# 2030: Future Nuclear Technology and Applications

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# NuScale SMR Overview

NAYGN Professional Development and NEA Conference

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Lenka Kollar
Director, Strategy & External Relations

# Acknowledgement and Disclaimer

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# Innovation and ingenuity for a new day of energy



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# A bold, new energy source

- **Smarter energy** – flexible design can support multiple applications, integrate with renewables resources, provide highly reliable power to mission critical facilities, and serve as clean baseload power.
- **Cleaner Energy** – 100% carbon-free energy – as clean as wind or solar – with a small land footprint.
- **Safer Energy** – should it become necessary, NuScale's SMR shuts itself down and self-cools for an indefinite period of time, with no operator action required, no additional water, and no AC or DC power needed.
- **Cost Competitive –** the NuScale SMR is far less complex than other designs. Off-site fabrication and assembly reduce cost. Components are delivered to the site in ready-to-install form. All of this results in construction occurring in a shorter, more predicable period of time.



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# Who is NuScale Power?

- NuScale Power was formed in 2007 for the sole purpose of completing the design and commercializing a small modular reactor (SMR) – the NuScale Power Module™.
- Initial concept had been in development and testing since the 2000 U.S. Department of Energy (DOE) MASLWR program.
- Fluor, global engineering and construction company, became lead investor in 2011.
- In 2013, NuScale won a $226M competitive U.S. DOE Funding Opportunity for matching funds.
- >400 patents granted or pending in nearly 20 countries.
- >350 employees in 6 offices in the U.S. and 1 office in the U.K.
- Making substantial progress with a rigorous design review by the U.S. Nuclear Regulatory Commission (NRC).
  - Phase 4 of NRC Review is on schedule for completion December 2019.
- Total investment in NuScale to date ~US$800M.
- On track for first plant operation in 2026 in the U.S.

*NuScale Engineering Offices Corvallis*


*One-third scale NIST-1 Test Facility*

*NuScale Control Room Simulator*



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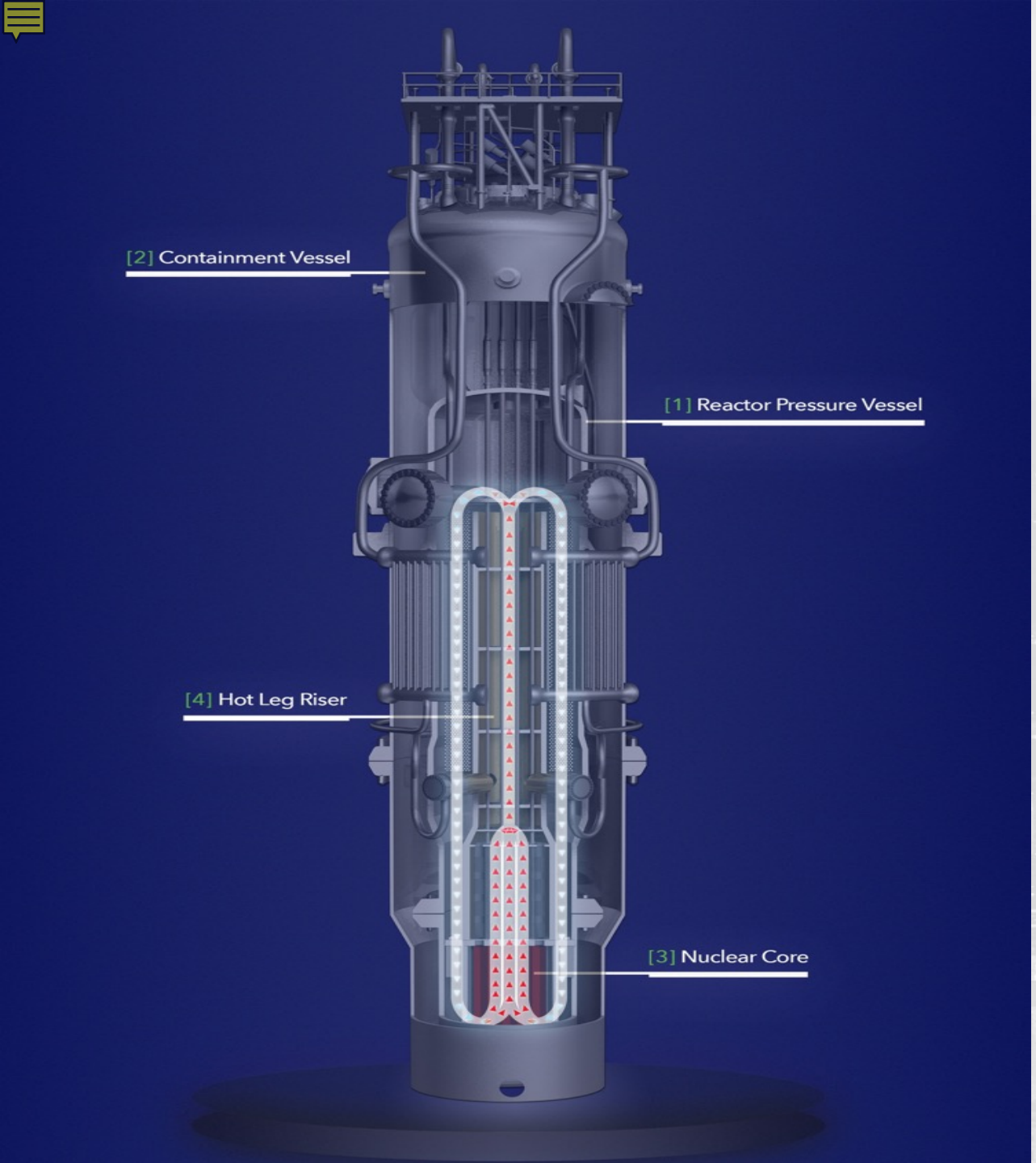


# Core Technology: NuScale Power Module

- A **NuScale Power Module**™ (NPM) includes the reactor vessel, steam generators, pressurizer, and containment in an **integral package** – simple design that eliminates reactor coolant pumps, large bore piping and other systems and components found in large conventional reactors.

- Each module produces **up to 60 MWe**
  - small enough to be factory built for easy transport and installation
  - dedicated power conversion system for flexible, independent operation
  - incrementally added to match load growth
    - up to **12 modules for 720 MWe** gross (684 MWe net) total output



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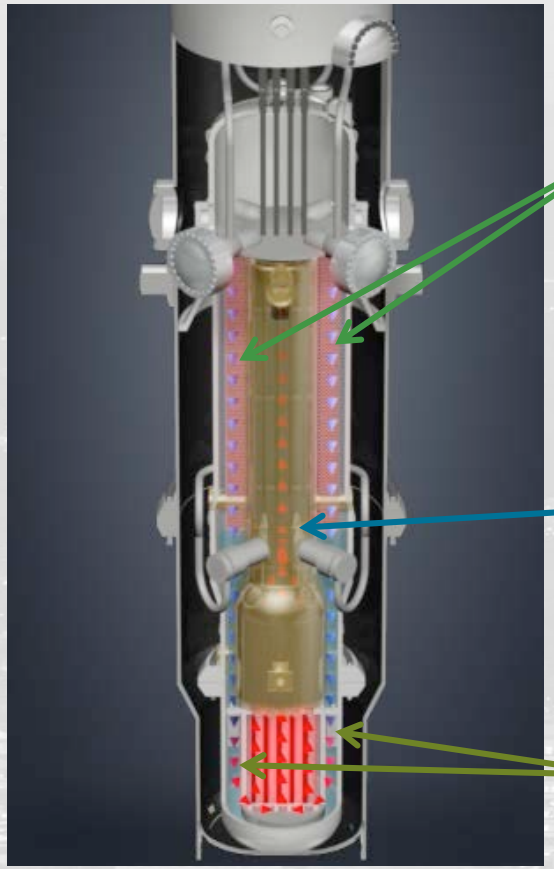
# Simplicity Enhances Safety

**Natural Convection for Cooling**
- Passively safe - cooling water circulates through the nuclear core by natural convection eliminating the need for pumps

**Seismically Robust**
- System submerged in a below-grade pool of water in an earthquake and aircraft impact resistant building

**Simple and Small**
- Reactor core is 1/20th the size of large reactor cores
- Integrated reactor design - no large-break loss-of-coolant accidents

**Defense-in-Depth**
- Multiple additional barriers to protect against the release of radiation to the environment



***Conduction*** **– the water heated by the nuclear reaction (primary water) transfers its heat through the walls of the tubes in the steam generator, heating the water inside the tubes (secondary water) and turning it to steam. This heat transfer cools the primary water.**

***Convection*** **– energy from the nuclear reaction heats the primary water causing it to rise by convection and buoyancy through the riser, much like a chimney effect**

***Gravity / Buoyancy –*** **colder (denser) primary water "falls" to bottom of reactor pressure vessel, and the natural circulation cycle continues**

**Second-to-none safety case – site boundary Emergency Planning Zone capable**



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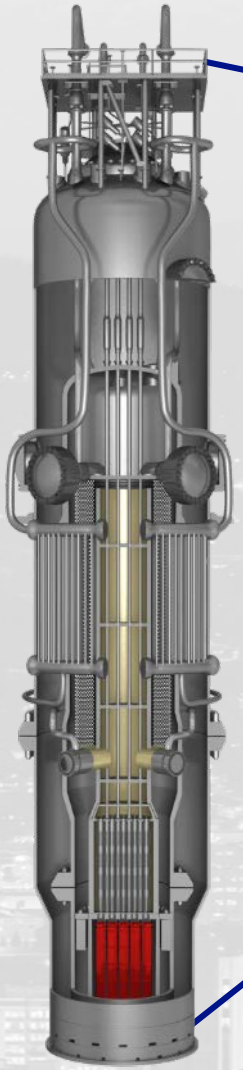
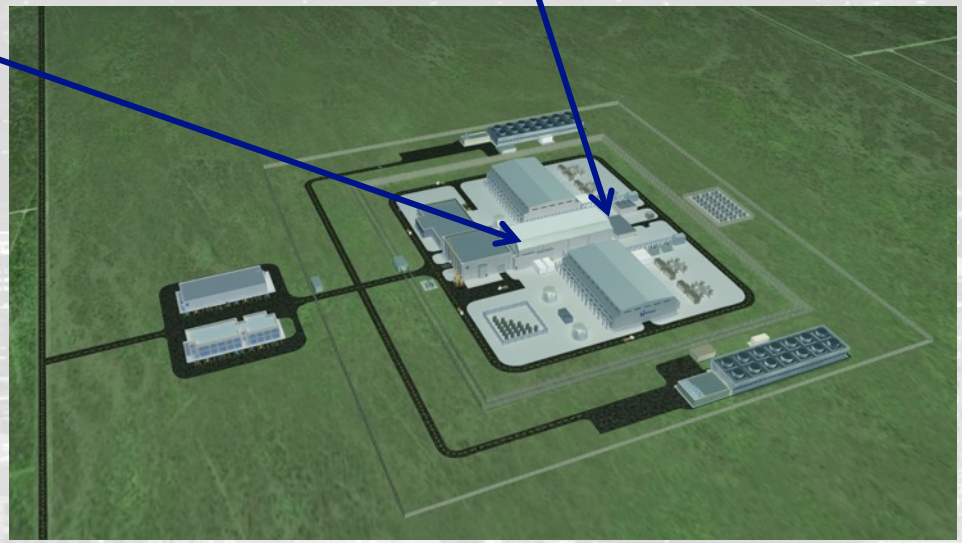
# NuScale Plant Site Overview







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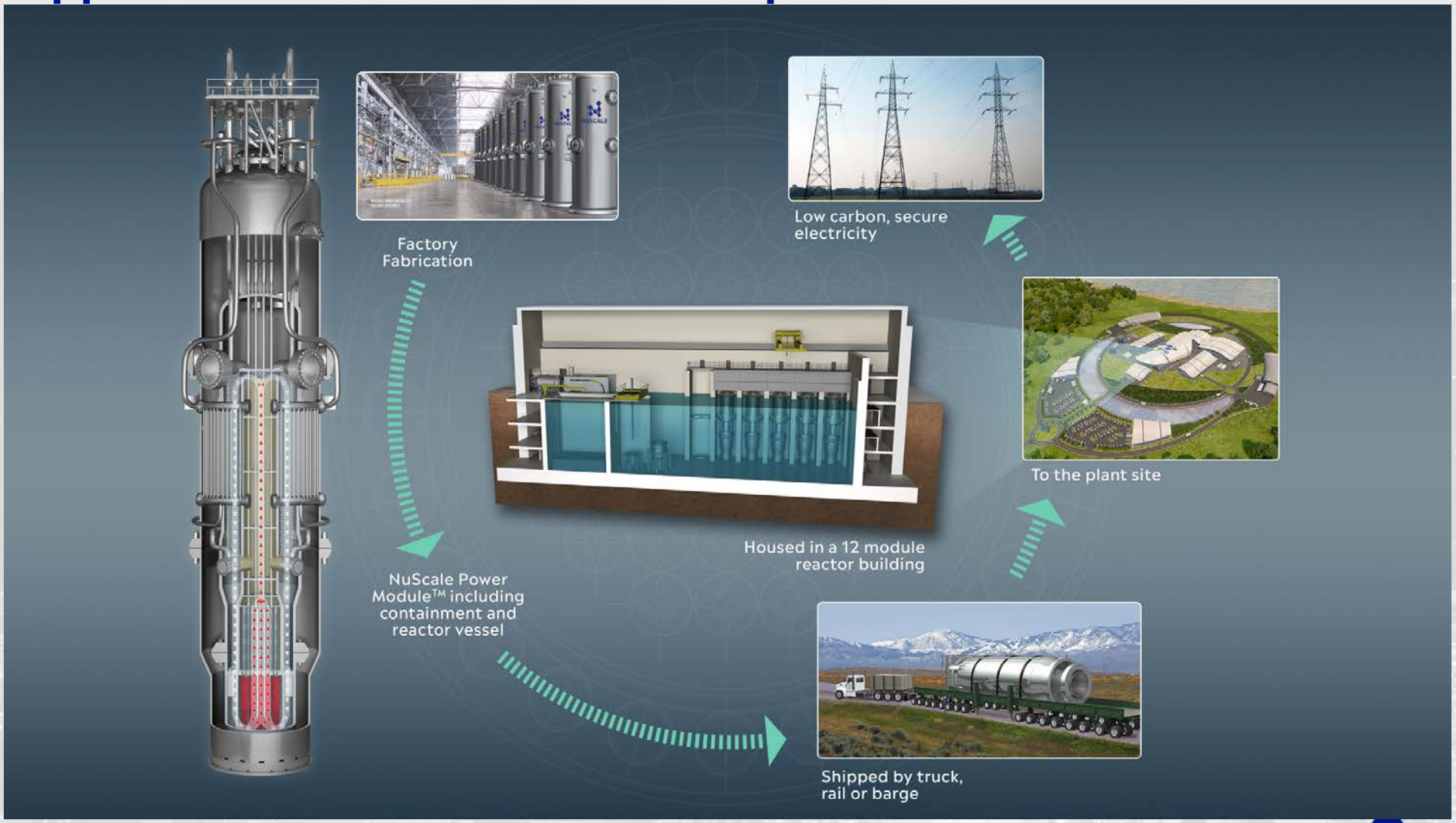
# A New Approach to Construction and Operation



