Introducing Small Modular Reactors into Canada

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Western Focus Track

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Discussion Topics

WHAT?
- Small Modular Reactors

WHY?
- Applications of Interest in Canada

HOW?
- Bringing Them Into Canada

WHEN?
- Next Steps Moving Forward

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Small Reactors

- Small reactors are not new

USS Nautilus launched in 1955. World's first nuclear submarine.

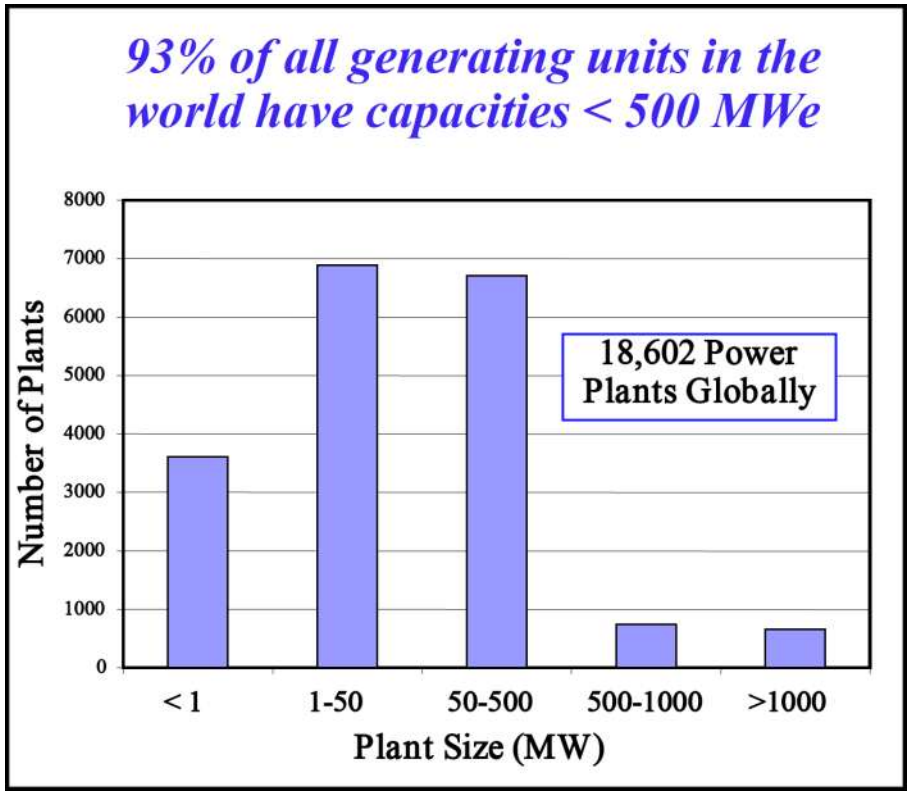
PM-2A: Assembled at Camp Century, Greenland. World's first portable plant. The first operating crew of one officer and 18 enlisted specialists built the plant in 77 days from the arrival of the first component. 2,000 kWe plus 1 x 107 Btu/hr steam heat. Completed in February 1961.

SM-1:This stationary military reactor was the Army's prototype and training facility at Fort Belvoir, VA. It began operation in 1957. It has the distinction of having been the first nuclear power plant to be hooked to an electrical grid. 2,000 kWe.

PM-3A: McMurdo Sound, Antarctica. Owned by Navy. 1750 kWe plus 3 x 106 Btu/hr heat. Initial criticality March 1962.

