental Impacts	70% drop in LCOH when including avoided emissions	CO_2 offsets from DDU v. BAU = 5.4 x10^5 kg CO_2/yr	N/A	Emissions analysis	CO_2 offsets from DDU vs. BAU = 2,248 MT/yr	Statement on emissions from NG life cycle vs. DDU
Societal Impacts	50% drop in LCOH when including regional economic impact	N/A	N/A	N/A	N/A	N/A
Other Calculated Benefits (e.g., storage, cooling)	N/A	Combined heating and cooling scenario	NPV for DDU cooling. LCOC = $21/MWh (competitive with alternatives)	Integrated heating and cooling system	N/A	Storage cost (LCOS) = $34/MMBTU (competitive with alternatives)
Resilience and Sustainability	DDU key component in Climate Action Plan	Energy security, weather resilience	N/A	Resilient energy source for sustainability plan	N/A	Reliability and resilience assessment: geothermal = high
Market Potential	Studied as part of ongoing ESH project	Regulatory assessment	Regulatory assessment	Regulatory assessment	Regulatory assessment	Regulatory assessment

Lessons Learned

- ✓ Wide variety in DDU projects' technical, economic, and financing conditions results in **wide range of projects' cost competitiveness**
- ✓ Geothermal DDU can be used for **heating, cooling, and thermal storage**
- ✓ Large **decarbonization** potential of geothermal DDU.

For DDU-related publications, go to
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https://github.com/NREL/GEOPHIRES-v2

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