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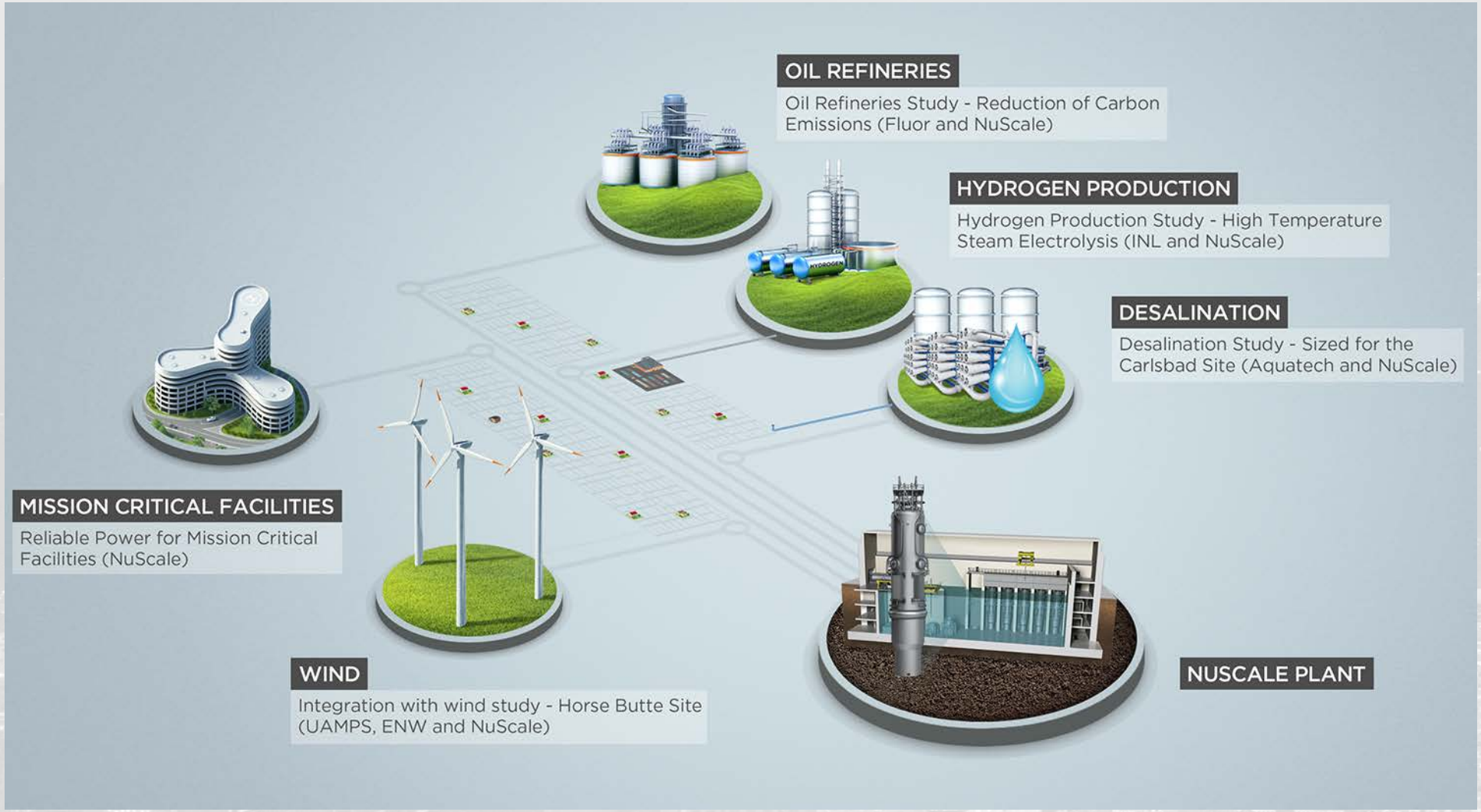
# Beyond Baseload: NuScale Diverse Energy Platform




*Reports for associated technical studies are available at: www.nuscalepower.com/technology/technical-publications*



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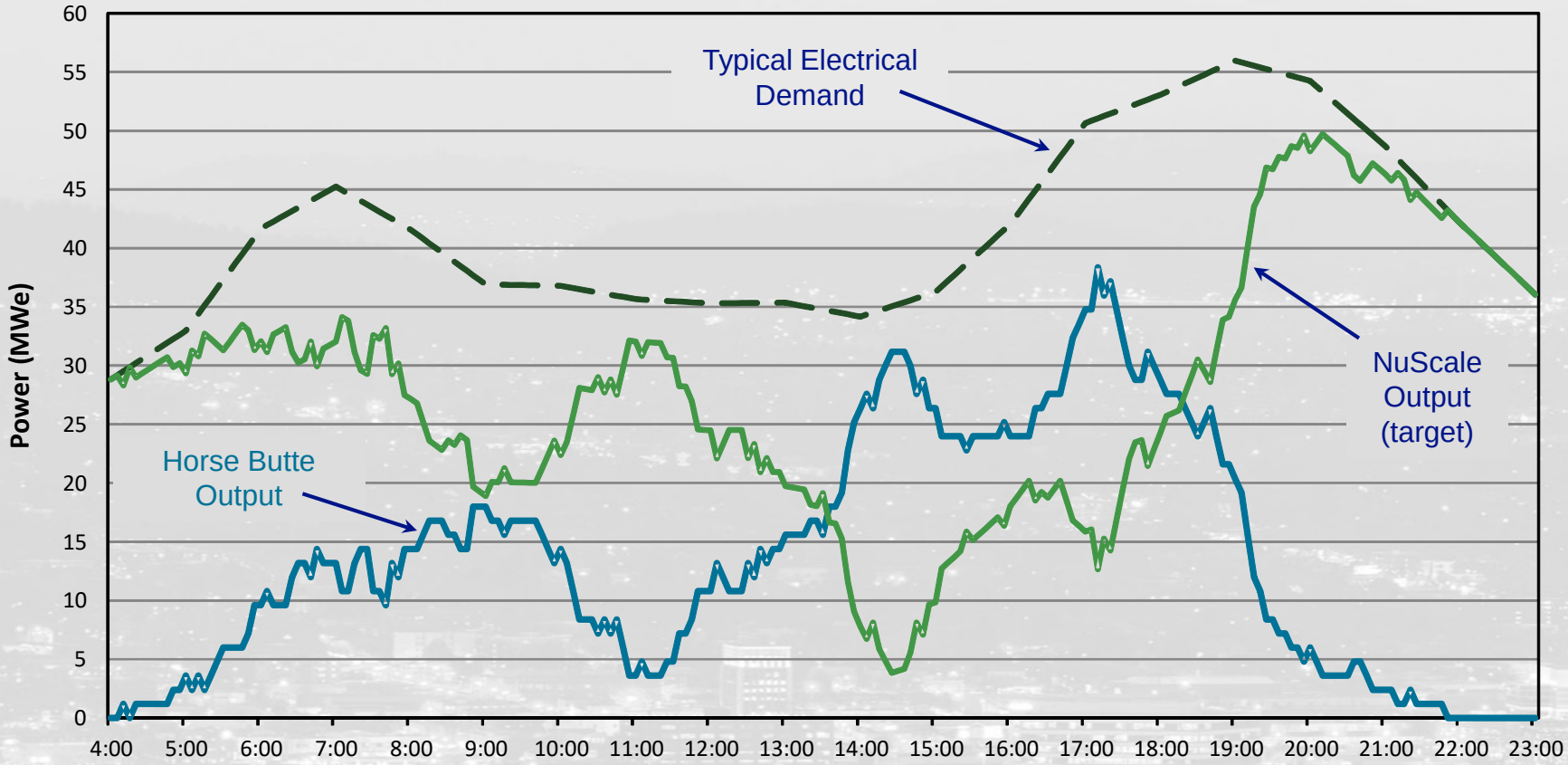
# Load-Following with Wind




NuScale design meets or exceeds EPRI Utility Requirements Document (URD), Rev. 13, load following and other ancillary service requirements.



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# NuScale Co-Generation Studies

## Oil Refinery Study Reducing Carbon Emissions *(Fluor and NuScale)*

**10-Module Plant** coupled to a 250,000 barrels/d refinery, thus avoiding ~230 MT/hr $CO_2$ emissions

## Desalination Study for Clean Water and Electricity *(Aquatech and NuScale)*

**8-Module Plant** producing 60 Mgal per day of clean water plus ~400 MWe to the grid


## High-Temp Steam Electrolysis for Carbon-free Hydrogen Production *(INL and NuScale)*

**6-Module Plant** producing ~240 tons per day carbon-free hydrogen for ammonia plant



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# A New Level of Plant Resiliency

### Island Mode/Loss of Offsite Power

A single module can power the entire plant in case of loss of the grid; no operator or computer actions, AC/DC power or additional water required to keep the reactors safe


### First Responder Power

On loss of the offsite grid, through variable (0% to 100%) steam bypass, all 12 modules can remain at power and be available to provide electricity to the grid as soon as the grid is restored

### Resilience to Natural Events

Reactor modules and fuel pool located below grade in a Seismic Category 1 Building

- Capable of withstanding a Fukushima type seismic event
- Capable of withstanding hurricanes, tornados, and floods

### Resilience to Aircraft Impact

Reactor building is able to withstand aircraft impact as specified by the NRC aircraft impact rule

### Cybersecurity

Module and plant protection systems are non-microprocessor based using field programmable gate arrays that do not use software and are therefore not vulnerable to internet cyber-attacks

### Electromagnetic Pulse (EMP/GMD)

Resilience to solar-induced geomagnetic disturbances (GMDs) and electromagnetic pulse (EMP) events beyond current nuclear fleet.



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*Image courtesy of Third Way Nuclear Reimagined*

# NuScale Micro-Reactor Concepts

## 10-50 MWe Micro-NuScale Power Module™

- **Builds on NuScale's existing technology; intended for:**
  - Supplying power to communities with small grids,
  - Remote and off-grid communities
  - Off-grid industrial facilities
  - Long duration remote mining
  - Stationary / permanent military installations
- **Design imperatives include:**
  - Reduced construction time
  - Simplified operations
  - Increased fuel cycle length

## 1-10 MWe Heat Pipe Reactor

- **Simple and inherently safe compact heat pipe cooled reactor concept** that require little site infrastructure, can be rapidly deployed, and are fully automated during power operation
- **Applications include:**
  - Remote small off-grid communities with seasonal fuel transportation delivery limitations
  - Remote mining operations with a short lifespan
  - Temporary power for disaster relief
  - Power in space



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# Current Progress in Commercialization: Licensing, Supply Chain, and Customers



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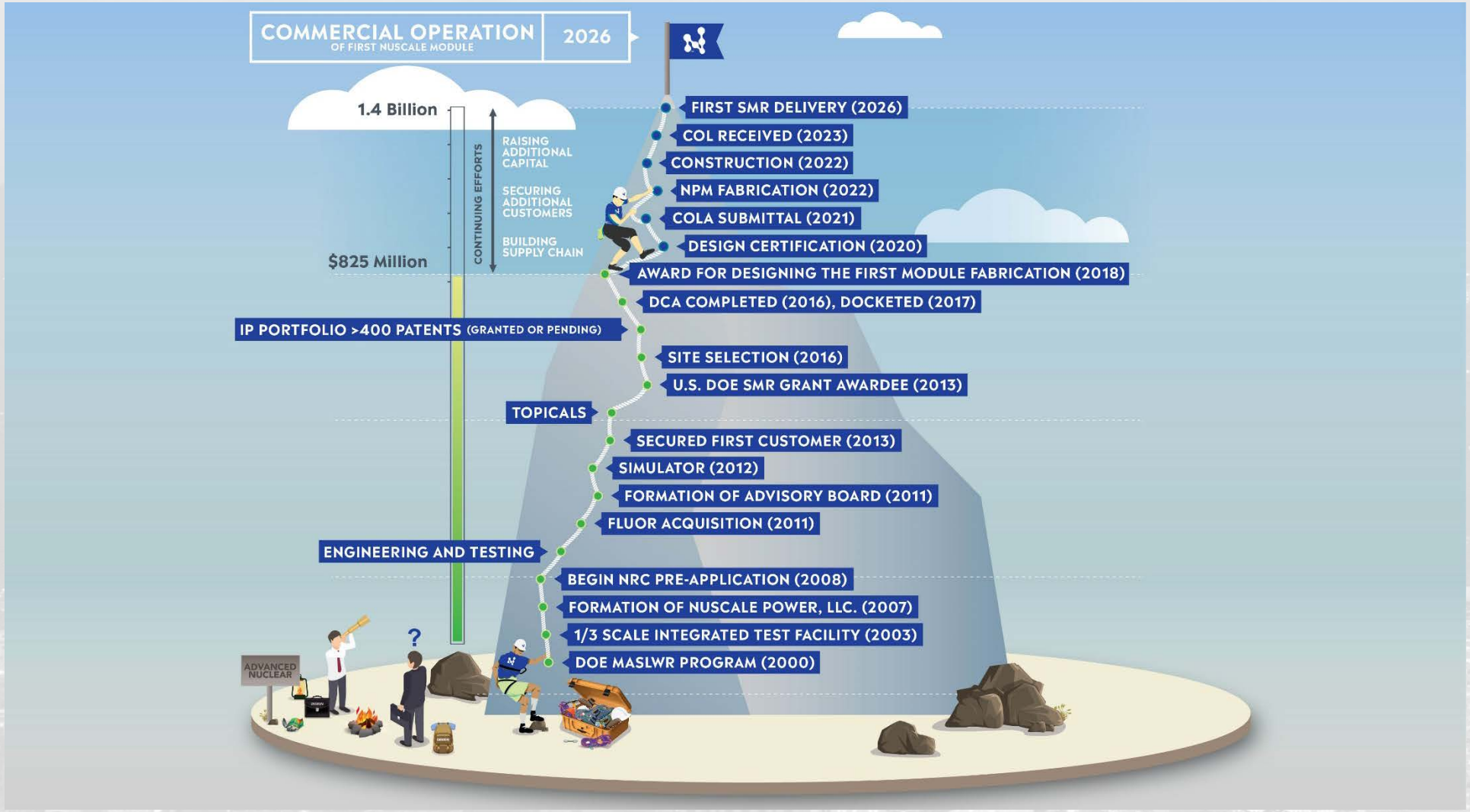
# Blazing the Trail to Commercialization



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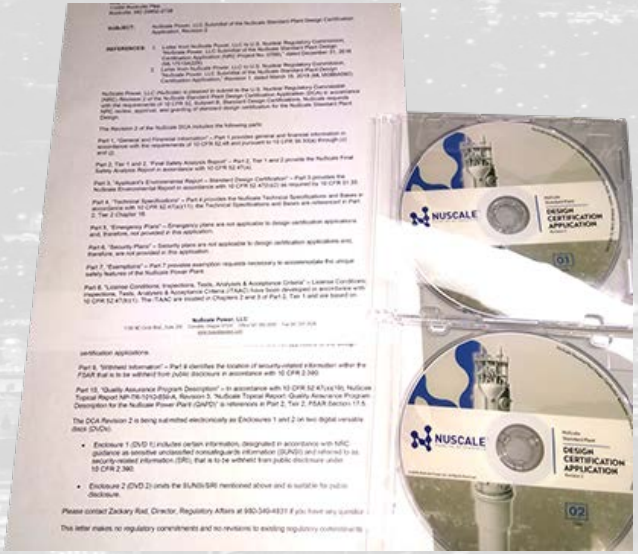
# First SMR to Undergo Licensing in the U.S.

- Design Certification Application (DCA) completed in December 2016
- Docketed and review commenced by U.S. Nuclear Regulatory Commission (NRC) in March 2017
- Phase 4 of the NRC review on schedule for completion December 2019. Technical review would be completed.
- NRC has published its review and approval schedule; **to be approved in September 2020**




DCA Statistics

- 12,000+ pages
- 14 Topical Reports
- >2 million labor hours
- >800 people
- >50 supplier/partners
- Over $500M



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# Factory Fabrication

- NuScale Power Modules™ (NPMs) are produced in a factory and then shipped onsite to be installed in the reactor building.
- In 2018, **BWX Technologies, Inc. (BWXT)** was selected to provide manufacturing input leading to fabricating the first NuScale Power Modules™.
  - The decision follows a rigorous 18-month selection process, with expressed interest from 83 companies based in 10 countries.
  - BWXT and NuScale are collaborating to update the design optimizing for manufacturing and transportation and reducing overall costs of the NPMs.
- In 2019, **Doosan Heavy Industries and Construction Co., Ltd. (DHIC)** and NuScale signed an MOU for strategic cooperation to support deployment of the NPM worldwide. DHIC will bring its expertise in nuclear pressure vessel manufacturing and will join the larger U.S.-led manufacturing team.
- Manufacturing trials are planned for 2020.



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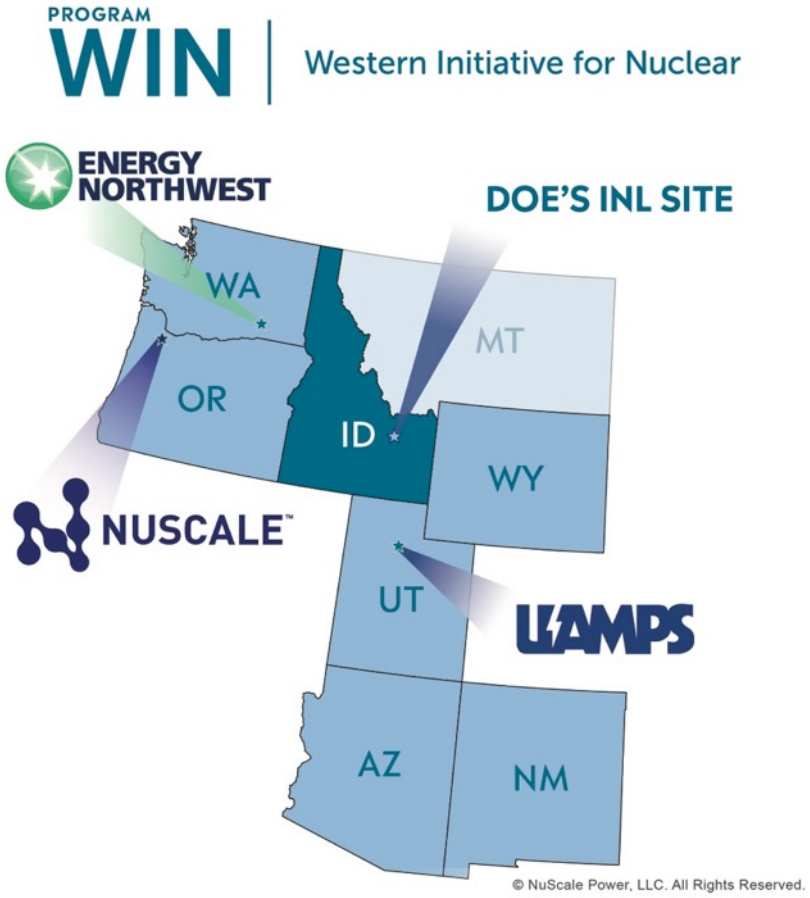
# First Deployment: UAMPS Carbon Free Power Project




- **Utah Associated Municipal Power Systems (UAMPS)** provides energy services to community-owned power systems throughout the Intermountain West.
- First deployment will be a **12-module plant (720 MWe)** within the Idaho National Laboratory (INL) site, slated for **commercial operation in 2026.**
- DOE awarded $16.5 million in matching funds to perform site selection, secure site and water, and prepare combined operating license application to NRC.
- **Joint Use Modular Plant (JUMP)** Program: INL-DOE will lease one of the modules in the 12-module plant, for research purposes, an additional module may be used in a Power Purchase Agreement (PPA) to provide power to INL.