Small Reactors / Power Plants

- Small power plants dominate the global energy market (nuclear and conventional)
- Nuclear power accounts for ~16% of worlds energy supply
- More than 15 countries rely on nuclear power for 25% or more of their electricity



Source: Department of Nuclear Engineering, University of California, Berkeley

Small Modular Reactors (SMRs)

- SMRs - Generally accepted acronym for
  - Small Modular Reactors
  - Small and Medium-sized Reactors

IAEA Definitions

Reactor "Size"	Power Rating, MWe
Very Small	< 150
Small	150 – 300
Medium	300 - 700
Large	> 700

- Canadian interest mainly 'Small' & 'Very Small' sizes

Small Modular Reactors (SMRs)

- DOE defines SMRs as those reactor designs that
  - Have power ratings of 300 MWe or less, and
  - Are fabricated in modules that are transportable from factory to site by rail, truck, or barge

- CNSC distinguishes between NPPs & Small Reactors
  - NPP: Thermal power ≈ >200 MWt (~75 MWe)
  - Small Reactor: Thermal power ≈ <200 MWt
  - SMR is not an acronym or terminology used by CNSC in
    - RD-367, *Design of Small Reactor Facilities*
    - RD-308, *Deterministic Safety Analysis for Small Reactor Facilities*

What Others Are Saying…

THINK SMALL !

Source: D. Ingersoll, "Deliberately Small Reactors and the Second Nuclear Era," *Progress in Nuclear Energy*, **51**, p 589-603, 2009.

"We get simplicity. And out of the simplicity, we get safety and we get economics."

Source: P. Lorenzini, Founder & CEO, NuScale Power

"I think we're on the verge of seeing a paradigm shift in power generation."

Source: D. Ingersoll, Oak Ridge National Laboratory

"The global demand for SMRs could reach 1,000 reactors by 2040"

Source: International Atomic Energy Agency

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Some Drivers For SMRs In Canada

Enhanced safety

Much lower unit capital cost

Can supply energy in locations with limited grid capacity

Factory fabrication of modules

Reduced financial risk

Zero GHG Emissions

Improved quality, reduced cost and schedule risk

Smaller unit footprint

Small modules & simplified designs

Diversity of energy supply

Free up natural gas for higher value-added products

Modules transportable to site by rail, barge or truck

Incremental addition of units as demand for energy grows

Operating units can provide funding for future units

Applications Of Interest In Canada

- With particular emphasis on Western Canada
  - More specifically – Saskatchewan
    - Applications will be matched to SMR 'size'

Locations with no grid connection

GHG emissions-free energy generation

Research & teaching

Cogeneration of heat & electricity

Replace aging fossil plants that can't meet emissions limits

Remote locations:
- Northern Canada
-Aboriginal lands

Remote mining operations

Military bases

Oil & gas upgrading to higher value products
- SCO, Syngas, etc.