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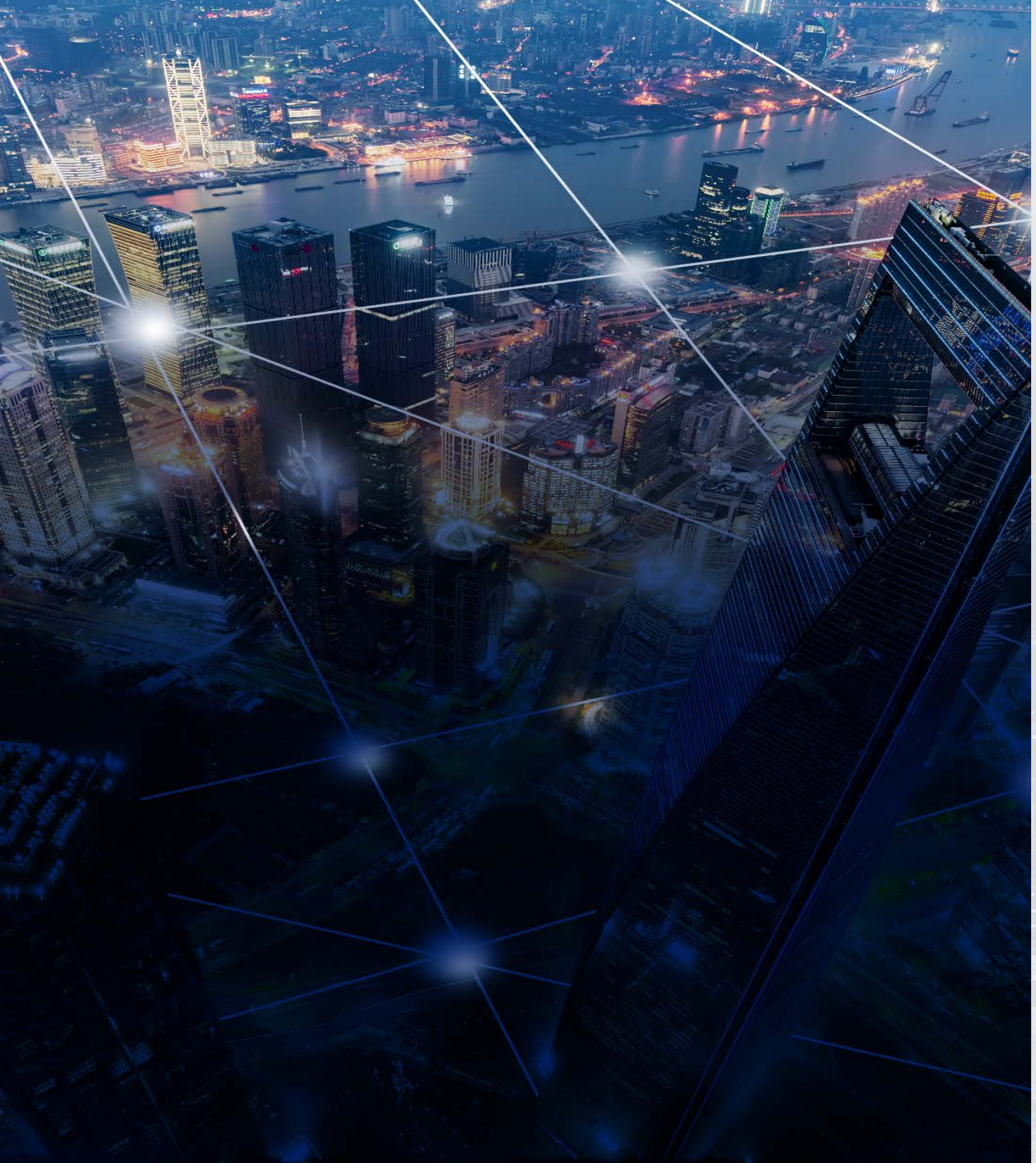

# International Opportunities

- NuScale informed the **Canadian Nuclear Safety Commission (CNSC)** of its intention to submit an application under the pre-licensing vendor design review process and signed MOUs with **Ontario Power Generation (OPG) and Bruce Power**
- NuScale has been actively involved in the **United Kingdom's** SMR market and continues to support UK government SMR program initiatives
- NuScale and Nuclearelectrica SA signed MOU to explore SMRs for **Romania**
- NuScale signed MOU with Jordan Atomic Energy Commission (JAEC) to evaluate NuScale's SMR for use in **Jordan**
- Many international opportunities for NuScale SMR deployment in **Eastern Europe**, the **Middle East**, **Southeast Asia**, and **Sub-Saharan Africa**



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# The Future of Energy is Here

NuFuel HTP2 Testing


One-third scale NIST-1 Test Facility


NuScale Control Room Simulator



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# Role of Advanced Reactors


Dr. Finis Southworth

*Chief Technology Officer*

*NGNP Industry Alliance*

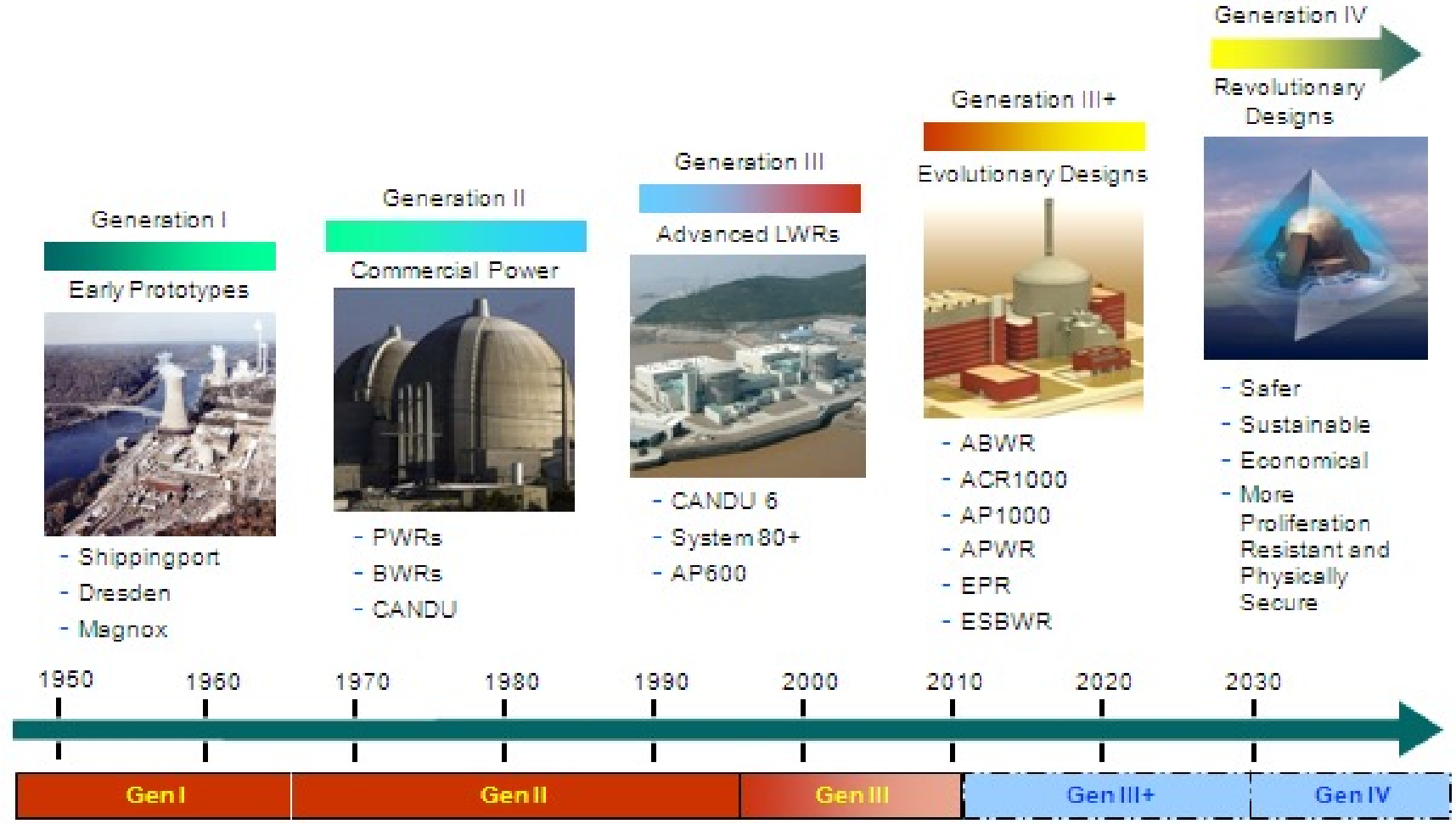

NAYGN Conference—Washington DC June 3, 2019

INL/MIS-16-40384

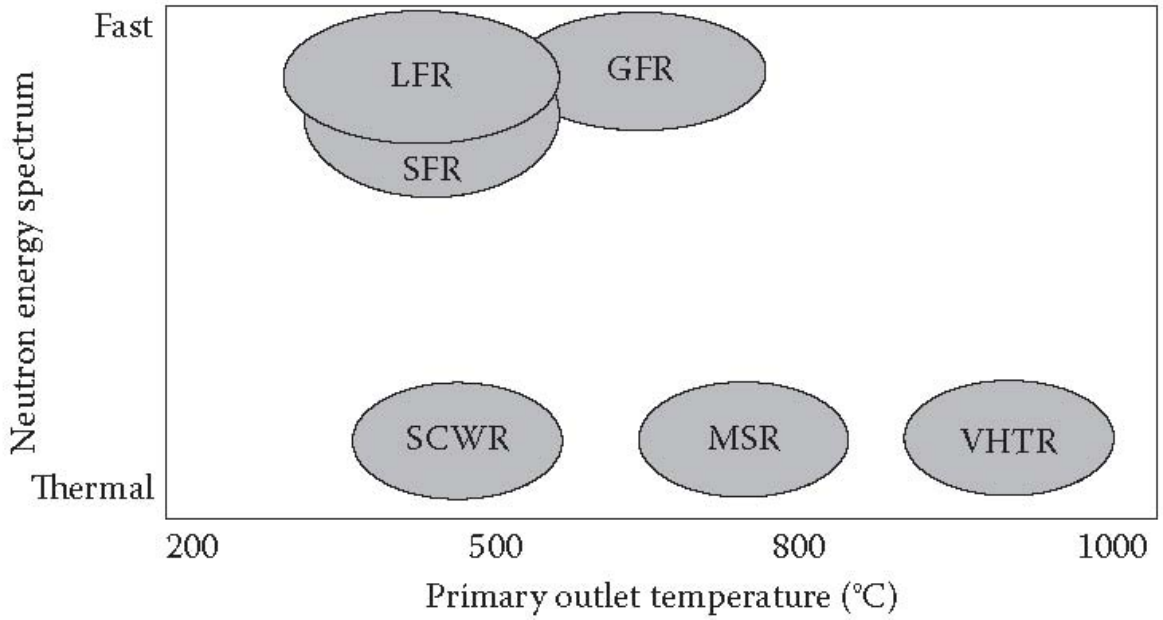
# Learning Objectives, Outline/Major Themes

- Summary of advanced reactors being considered
- Attributes—
- Roles—
  - Improved safety case
  - Resilience
  - Hybrid energy
  - Dual markets
  - Need for GHG free technologies across many energy sector…
  - Economics  (unproven for all concepts)

# The Evolution of Nuclear Power



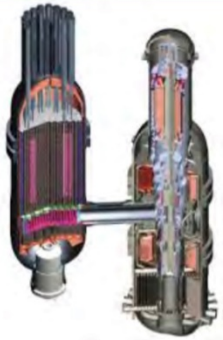
# Conceptual Mapping of Generation IV Nuclear Reactor Concepts



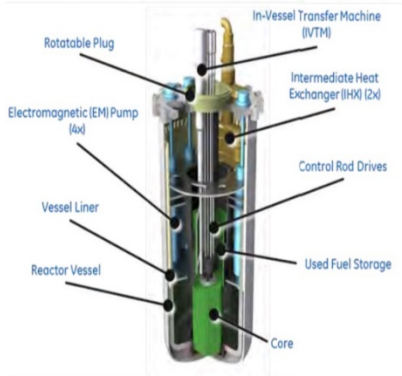

(Adapted from Corradini, M. L. *Rohsenow Symposium on Future Trends in Heat Transfer*, Massachusetts Institute of Technology, MA. 16 May 2003.)

# Advanced Reactors (Generation-IV)

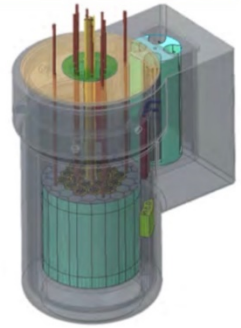
## High Temperature Gas-Cooled Reactors



## Sodium Fast Reactors

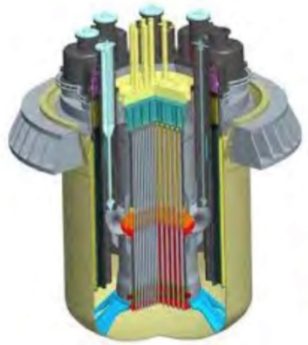



## Fluoride High Temperature Reactors

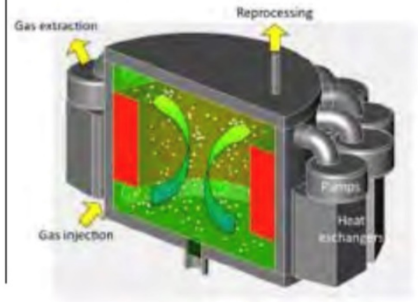


## Gas-Cooled Fast Reactors

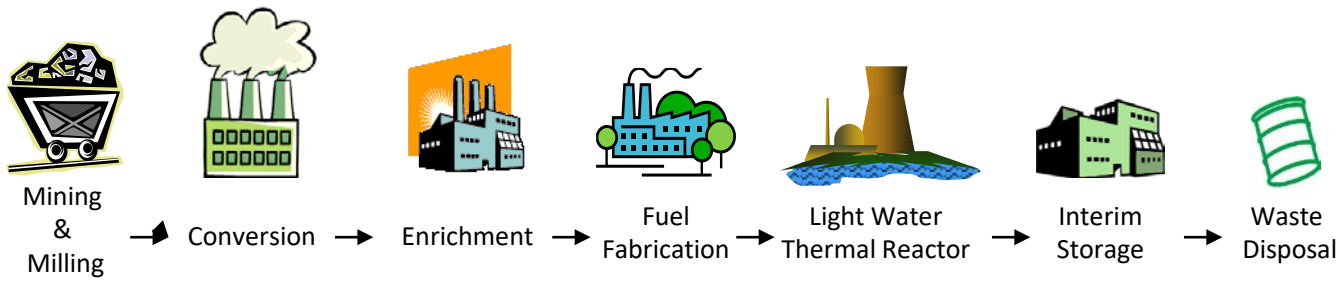
## Lead-Cooled Fast Reactors



## Molten Salt Reactors



# Once Through Fuel Cycle




**Depleted Uranium**
**Undefined Future**

**Mine Tailings**

**←Two Major Wastes→**
**In Terms of Radioactivity**

**Spent Nuclear Fuel**

# Micro-reactors and Small Modular Reactors

- **Faster more predictable construction**
- **Factory fabrication**
- **Strong safety case (completely passive DHR)**
- **Lower financial risk with staged deployment**
- **Siting flexibility**

- **Almost all advanced reactor concepts are micro- or small.**

- **There are 52 active development companies pursuing an advanced reactor design.**

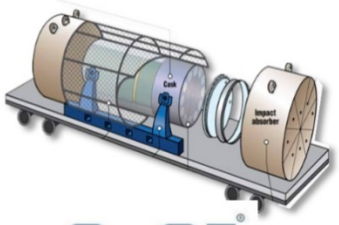
- **Micro—1-25 Mwe**
- **Small—300 MWe**

# Micro-Reactors

INL Idaho National Laboratory

## *Microreactors (vSMR) – a quick deployment success story or a market waiting to be discovered?*

- **2-20 MW, transportable, inherently safe**
- **LANL/Oklo heat pipe reactor - among others that look interesting**
- **Working through a successful demonstration at INL can resolve a number uncertainties in the AR deployment process at a reduced cost**
- **Successful deployment in niche markets (space, defense, remote off-grid) can open up broader commercial markets**

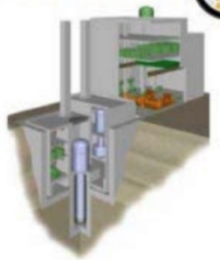


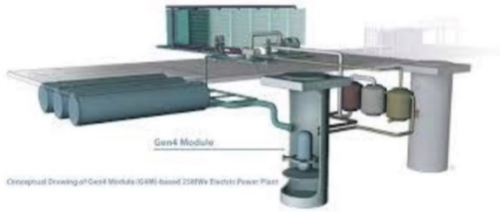
OKLO

U BATTERY Local Modular Energy

STARCORE NUCLEAR


TOSHIBA Micro Nuclear






*Gen4Energy, 25MWe 'battery'*

US ULTRA SAFE NUCLEAR

GE HITACHI

5

# Exceptional Safety Case

- **TRISO fueled reactors concepts generally require no off-site AC, no on-site AC, or on-site DC for DHR.**
- **Most aim to meet ASME safety case (no social disruption)**

- **Micro—1-25 Mwe**
- **Small—300 MWe**

# Fuel

## *Fuel Qualification (5 < TRL < 6)*

INL Idaho National Laboratory

- **Once a candidate fuel system is identified, a qualification program can be executed**
  - Lab, pilot, and production scale fabrication
  - Testing at prototypical service conditions (irradiation, temperature, chemistry)
  - Source term characterization
  - Fuel performance modeling (MOOSE-BISON-MARMOT)
  - HTR (TRISO) and SFR (U-Zr) fuel
- **The INL has led a high temperature reactor (TRISO) fuel qualification effort that will be completed ~2024**
  - Highest priority task in the gas-cooled reactor campaign, supported by all members of the HTR Technical Working Group

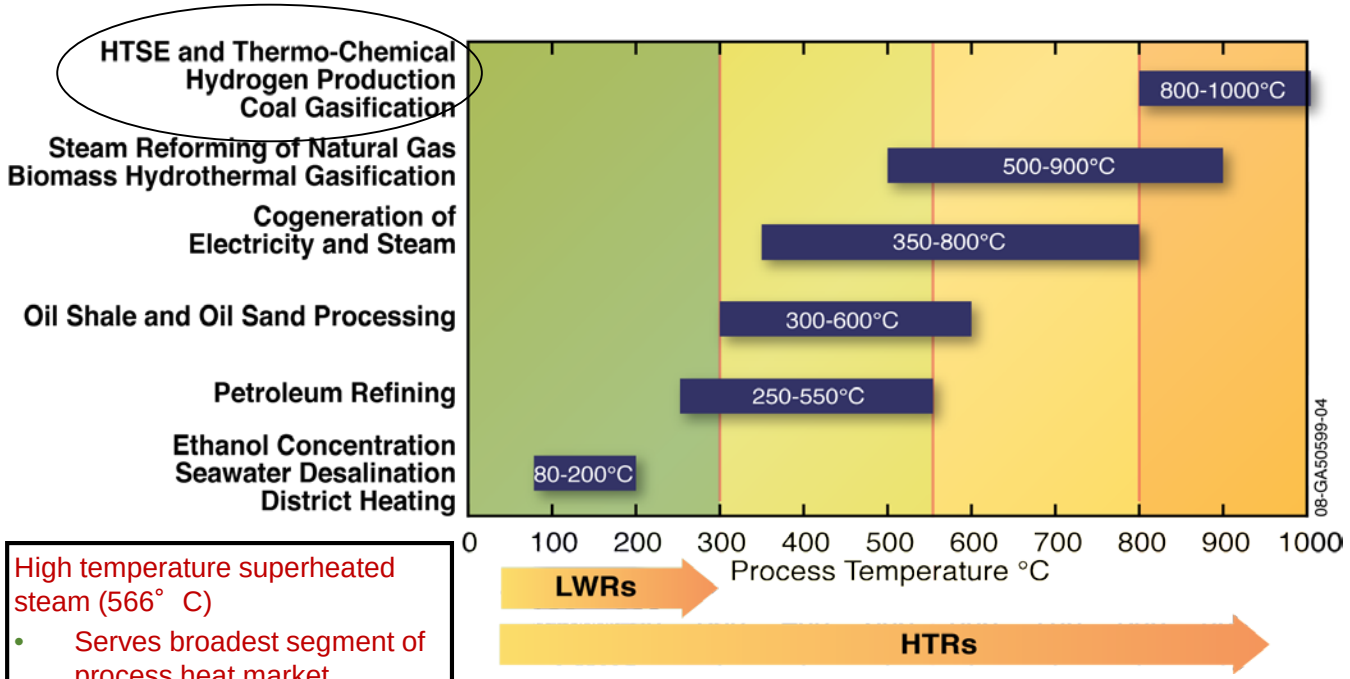
*Reactor vendors supported by the AGR Fuel Qualification program*

# Hybrid Energy

- **Most high temperature reactors can load-follow well, allowing a meshing with intermittent renewables**
- **HTRs can satisfy multiple markets—electricity to the grid, and process heat to industry.**

- **Micro—1-25 Mwe**
- **Small—300 MWe**

# HTGRs Can Serve Wide Variety of Applications




High temperature superheated steam (566˚ C)

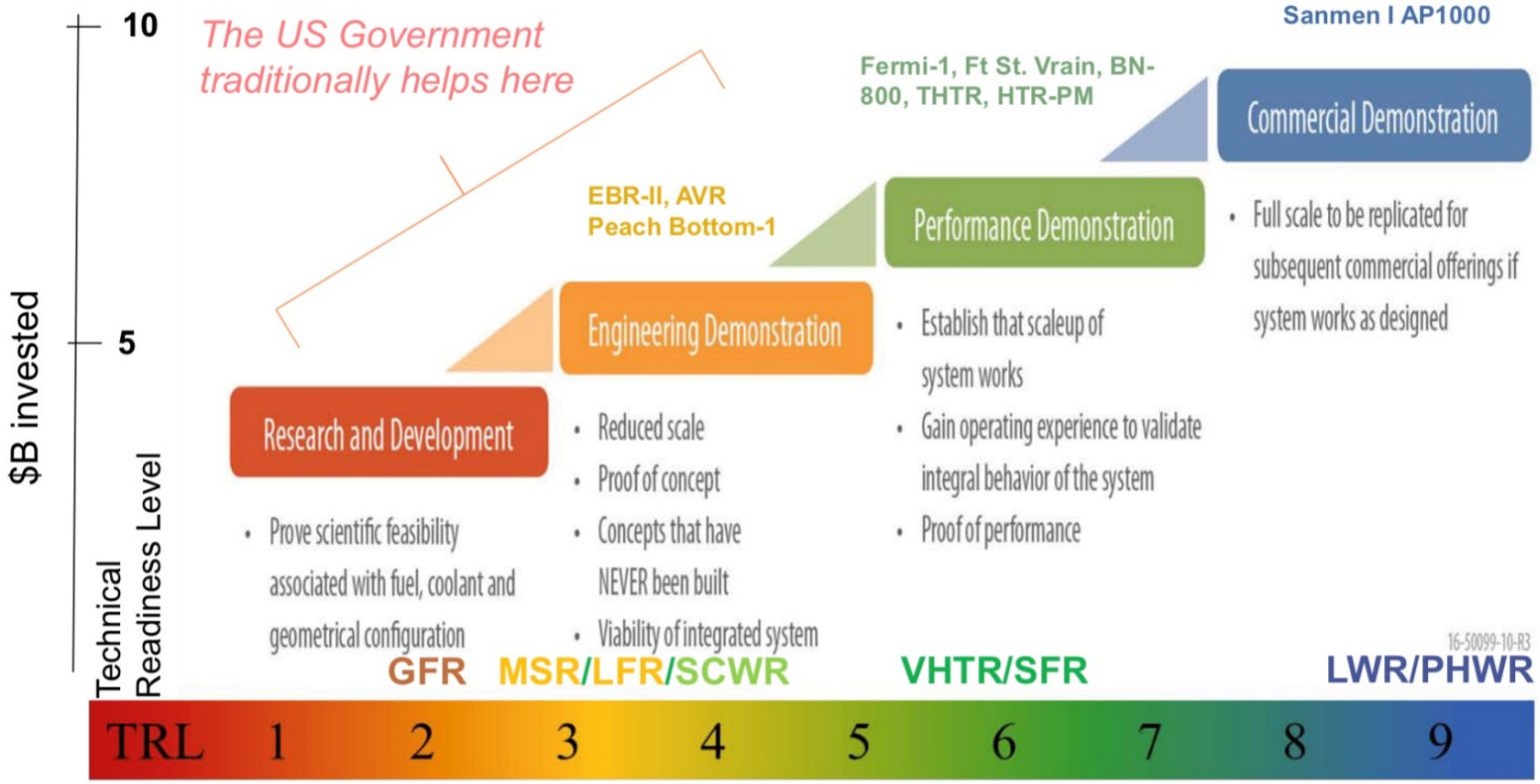
- Serves broadest segment of process heat market
- High efficiency electricity generation (~43.5% net)

*High Temperature Reactors can provide energy production that supports the spectrum of industrial applications including the petrochemical and petroleum industries*

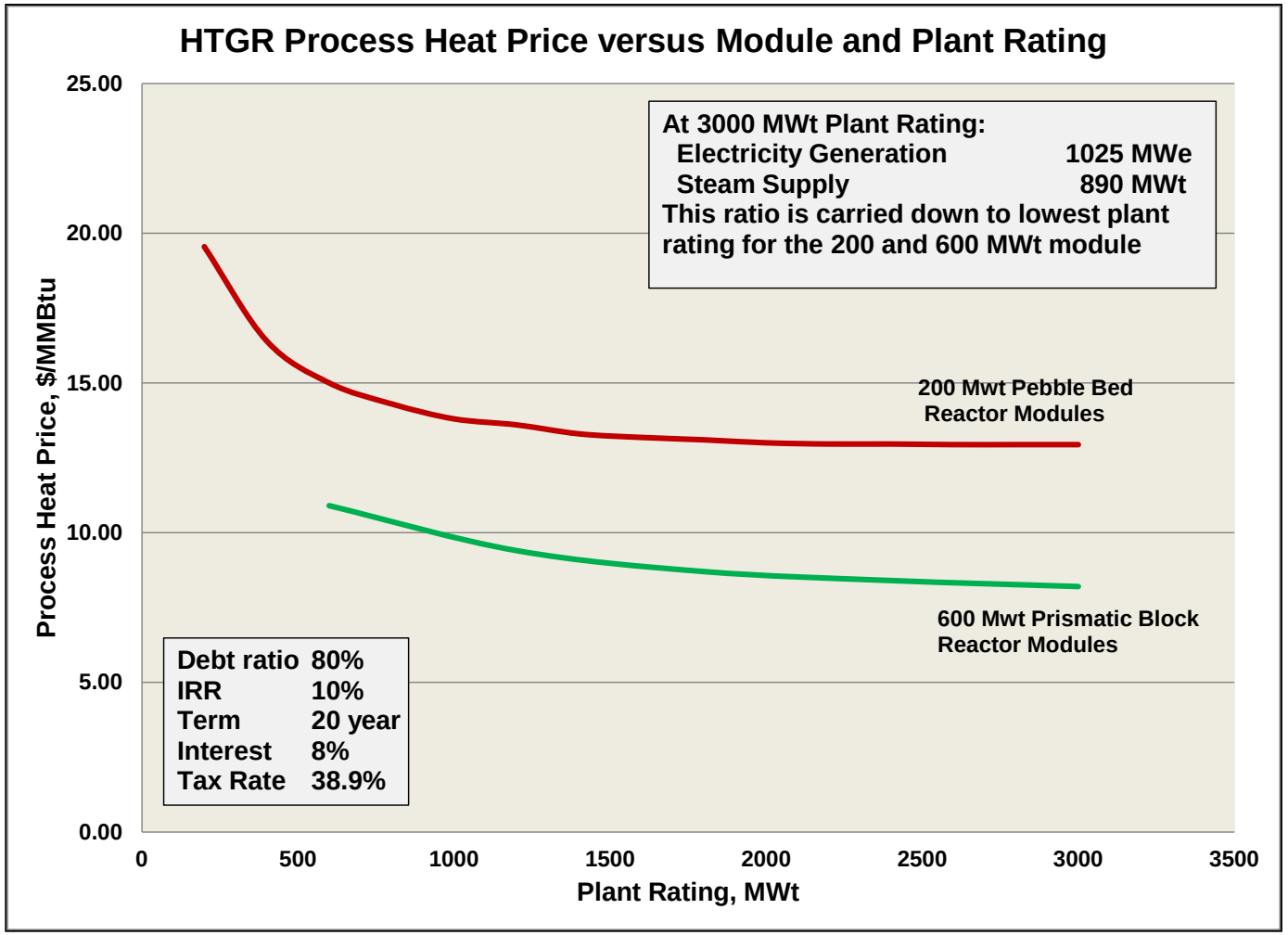
# Cost and Economics

- One-time costs include R&D, design, and initial licensing. At best, about $1 B. Can be much more if significant R&D needed
- Site specific design and construction about $5,000/kwe or $2,000/kwth overnight cost.
- Owners costs may add significantly more
- Delays in schedule linearly drive up cost (ten years instead of five years to build will be $10,000/Kwe).

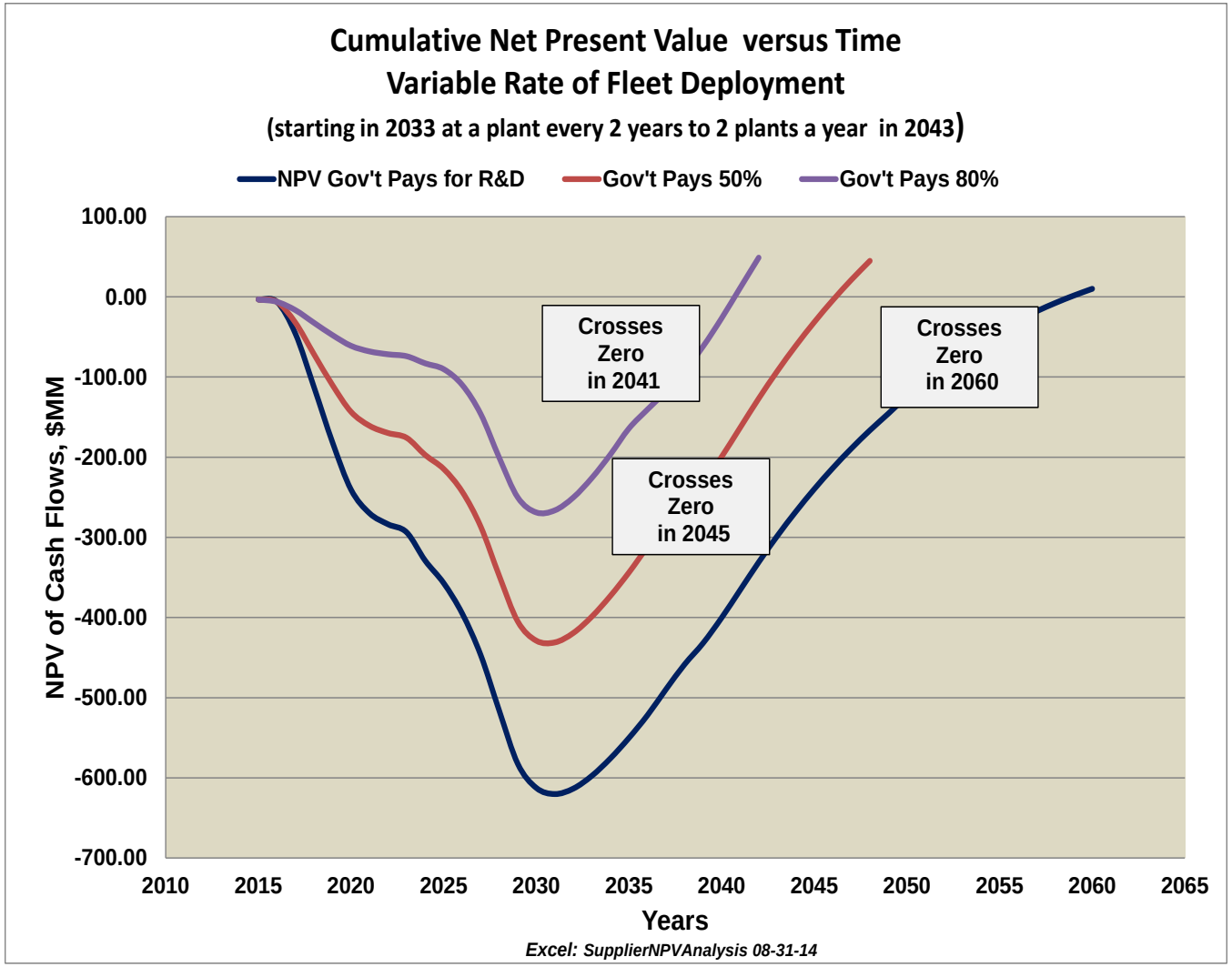
# The Path to (and cost of) Deployment



# Construction cost



# Financing Risk



# What you should take away from this lecture

- There are many advanced reactor concepts being examined and receiving investment today
- Meeting multiple markets is a significant driver
- Load following flexibility
- Economics is a driver but as yet unproven.
- Advanced reactors may be a solution to climate change