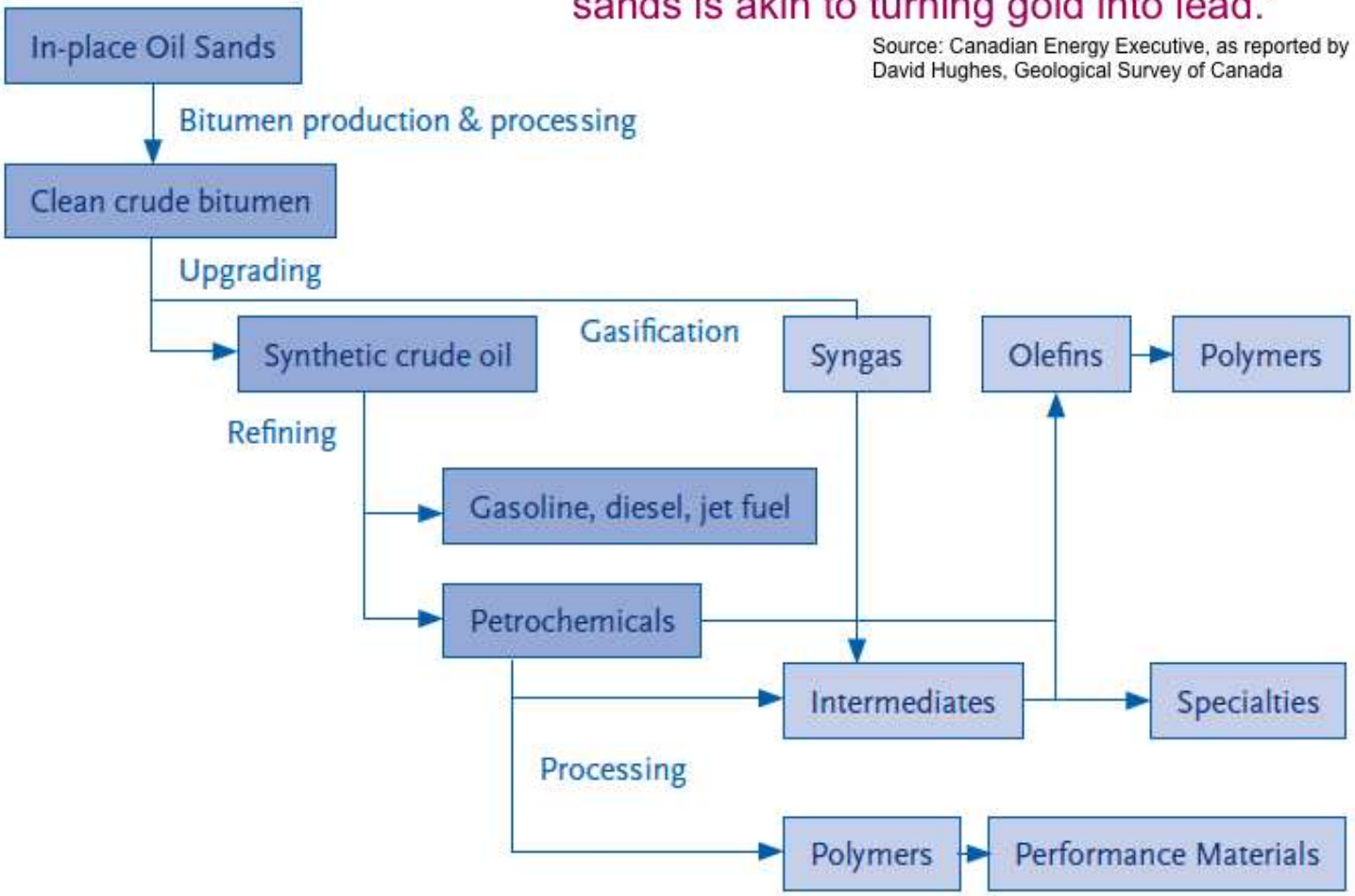
Multi-industry energy parks

In-situ bitumen production (SAGD)

Hydrocarbon Value Chain

"Using natural gas to produce oil from tar sands is akin to turning gold into lead."

Source: Canadian Energy Executive, as reported by David Hughes, Geological Survey of Canada



Source: Alberta's Provincial Energy Strategy, 2008

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Canadian Regulatory Framework

- CNSC has been updating Regulatory Framework
  - Systematically developing or upgrading documents to specifically include what it describes as Small Reactors
  - Some complete now, others in 2012 and 2013
- Key features
  - Technology neutral (water, gas or liquid-metal cooled)
  - Applies to any to any reactor size
  - 'Graded approach' where
    - Driver for safety case is risk, not size
    - Safety case commensurate with risk posed by facility
  - For small reactors more flexibility in the use of the graded approach is possible