# Backup

# Core Meltdowns/Safety Fundamentals

| | | Safety Elements | | |
|---|---|---|---|---|
| | | Design | Material Condition | People |
| Safety Functions | Nuclear (Reactivity) Excursion | Chernobyl (RBMK) → | | |
| | Fuel Overheating | ← | | TMI-2 (PWR) |
| | Decay Heat Removal | Fukushima (BWR) → | | |

# Fast Reactors

- **Charm of Fast Reactors**
  - Breeding
  - New Waste Management
- **Coolants**
  - Sodium
  - Sodium-Potassium
  - Lead
  - Gas (Helium, Steam)
  - Salt
  - Lithium

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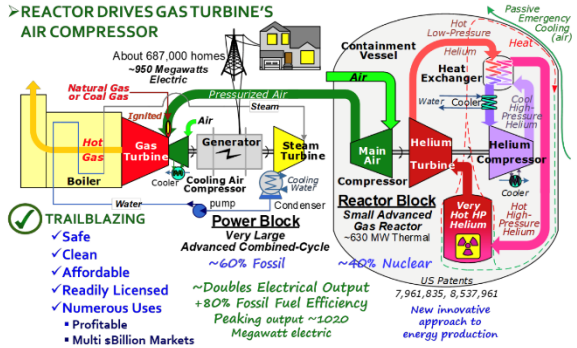
## HYBRID POWER TECHNOLOGIES LLC

Hybrid Power Technologies LLC

➢REACTOR DRIVES GAS TURBINE'S AIR COMPRESSOR




TRAILBLAZING
- ✓Safe
- ✓Clean
- ✓Affordable
- ✓Readily Licensed
- ✓Numerous Uses
  - Profitable
  - Multi sBillion Markets

**Power Block**
Very Large Advanced Combined-Cycle
~60% Fossil

~Doubles Electrical Output
+80% Fossil Fuel Efficiency
Peaking output ~1020 Megawatt electric

~40% Nuclear

US SMALL BUSINESS INNOVATION

**Location:** Overland Park, KS
**Founded:** 2011
**Principal/CEO:** Michael F. Keller
**Major Investors:** Privately funded
**Technology Class:** Gas cooled
**Reactor Type:** Graphite moderated, helium cooled
**Power Output (MWe/MWT):** 950 MWe / 630 MWt
**Federal Engagement:** N/A
**Preferred Point of Contact:** Michael F. Keller / m.keller@hybridpwr.com / 913-681-7687

www.www.hybridpwr.com

ADVANCED NUCLEAR | DEVELOPER

19

11:59 AM Mon Apr 8 LTE 100%

Advanced Nuclear Directory_3-13-19 PDF

## FRAMATOME, INC.

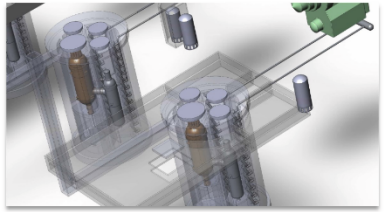
ADVANCED NUCLEAR | DEVELOPER

framatome

14

*Framatome is a major international player in the nuclear energy market recognized for its innovative solutions and value-added technologies for designing, building, maintaining, and advancing the global nuclear fleet. The company designs, manufactures, and installs components, fuel and instrumentation and control systems for nuclear power plants and offers a full range of reactor services.*

*Framatome is developing the Steam Cycle HTGR Generation IV advanced reactor concept. Its scalable design provides options for a variety of customer needs for high-temperature steam and electricity. Its unparalleled safety profile allows co-location with customer facilities. True walk-away safety and restart capability following a design-basis accident make the SC-HTGR a low investment risk for plant owners and operators.*



**Location:** Lynchburg, VA
**Founded:** 1989
**Principal/CEO:** Gary Mignogna
**Major Investors:** N/A
**Technology Class:** High temperature gas cooled
**Reactor Type:** Steam cycle high temperature gas cooled reactor
**Power Output (MWe/MWT):** 22-272 MWe / 50-625 MWt
**Federal Engagement:** DOE, GAIN, ARPA-E, NRC
**Preferred Point of Contact:** Darryl Gordon / Darryl.gordon@framatome.com / 434-832-5199

***www.framatome.com***

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## KAIROS POWER LLC

ADVANCED NUCLEAR | DEVELOPER

Kairos Power

*Our mission: enable the world's transition to clean energy, with the ultimate goal of dramatically improving people's quality of life while protecting the environment. Kairos Power will commercialize the fluoride salt-cooled high-temperature reactor (FHR), which can be deployed with robust safety, cost competitiveness through high efficiency and low-pressure small modular design, and flexible operation to accommodate the expansion of variable renewables.*

**Location:** San Francisco, CA
**Founded:** 2016
**Principal/CEO:** Michael Laufer
**Major Investors:** N/A
**Technology Class:** Solid-fueled/Molten salt cooled
**Reactor Type:** Graphite-moderated, fluoride salt-cooled, high temperature reactor
**Power Output (MWe/MWT):** N/A
**Federal Engagement:** GAIN
**Preferred Point of Contact:** Jaclyn Rodriguez / rodriguez@kairospower.com

***www.kairospower.com***

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## NUSCALE POWER

NuScale Power™

ADVANCED NUCLEAR | DEVELOPER

*NuScale is developing SMR that integrate the reactor, steam generator, pressurizer, and containment into a single module. Nuclear power plants using NuScale technology can be designed to accommodate growing electrical demand by simply adding additional modules as the need arises.*

**Location:** Tigard, OR
**Founded:** 2007
**Principal/CEO:** John Hopkins
**Major Investors:** Fluor Corporation
**Technology Class:** Water cooled
**Reactor Type:** Integral pressurized water reactor
**Power Output (MWe/MWT):** 50 MWe
**Federal Engagement:** DOE, NRC
**Preferred Point of Contact:** Lenka Kollar / lkollar@nuscalepower.com

***www.nuscalepower.com***

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## TERRESTRIAL ENERGY USA, INC.

TERRESTRIAL ENERGY USA

ADVANCED NUCLEAR | DEVELOPER

*Terrestrial Energy USA (TEUSA) is developing an advanced Small Modular Reactor (aSMR) using Integral Molten Salt Reactor (IMSR®) technology, for first commercial deployment in the 2020's, and to provide cost-competitive electricity and process heat to industry. The IMSR® design is a graphite moderated, LEU once-through fueled, fluoride molten salt reactor (MSR) that uses a replaceable reactor core architecture.*

**Location:** New York, NY
**Founded:** 2014
**Principal/CEO:** Simon Irish
**Major Investors:** Private investors
**Technology Class:** Advanced small modular reactor
**Reactor Type:** Molten salt reactor
**Power Output (MWe/MWT):** 192 MWe / 400 MWt
**Federal Engagement:** DOE, GAIN, ARPA-E, NRC
**Preferred Point of Contact:** Robin Rickman / rrickman@terrestrialusa.com / 724-421-6434

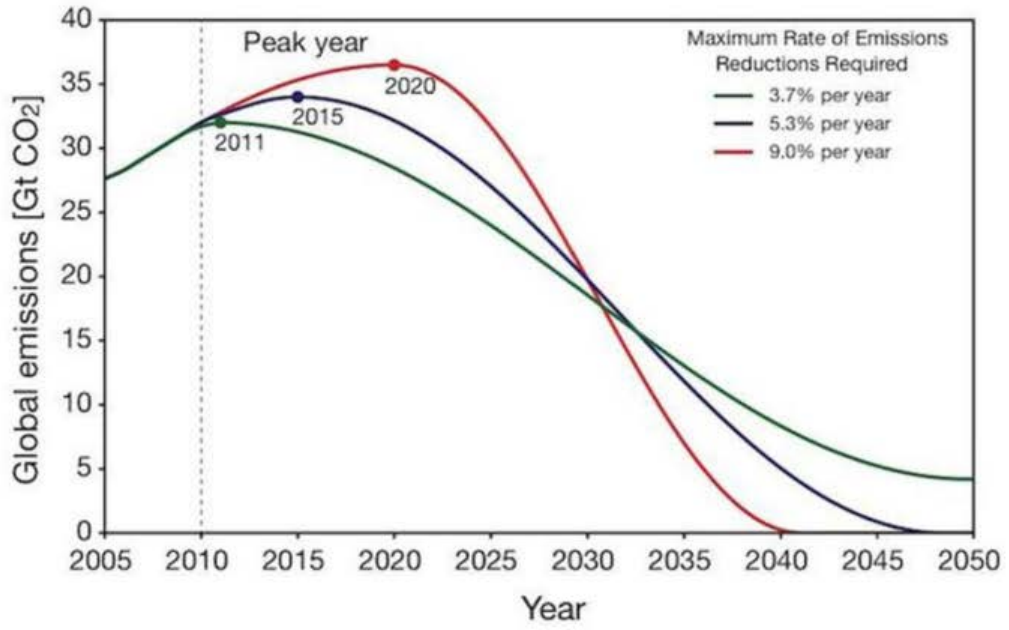
***www.terrestrialusa.com***

28

PM Thu Jan 3

Forbes

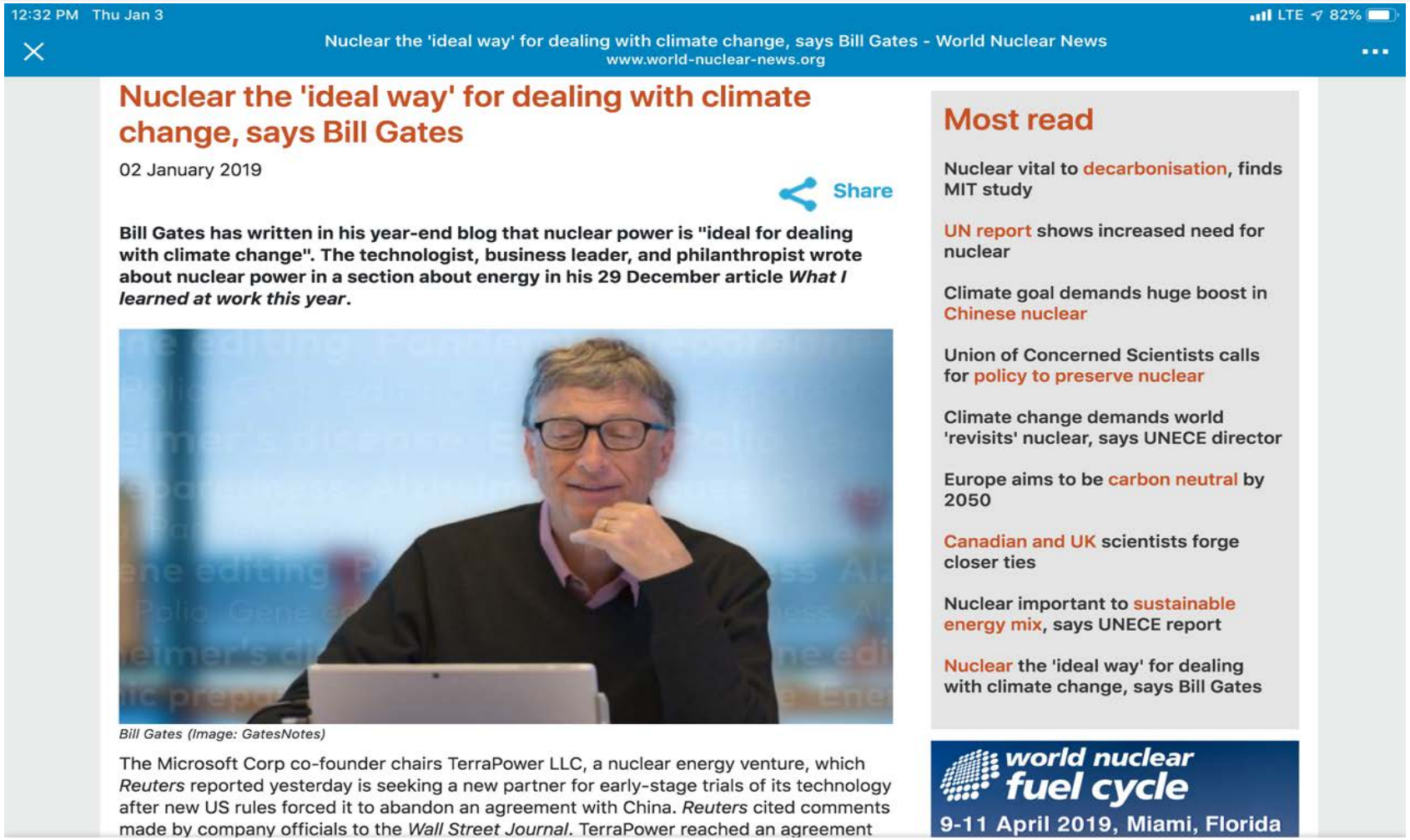
limit global warming to only a few degrees, we need to reduce emissions as fast as possible and reach near-zero human-made by 2050.




Emissions pathways to limiting global warming to just 2º Celsius (3.6º Fahrenheit) above the temperatures of the 1800s.

The situation is urgent. In order to limit global warming to only a few degrees, we need to reduce human emissions as fast as possible and reach near-zero by 2050. But the longer we wait to begin decreasing, the faster we have to decrease every year. RICHARD SOMERVILLE

# What Can Turn This Situation Around?


12:32 PM Thu Jan 3
LTE 82%
Nuclear the 'ideal way' for dealing with climate change, says Bill Gates - World Nuclear News
www.world-nuclear-news.org
Nuclear the 'ideal way' for dealing with climate change, says Bill Gates
02 January 2019
Share
Bill Gates has written in his year-end blog that nuclear power is "ideal for dealing with climate change". The technologist, business leader, and philanthropist wrote about nuclear power in a section about energy in his 29 December article What I learned at work this year.
Bill Gates (Image: GatesNotes)
The Microsoft Corp co-founder chairs TerraPower LLC, a nuclear energy venture, which Reuters reported yesterday is seeking a new partner for early-stage trials of its technology after new US rules forced it to abandon an agreement with China. Reuters cited comments made by company officials to the Wall Street Journal. TerraPower reached an agreement
Most read
Nuclear vital to decarbonisation, finds MIT study
UN report shows increased need for nuclear
Climate goal demands huge boost in Chinese nuclear
Union of Concerned Scientists calls for policy to preserve nuclear
Climate change demands world 'revisits' nuclear, says UNECE director
Europe aims to be carbon neutral by 2050
Canadian and UK scientists forge closer ties
Nuclear important to sustainable energy mix, says UNECE report
Nuclear the 'ideal way' for dealing with climate change, says Bill Gates
world nuclear fuel cycle
9-11 April 2019, Miami, Florida
NEI Nuclear Energy Institute's post
34 3
Like Comment Share

# Recent Articles

Forbes Magazine: **Had They Bet On Nuclear, Not Renewables, Germany & California Would Already Have 100% Clean Power**

*I write about energy and the environment:* **Michael Shellenberger**
Contributor

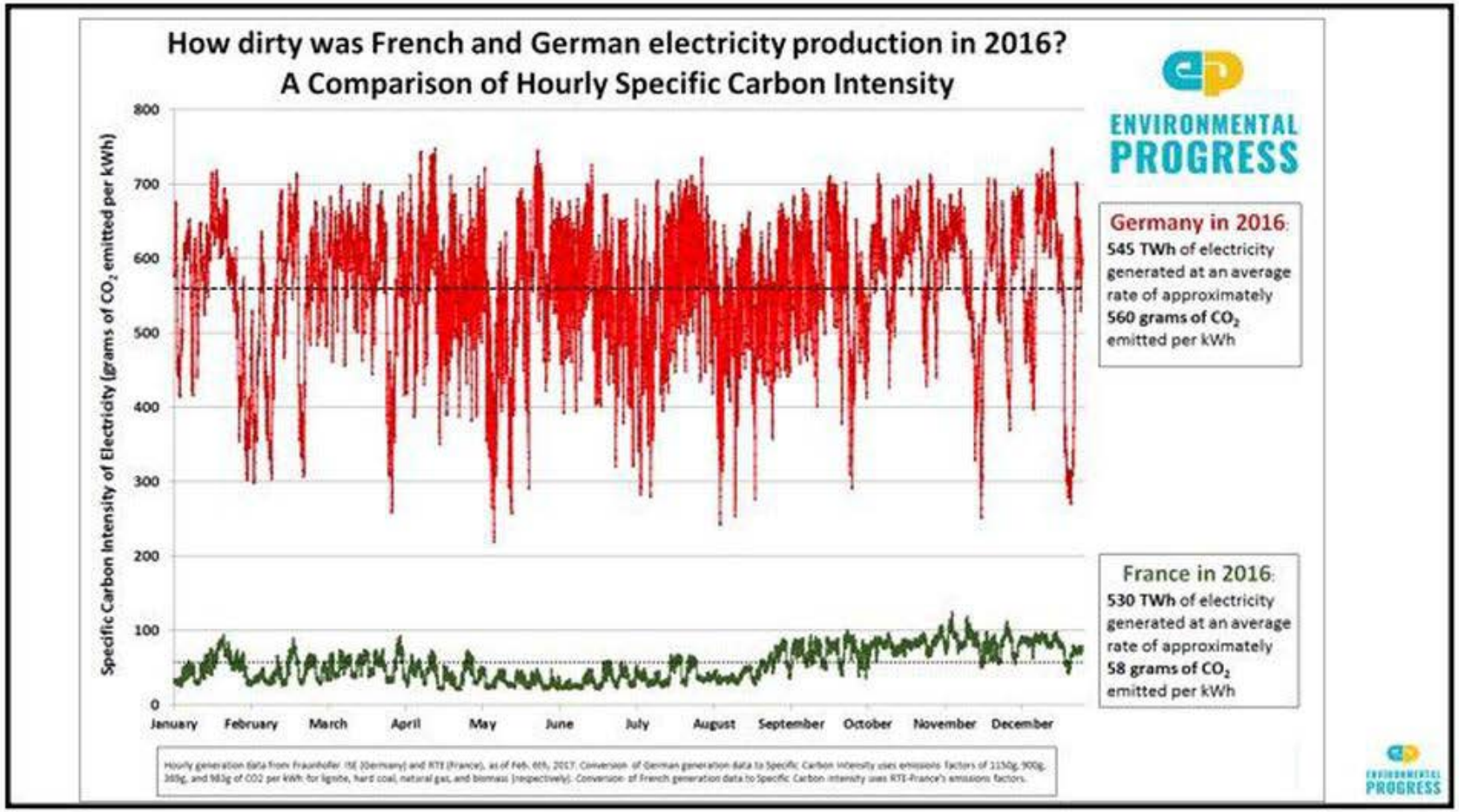
Had California and Germany invested $680 billion into new nuclear power plants instead of renewables like solar and wind farms, the two would already be generating 100% or more of their electricity from clean (low-emissions) energy sources, according to a new analysis by Environmental Progress.

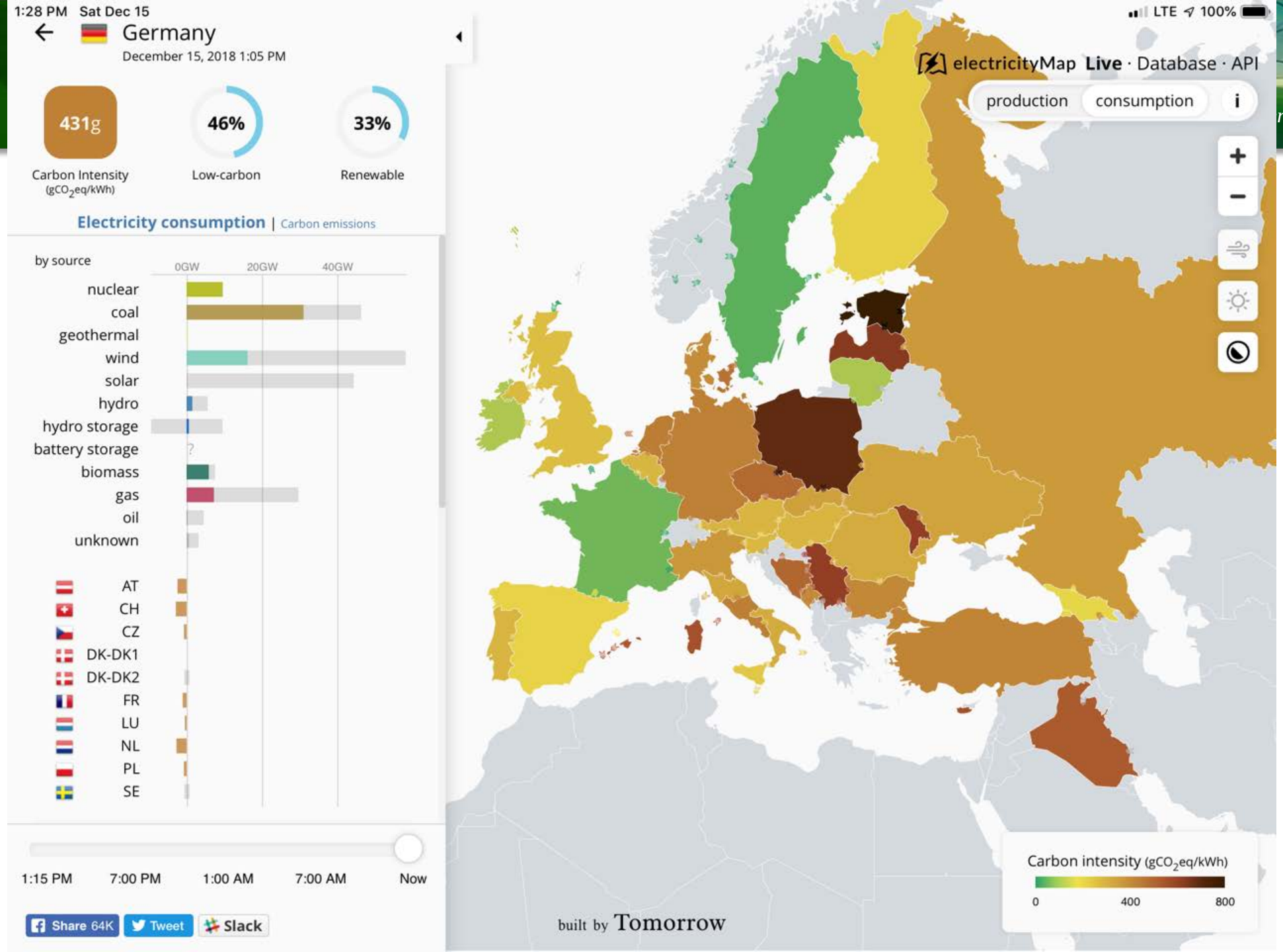
# Schellenberger (cont'd.)

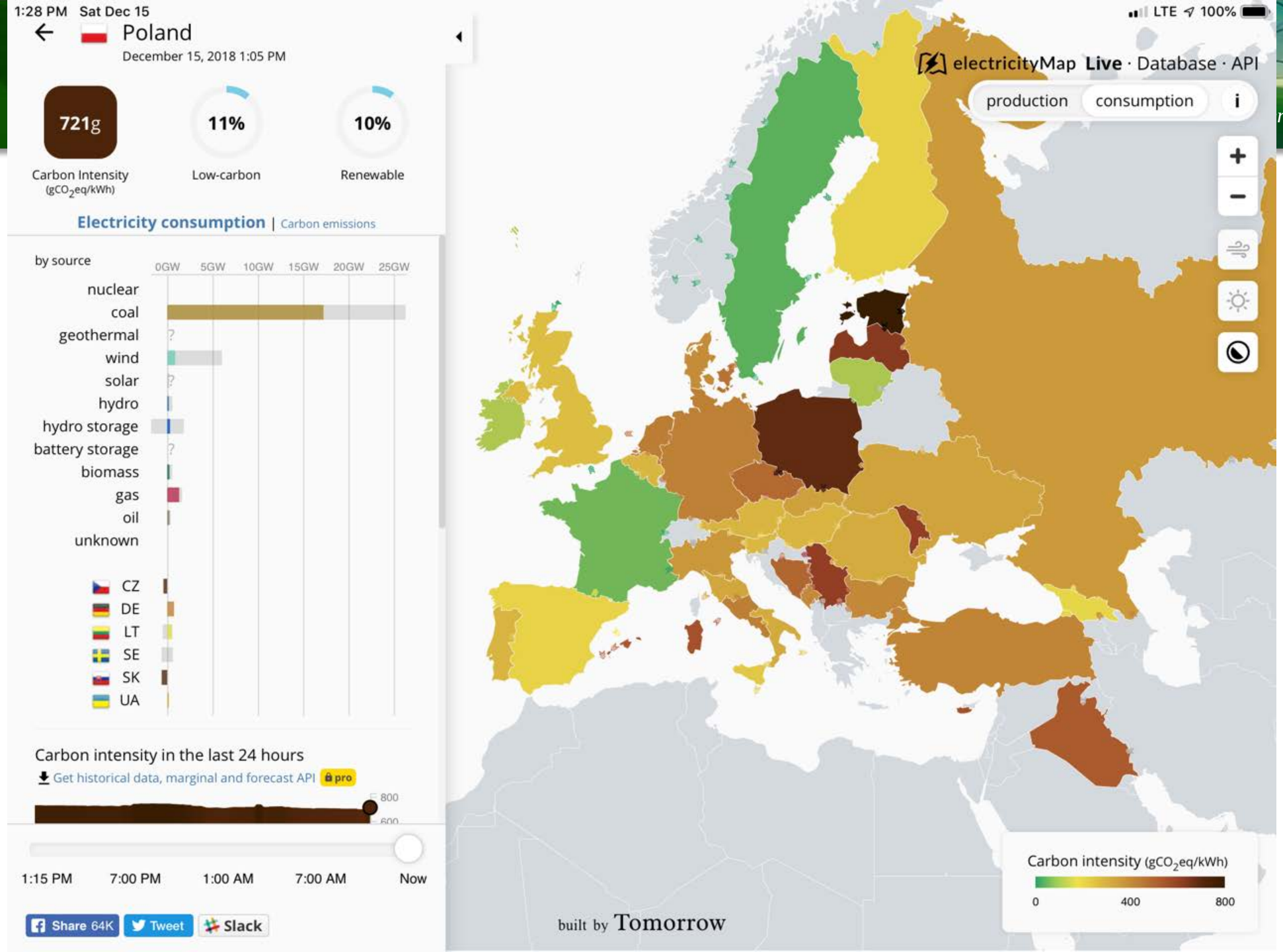
- Had Germany spent $580 billion on nuclear instead of renewables, it would have had enough energy to both replace all fossil fuels and biomass in its electricity sector *and* replace *all* of the petroleum it uses for cars and light trucks.

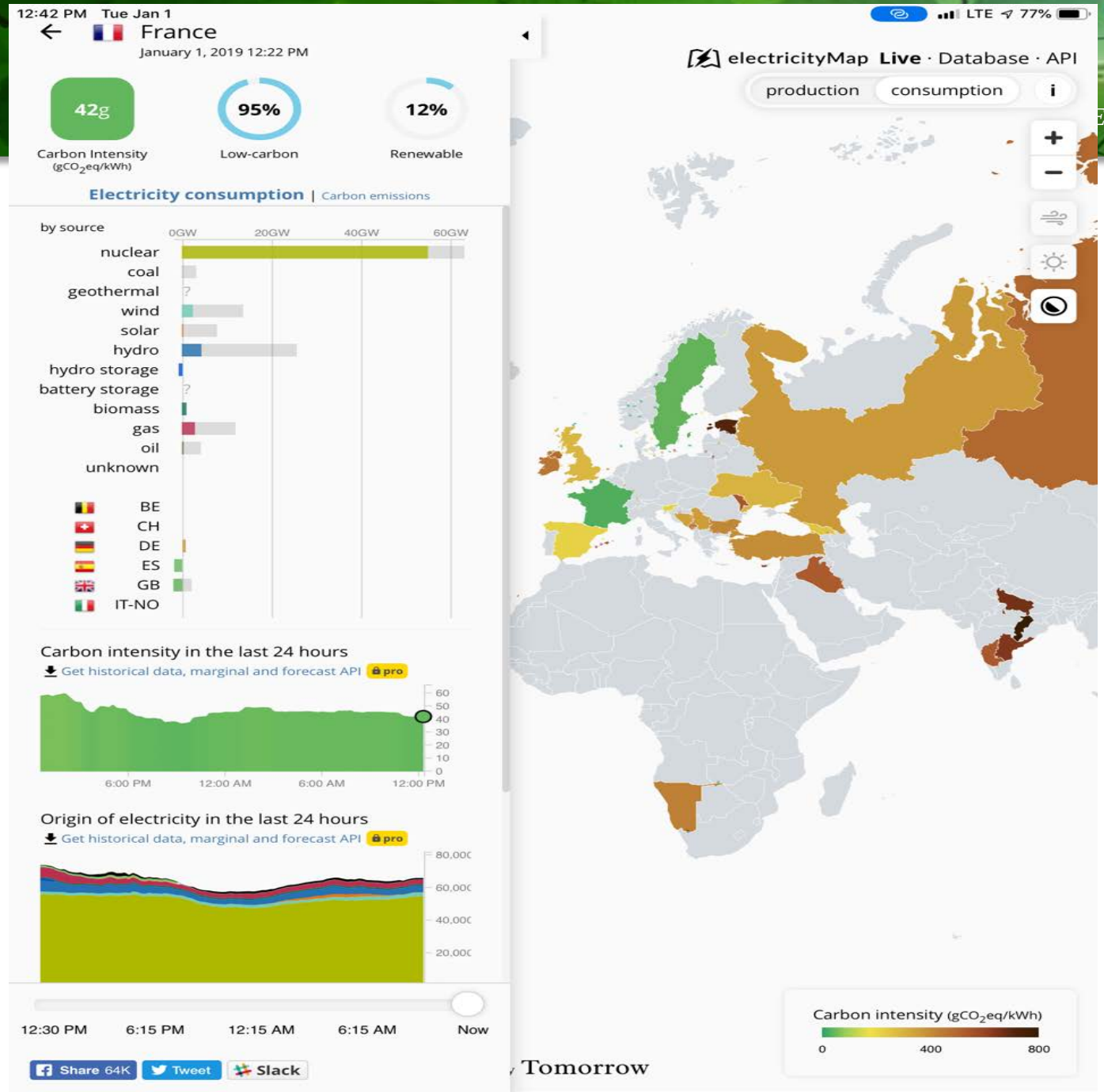
- Had California spent an estimated $100 billion on nuclear instead of on wind and solar, it would have had enough energy to replace *all* fossil fuels in its in-state electricity mix.

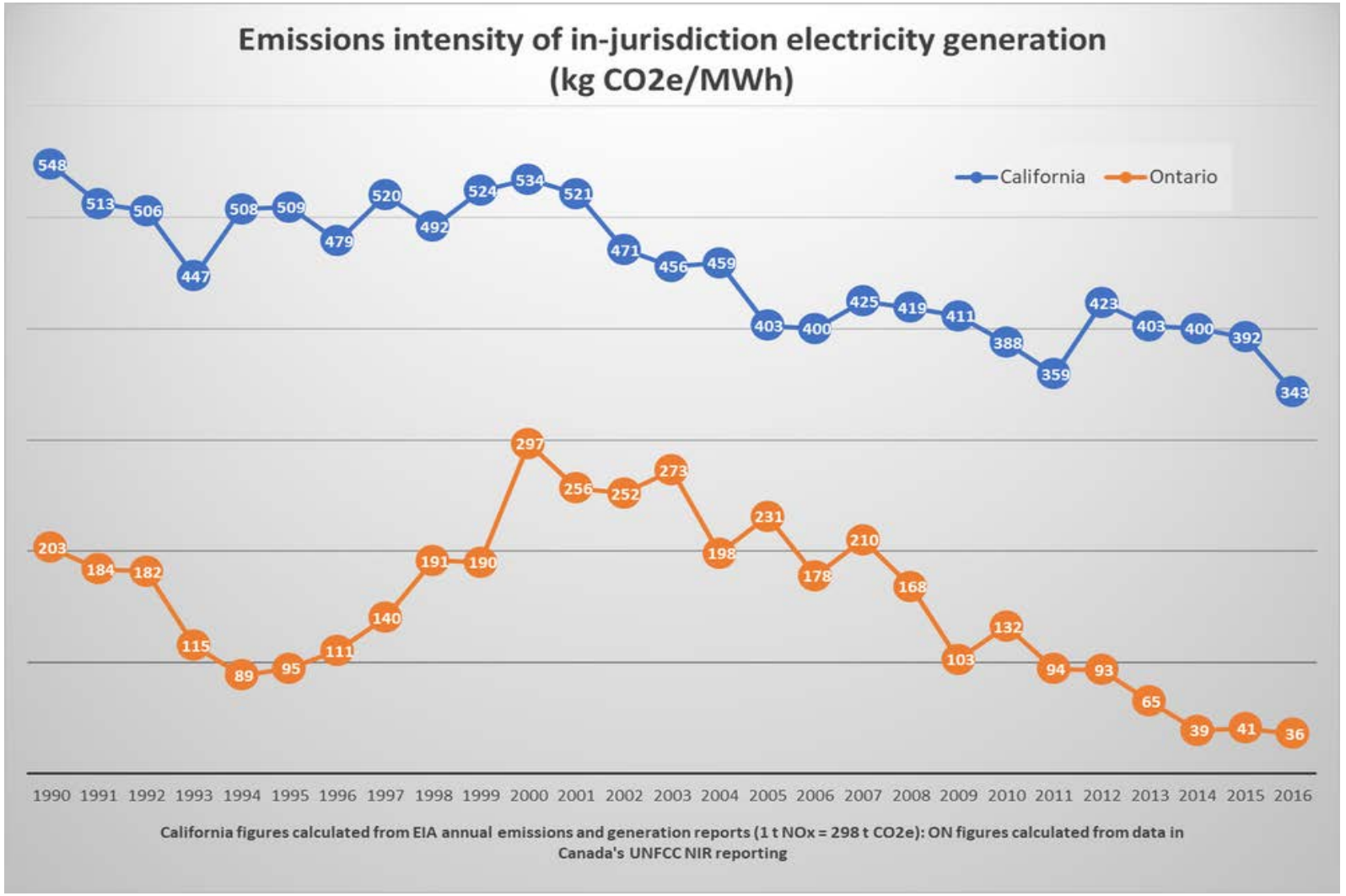
# GHG Intensity of French and German Power