Safety and Licensing in Canada

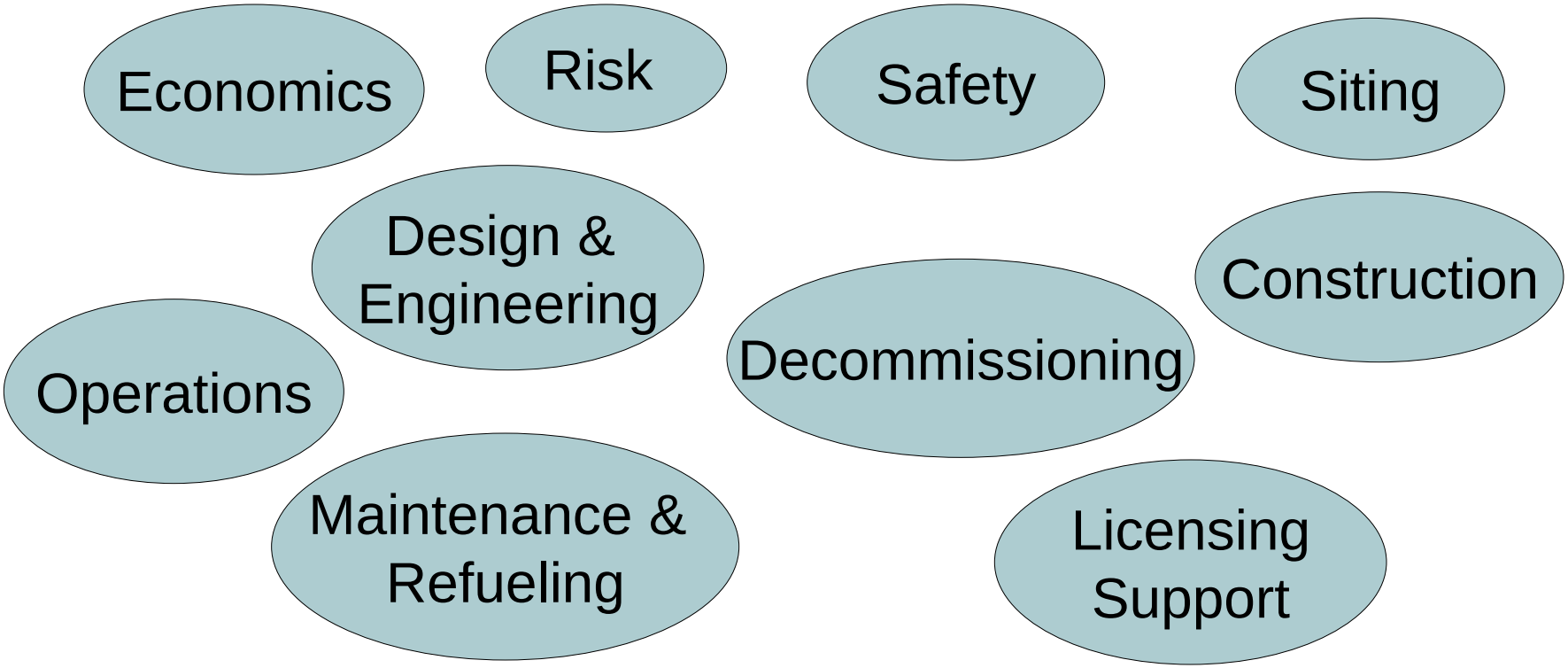
- ‘Safety’ and ‘licensing’ are not the same thing
  - Proponent responsible for safety
  - CNSC responsible for licensing
  - While not the same thing, they are closely linked and must be addressed cooperatively
- Risk-informed approach allows clearer distinction between requirements for ‘safety’ & for ‘licensing’
- CNSC proactive in developing/extending/clarifying its licensing process to include small reactors

Beyond Licensing

- ‘Industry’ needs to be equally proactive in developing the safety case and addressing other factors that
  - Are crucial to successfully introduce SMRs into Canada
  - Eventually become a part of the licensing story
- Who is the ‘Industry’ ?
  - The SMR suppliers/vendors
  - The potential User industries and/or communities
- These ‘other factors’ can generally be categorized as
  - Infrastructure
  - Institutional
  - Business model

Some of the Other Considerations

- Other considerations that need to be taken into account include, but are not necessarily limited to



  - Supplementary information available at end of slides.