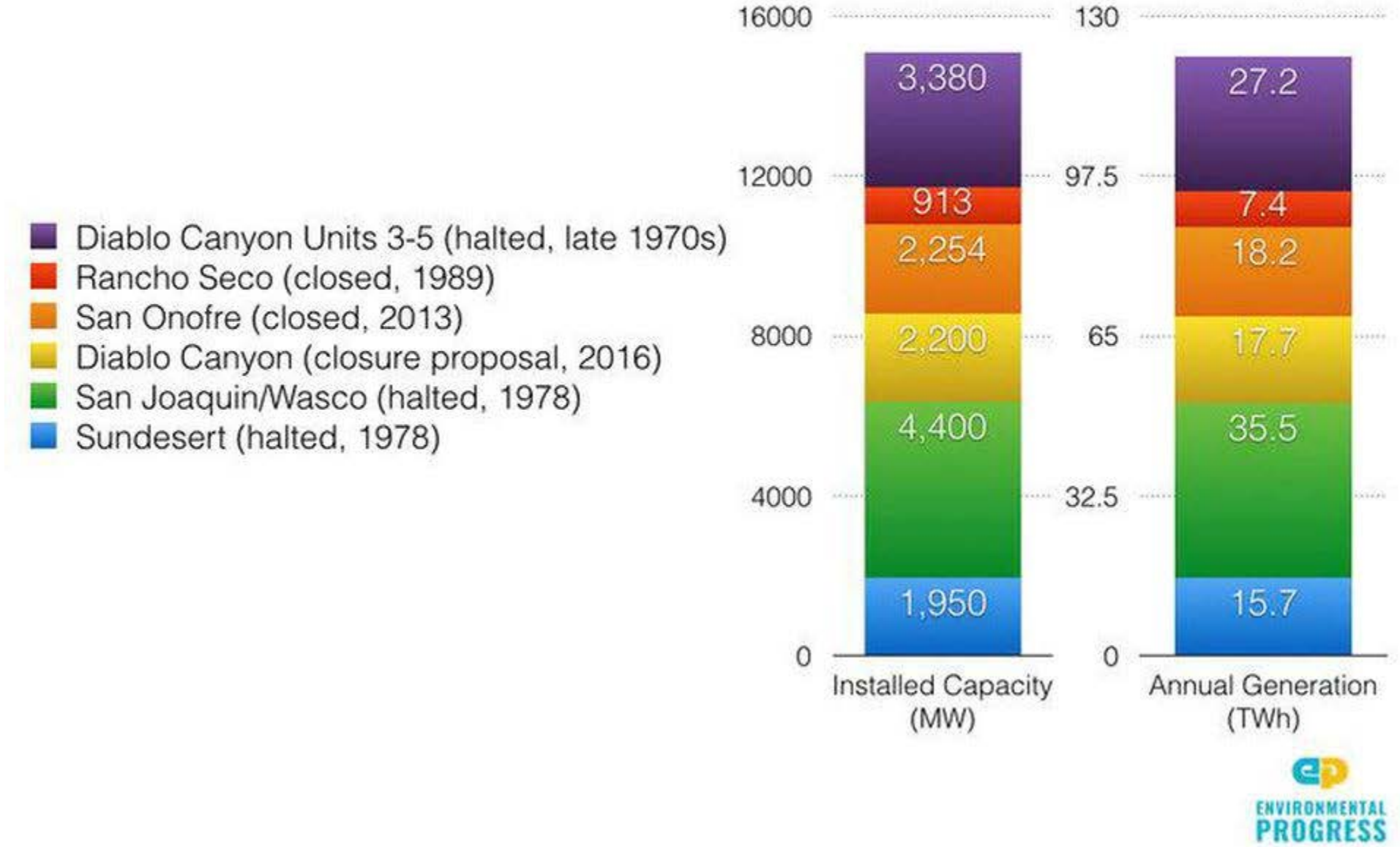

1:28 PM Sat Dec 15
Germany
December 15, 2018 1:05 PM
431g
Carbon Intensity
(gCO2eq/kWh)
46%
Low-carbon
33%
Renewable
Electricity consumption | Carbon emissions
by source
0GW
20GW
40GW
nuclear
coal
geothermal
wind
solar
hydro
hydro storage
battery storage
biomass
gas
oil
unknown
AT
CH
CZ
DK-DK1
DK-DK2
FR
LU
NL
PL
SE
1:15 PM
7:00 PM
1:00 AM
7:00 AM
Now
Share 64K
Tweet
Slack
LTE 100%
electricityMap Live · Database · API
production
consumption
i
Carbon intensity (gCO2eq/kWh)
0
400
800
built by Tomorrow


1:28 PM Sat Dec 15
Poland
December 15, 2018 1:05 PM
721g
Carbon Intensity
(gCO2eq/kWh)
11%
Low-carbon
10%
Renewable
Electricity consumption | Carbon emissions
by source
0GW 5GW 10GW 15GW 20GW 25GW
nuclear
coal
geothermal
wind
solar
hydro
hydro storage
battery storage
biomass
gas
oil
unknown
CZ
DE
LT
SE
SK
UA
Carbon intensity in the last 24 hours
Get historical data, marginal and forecast API
pro
800
600
1:15 PM
7:00 PM
1:00 AM
7:00 AM
Now
Share 64K
Tweet
Slack
LTE 100%
electricityMap Live · Database · API
production
consumption
i
Carbon intensity (gCO2eq/kWh)
0
400
800
built by Tomorrow


12:42 PM Tue Jan 1
France
January 1, 2019 12:22 PM
42g
Carbon Intensity
(gCO2eq/kWh)
95%
Low-carbon
12%
Renewable
Electricity consumption | Carbon emissions
by source
0GW
20GW
40GW
60GW
nuclear
coal
geothermal
wind
solar
hydro
hydro storage
battery storage
biomass
gas
oil
unknown
BE
CH
DE
ES
GB
IT-NO
Carbon intensity in the last 24 hours
Get historical data, marginal and forecast API
pro
60
50
40
30
20
10
0
6:00 PM
12:00 AM
6:00 AM
12:00 PM
Origin of electricity in the last 24 hours
Get historical data, marginal and forecast API
pro
80,000
60,000
40,000
20,000
12:30 PM
6:15 PM
12:15 AM
6:15 AM
Now
Share 64K
Tweet
Slack
LTE 77%
electricityMap Live · Database · API
production
consumption
i
Carbon intensity (gCO2eq/kWh)
0
400
800
Tomorrow

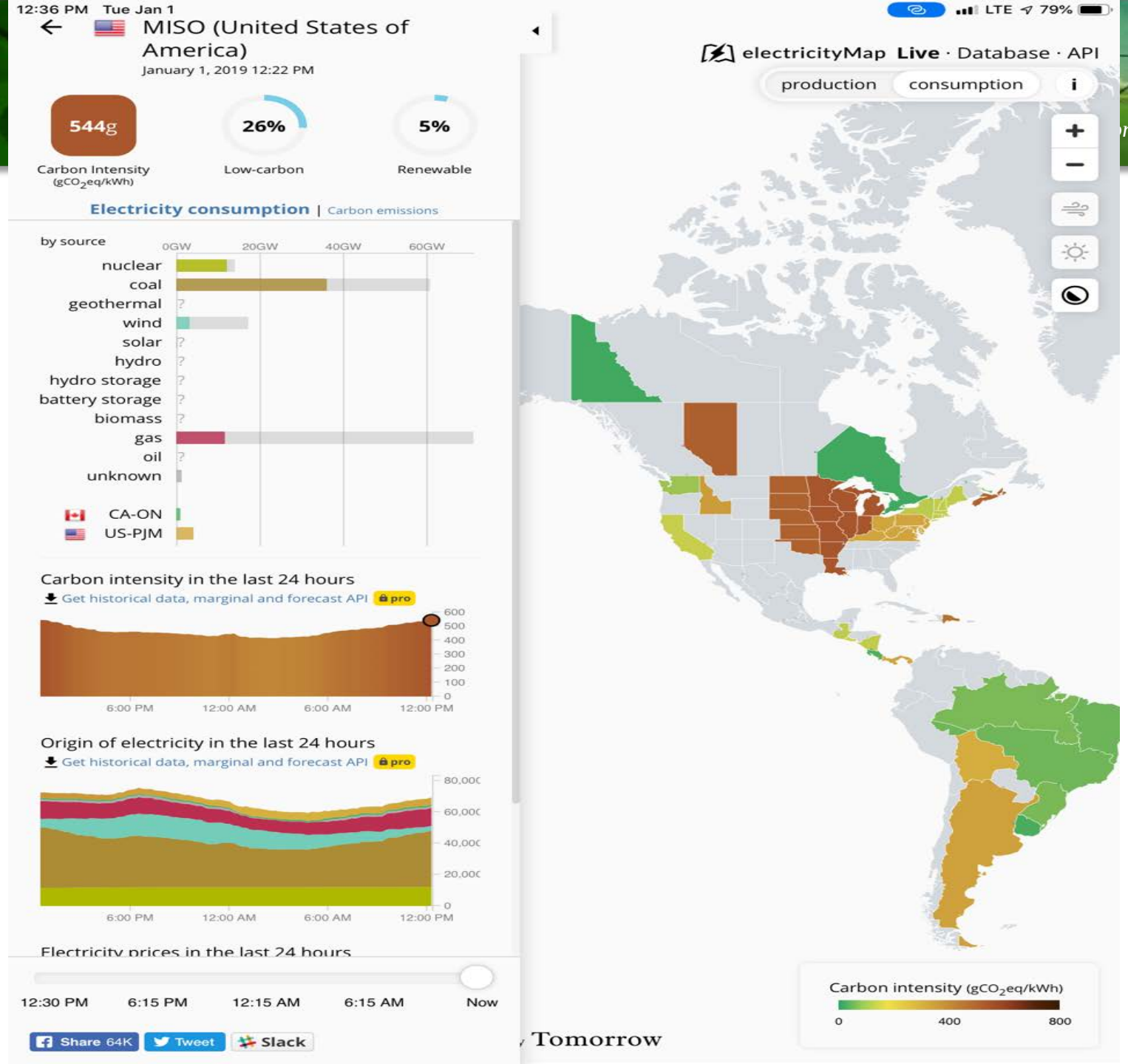

Emissions intensity of in-jurisdiction electricity generation
(kg CO2e/MWh)
California
Ontario
548 513 506 447 508 509 479 520 492 524 534 521 471 456 459 403 400 425 419 411 388 359 423 403 400 392 343
203 184 182 115 89 95 111 140 191 190 297 256 252 273 198 231 178 210 168 103 132 94 93 65 39 41 36
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
California figures calculated from EIA annual emissions and generation reports (1 t NOx = 298 t CO2e): ON figures calculated from data in Canada's UNFCC NIR reporting

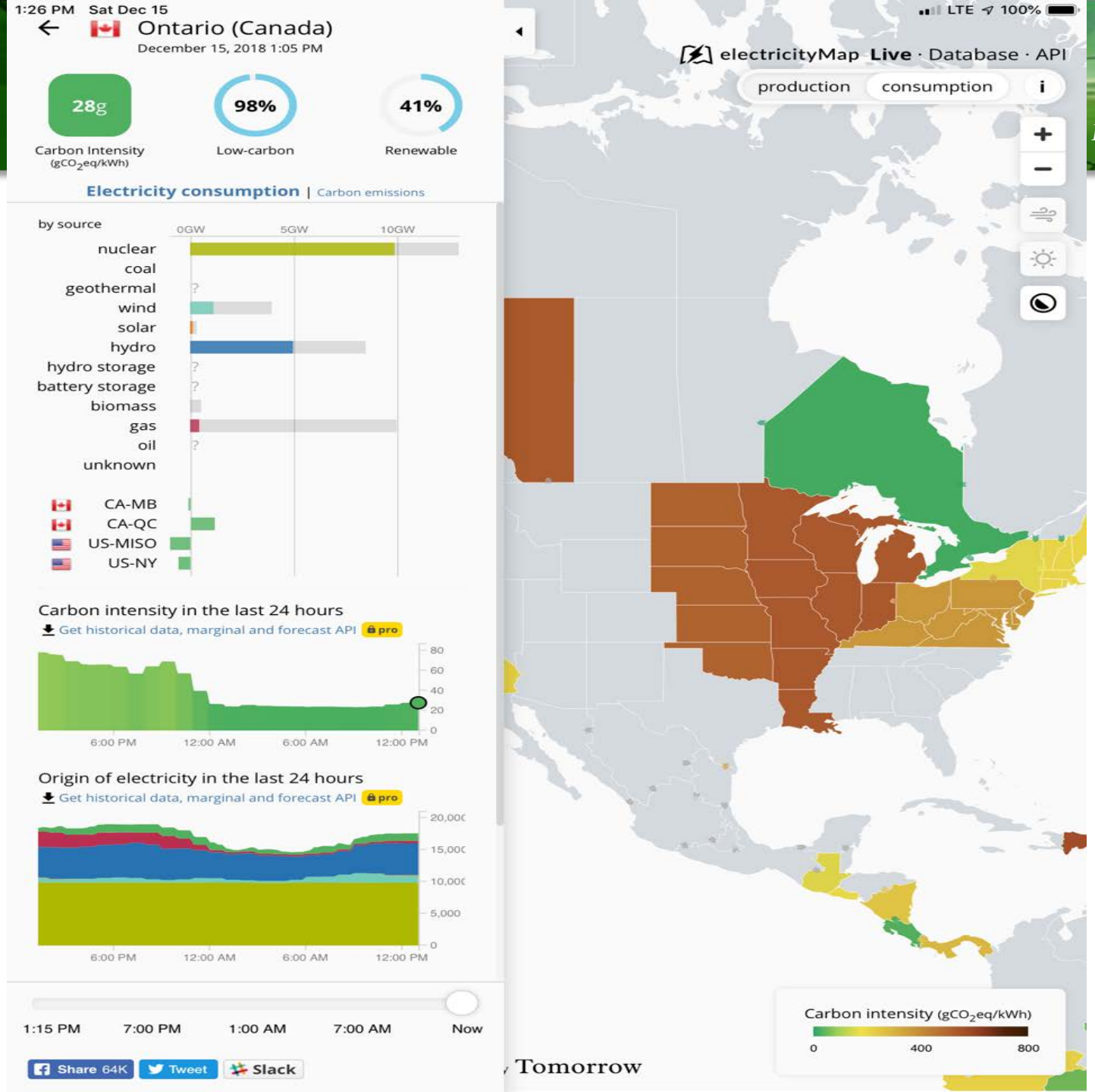
# California Nuclear Abandonments

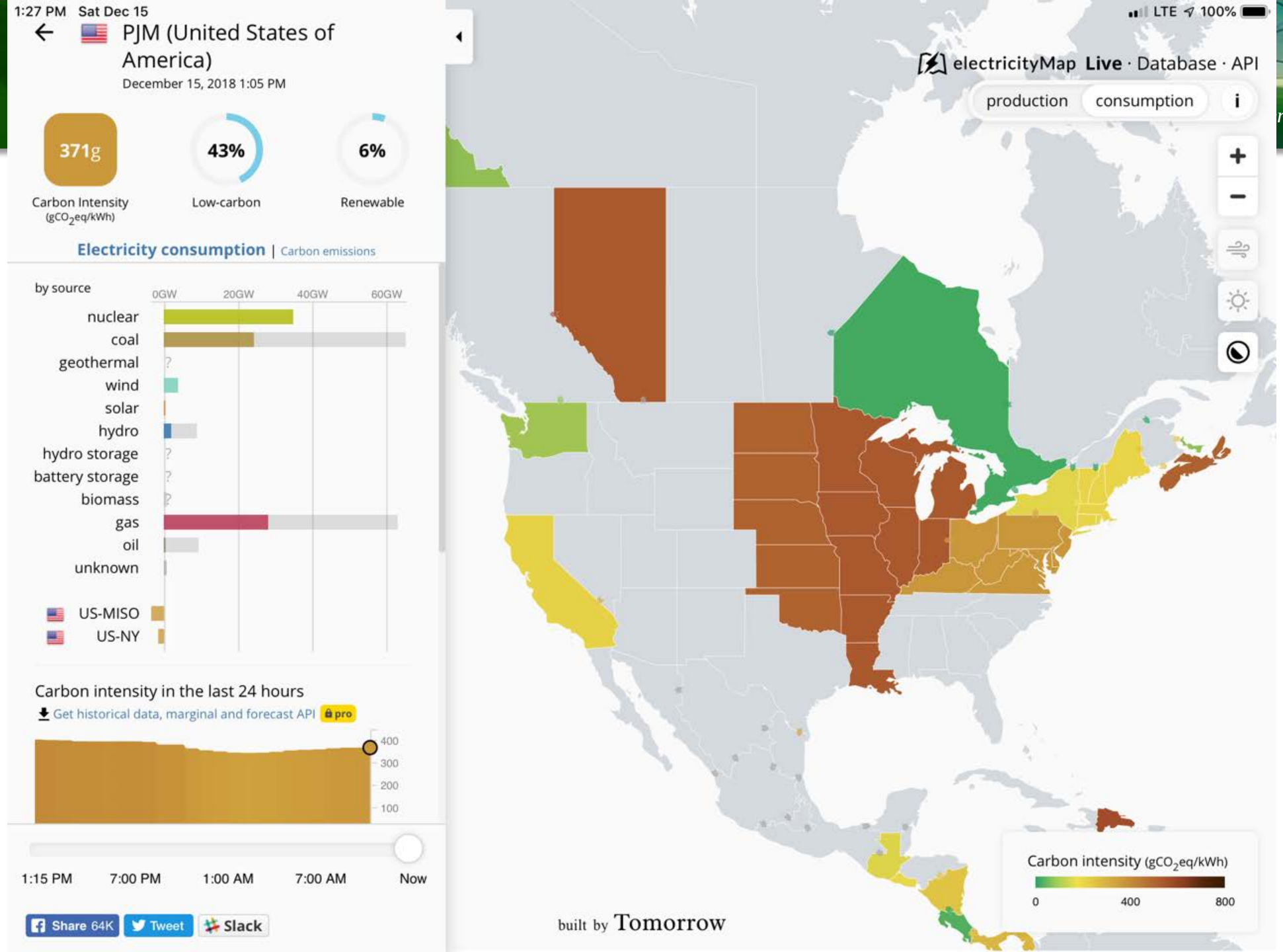


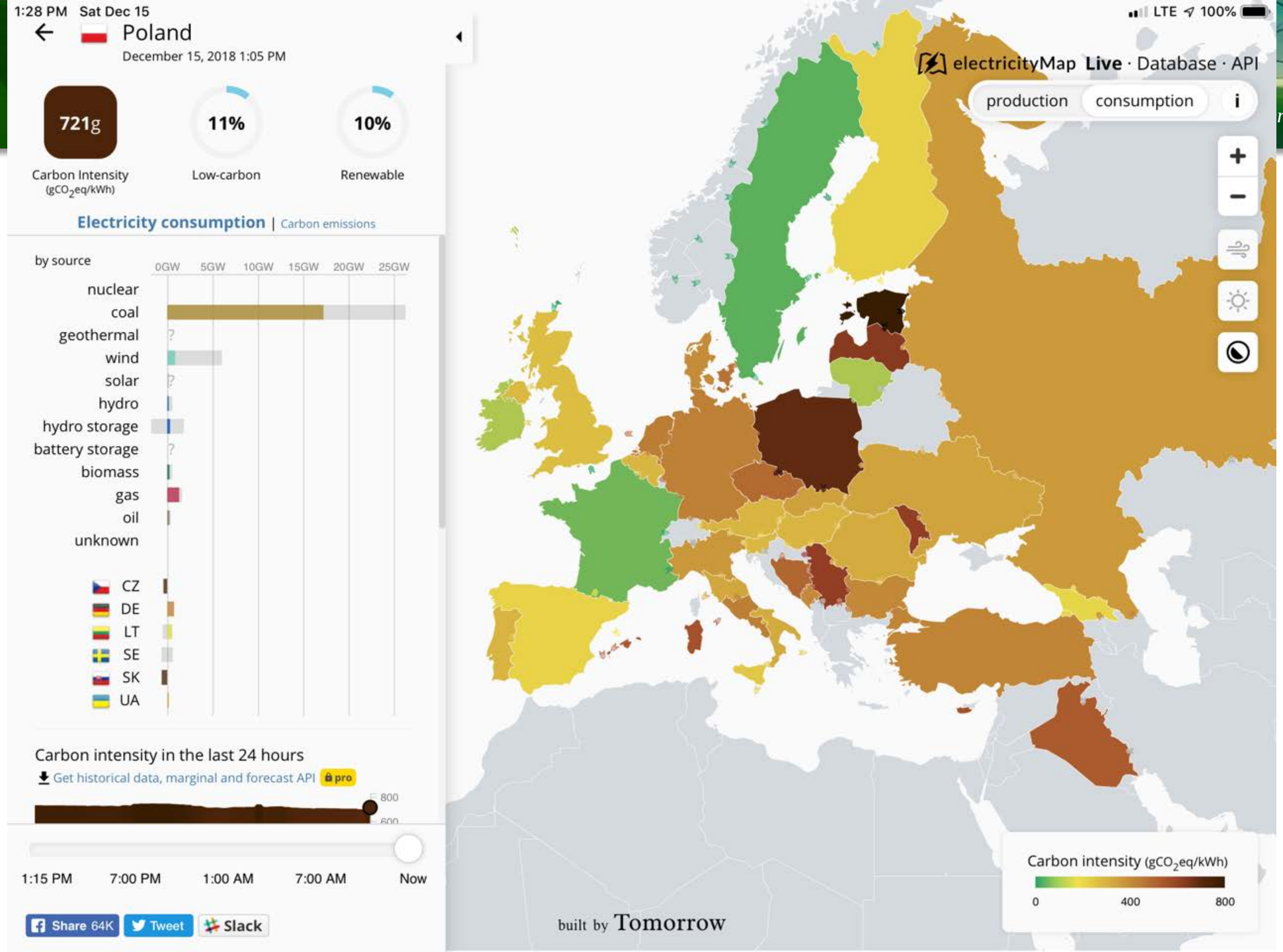
# What are we doing in the US?

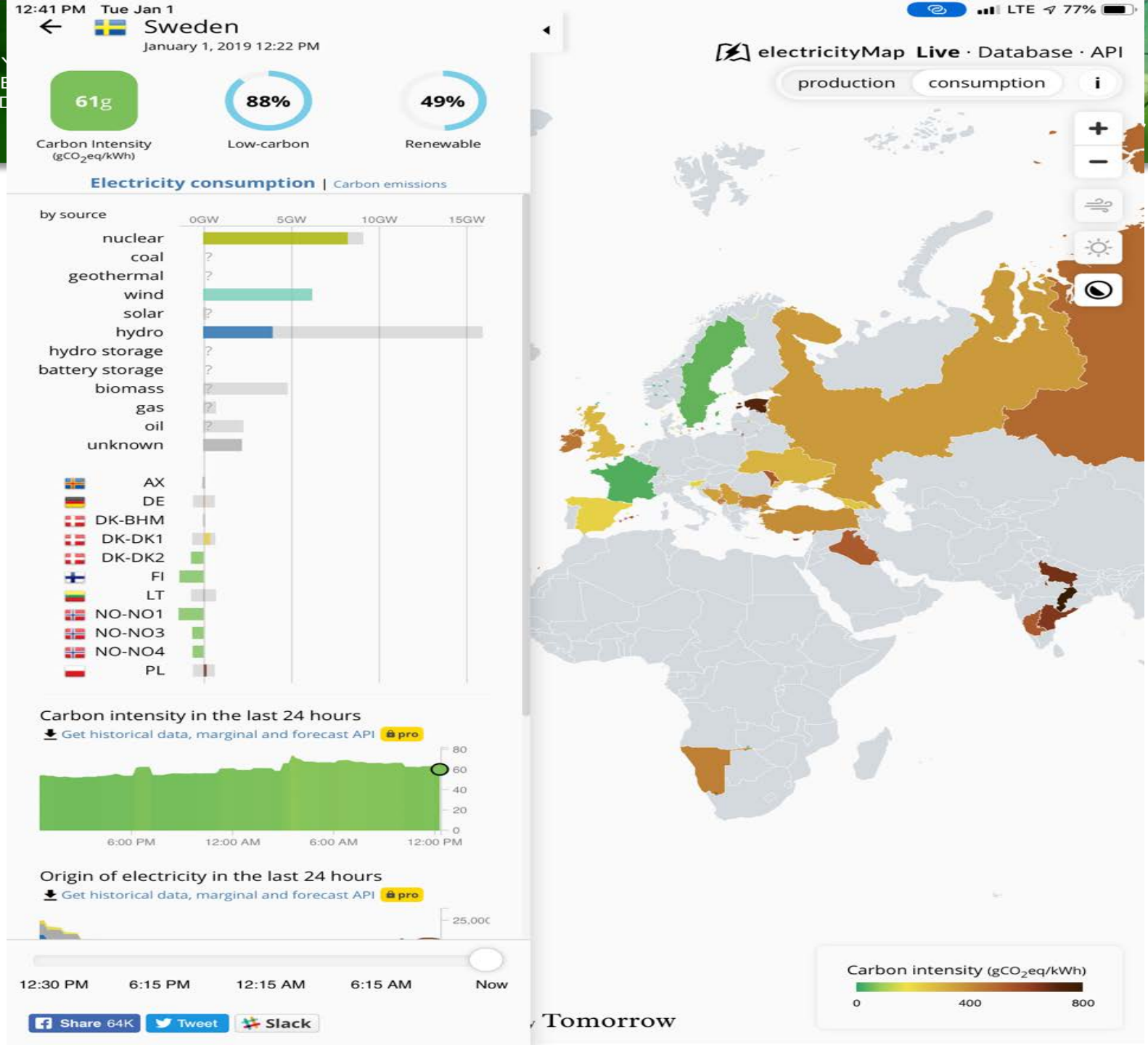
- 20 % Electricity is from Nuclear
- We have the most operating nuclear plants with 99 (France has 55)
- We shut down five plants in the past five years
- We have been building many windmills, especially out West, Texas, and selectively in New England


12:36 PM Tue Jan 1
MISO (United States of America)
January 1, 2019 12:22 PM
544g
Carbon Intensity (gCO2eq/kWh)
26%
Low-carbon
5%
Renewable
Electricity consumption | Carbon emissions
by source
0GW 20GW 40GW 60GW
nuclear
coal
geothermal
wind
solar
hydro
hydro storage
battery storage
biomass
gas
oil
unknown
CA-ON
US-PJM
Carbon intensity in the last 24 hours
Get historical data, marginal and forecast API pro
600
500
400
300
200
100
0
6:00 PM 12:00 AM 6:00 AM 12:00 PM
Origin of electricity in the last 24 hours
Get historical data, marginal and forecast API pro
80,000
60,000
40,000
20,000
0
6:00 PM 12:00 AM 6:00 AM 12:00 PM
Electricity prices in the last 24 hours
12:30 PM 6:15 PM 12:15 AM 6:15 AM Now
Share 64K Tweet Slack
LTE 79%
electricityMap Live · Database · API
production consumption i
Carbon intensity (gCO2eq/kWh)
0 400 800
Tomorrow


1:26 PM Sat Dec 15
Ontario (Canada)
December 15, 2018 1:05 PM
28g
Carbon Intensity (gCO2eq/kWh)
98%
Low-carbon
41%
Renewable
Electricity consumption | Carbon emissions
by source
0GW
5GW
10GW
nuclear
coal
geothermal
wind
solar
hydro
hydro storage
battery storage
biomass
gas
oil
unknown
CA-MB
CA-QC
US-MISO
US-NY
Carbon intensity in the last 24 hours
Get historical data, marginal and forecast API
pro
80
60
40
20
0
6:00 PM
12:00 AM
6:00 AM
12:00 PM
Origin of electricity in the last 24 hours
Get historical data, marginal and forecast API
pro
20,000
15,000
10,000
5,000
0
6:00 PM
12:00 AM
6:00 AM
12:00 PM
1:15 PM
7:00 PM
1:00 AM
7:00 AM
Now
Share 64K
Tweet
Slack
LTE 100%
electricityMap Live · Database · API
production
consumption
i
Carbon intensity (gCO2eq/kWh)
0
400
800
Tomorrow


1:27 PM Sat Dec 15
PJM (United States of America)
December 15, 2018 1:05 PM
371g
Carbon Intensity
(gCO2eq/kWh)
43%
Low-carbon
6%
Renewable
Electricity consumption | Carbon emissions
by source
0GW
20GW
40GW
60GW
nuclear
coal
geothermal
wind
solar
hydro
hydro storage
battery storage
biomass
gas
oil
unknown
US-MISO
US-NY
Carbon intensity in the last 24 hours
Get historical data, marginal and forecast API
pro
400
300
200
100
1:15 PM
7:00 PM
1:00 AM
7:00 AM
Now
Share 64K
Tweet
Slack
LTE 100%
electricityMap Live · Database · API
production
consumption
Carbon intensity (gCO2eq/kWh)
0
400
800
built by Tomorrow


1:28 PM Sat Dec 15
Poland
December 15, 2018 1:05 PM
721g
Carbon Intensity
(gCO2eq/kWh)
11%
Low-carbon
10%
Renewable
Electricity consumption | Carbon emissions
by source
0GW 5GW 10GW 15GW 20GW 25GW
nuclear
coal
geothermal
wind
solar
hydro
hydro storage
battery storage
biomass
gas
oil
unknown
CZ
DE
LT
SE
SK
UA
Carbon intensity in the last 24 hours
Get historical data, marginal and forecast API
pro
800
600
1:15 PM
7:00 PM
1:00 AM
7:00 AM
Now
Share 64K
Tweet
Slack
LTE 100%
electricityMap Live · Database · API
production
consumption
i
Carbon intensity (gCO2eq/kWh)
0
400
800
built by Tomorrow


12:41 PM Tue Jan 1
Sweden
January 1, 2019 12:22 PM
61g
Carbon Intensity (gCO2eq/kWh)
88%
Low-carbon
49%
Renewable
Electricity consumption | Carbon emissions
by source
0GW 5GW 10GW 15GW
nuclear
coal
geothermal
wind
solar
hydro
hydro storage
battery storage
biomass
gas
oil
unknown
AX
DE
DK-BHM
DK-DK1
DK-DK2
FI
LT
NO-NO1
NO-NO3
NO-NO4
PL
Carbon intensity in the last 24 hours
Get historical data, marginal and forecast API pro
80
60
40
20
0
6:00 PM
12:00 AM
6:00 AM
12:00 PM
Origin of electricity in the last 24 hours
Get historical data, marginal and forecast API pro
25,000
12:30 PM
6:15 PM
12:15 AM
6:15 AM
Now
Share 64K
Tweet
Slack
LTE 77%
electricityMap Live · Database · API
production
consumption
i
Carbon intensity (gCO2eq/kWh)
0
400
800
Tomorrow

# What will reduce GHGs….

- Nuclear plus renewables
- Nuclear
  - Make these options cost-effective by putting a price on GHGs
  - Make this fee acceptable by returning it to the public
- Use electricity and hydrogen as energy ‘carriers’
  - Electrify or use hydrogen for light duty vehicles, heavy duty vehicles, and rail transport
  - Electrify mass transit
  - New steel making technology, new cement processes
  - Better refrigerant fluids
- Hydro and geothermal will work on their own if your nation is geologically
  lucky (Iceland, Scandinavia)

# Questions?

**Dr. Finis Southworth**
**Chief Technology Officer**
finis@ngnpalliance.org

*www.ngnpalliance.org*

# The Four PRIME Parties

**NGNP Industry Alliance**
U.S. Industry group created to move forward HTGRs and nuclear process heat
Considerable HTGR experience

**Japan Atomic Energy Agency**
Substantial historic and current HTGR and H2 experience including the HTTR Test Reactor.
Strong emphasis on nuclear H2

**Korean Atomic Energy Research Institute**
Substantial historic and current HTGR and H2 experience.
Strong emphasis on nuclear H2

**Poland and EU's Nuclear Cogeneration Industrial Initiative**
Strong interest in nuclear industrial process heat.
Considerable HTGR historic experience

# As an Advanced Gen IV Reactor the HTGR Is:

Robust – tolerates loss of pressure, flow, coolant & backup cooling without significant release from fuel

Real - 6 reactors have been licensed and operated, two in ~800 MWt class & three on the grid, two new PBs under construction

Ready- technology development largely complete; proven fuel; designs are largely complete; US NRC has been engaged thru White Papers

Revolutionary Applications – addresses high temperature process heat applications which currently require fossil fuel & produce 20% of world CO2 emissions; uniquely offers potential for clean, high efficiency hydrogen production