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Next Steps Moving Forward

- Strategic plan for ongoing development/evaluation
- Comprehensive economic assessment
- Establish viable business model
- Identify and engage stakeholders
  - Regulatory agencies
  - Potential investors and owner/operator
  - Public
- Identification of highest priority concerns
- Detailed work plans for each issue/concern

Next Steps Moving Forward

- Structured, comprehensive evaluation program
- Leading to incremental, ‘easy’ decisions
- Based on
  - Clear statement of risks, benefits & costs to proceed
  - Enhanced ability to make risk-informed decisions
  - Increased likelihood of successful outcome at each step
- Evaluation program terminated if
  - Successful outcome can not be achieved
  - Cost to proceed outweighs the likely benefits

Questions...

Thank you!

I would be happy to take your questions,
or you may contact me later at:

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Supplementary Slides

Some Considerations to be Assessed

Economic Considerations

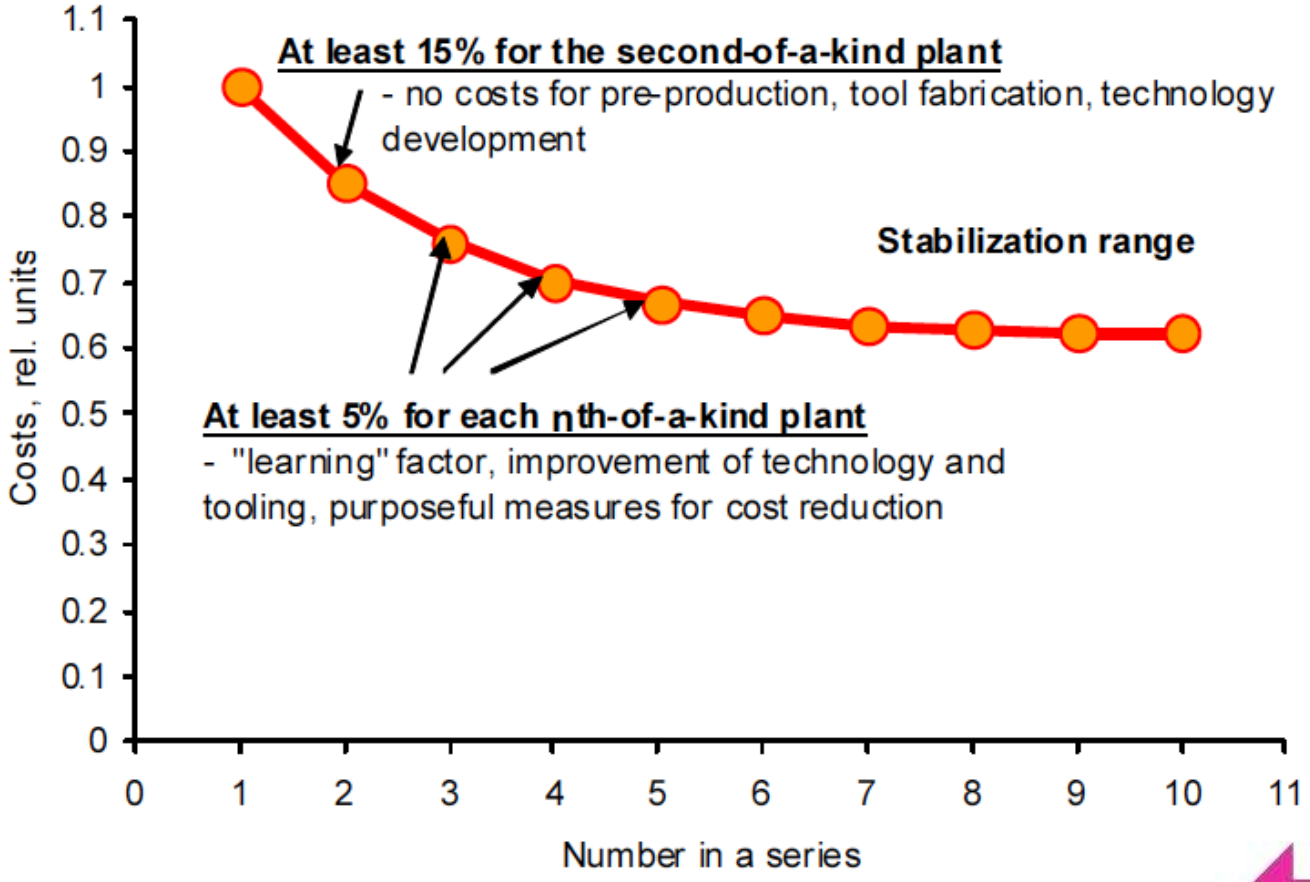
- Detailed economic evaluation needed
- Cost comparison to other alternatives
- How do infrastructure alternatives affect costs
- Annual fee for SMR multi-module facilities
- Insurance and liability for SMRs
- Is economy of scale offset by modular fabrication, fewer parts, simpler design, faster construction

"Factory built SMRs at 100 MW are far cheaper per unit of delivered power than the big reactors at 1,000 MW built on site."

Source: Anonymous

Economics of Serial Production

Reduction of costs of equipment fabrication and installation in serial production of nuclear propulsion plants.



Source: Draft IAEA report, "Approaches to Assess Competitiveness of SMRs", 2010

Return to Issues

Design & Engineering Considerations

- Design based on proven reactor technologies
- Treated as first-of-a-kind unit or as prototype facility?
- Successful design concept must
  - Address large-reactor shortcomings
  - Defend challenges from other industrial sectors by demonstrating cost competitiveness of this solution

Return to Issues

Risk Considerations

- Licensing uncertainty can be biggest risk factor
- Economic risk
- Schedule risk
- Public perception
- Use of PRA and risk-informed decision making in the licensing process for SMR
  - Consistent with CNSC ‘graded’ approach

Return to Issues

Safety Considerations

- Inherently safe integral design
- Remote location
  - Both a benefit and a concern
    - Low population density
    - Accessibility / extreme weather conditions
- Safety considerations for SMRs include
  - High priority on preliminary safety assessment
  - Appropriate source term, dose calculations for SMRs
  - Implementation of defense-in-depth philosophy
  - Accident selection for SMRs

Return to Issues

Licensing Considerations

- License framework for SMR multi-module facilities
- Manufacturing license requirements for SMRs
  - Fabrication plant may be Class I nuclear facility
- License as prototype reactor may allow early start
- Loaded reactor vessel as shipping container
- Canadian licensing process cited by some in U.S. as possible model for multi-unit SMR stations

Return to Issues

Operational Considerations

- Operating requirements for SMR facilities
- Integration of non-electric reactor operations
- Operator staffing requirements for SMR facilities
  - Staffing levels
  - Who operates the reactor
  - Training & certification requirements
- Operations for multiple adjacent facilities

Return to Issues

Maintenance/Refueling Considerations

- Centralized maintenance & refueling facility
- Extent of on-site maintenance capability
- Refueling at centralized facility
- Fuel handling capability between refueling
- Installation/replacement of SMR modules during operation for multi-module facilities

Return to Issues

Construction Considerations

- Modules built in centralized fabrication facility
- Who gets ‘construction’ license?
- Construction schedules
  - Impact of factory production of modules
  - Scope and schedule similar to gas-fired facility
- Containment functional capability for SMRs
- Integration of heating application and reactor facilities
  - Industrial facilities using nuclear-generated process heat
- Serial fabrication

Return to Issues

Siting Considerations

- Site layout eliminates external hazards, requires minimal operations and security personnel
- Security and safeguards requirements for SMRs
- Aircraft impact assessments for SMRs
- Offsite emergency planning requirements for remotely located SMRs
- Site-specific environmental assessment and safety analysis.

Return to Issues

Decommissioning Considerations

- Reactor facility decommissioned & disassembled
  - Reactor plant transported to central maintenance facility for refueling/maintenance
- Plant site returned to original condition (‘gray’ or ‘green’ field) some time after plant shut down
- CNSC graded approach taken into account in establishing decommissioning funds

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