CanInfra Challenge
and Canadian Transformational Infrastructure Summit

INZEM EnergyTeam

An Integrated Zero Emission (INZEM) Energy System

Video can be viewed at:
https://youtu.be/VAblCjPtNF8

Peter Ottensmeyer
BASc PhD FRSC

Charles Rhodes
MASc PhD PEng

Paul Acchione
MEng PEng FCAE

May 10, 2018

The INZEM EnergySystem overview …

The INZEM Energy System is a sustainable …

low emission energy system that meets all of Canada's energy needs for over 500 years by consuming and eliminating existing stockpiles of nuclear fuel waste using walk-away safe small modular nuclear reactors

The INZEM Energy System is transformational …

Combines economically sound electricity price reform to use all of the heat and electrical energy from safe compact fast-neutron reactors and from renewables to provide CO_2 free power in Canada for centuries

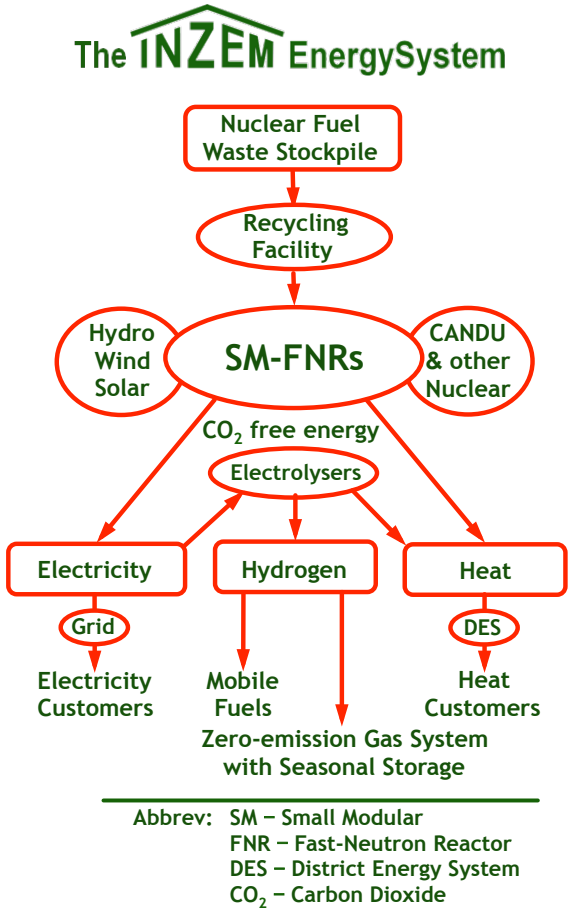
Surplus electricity is retained to displace fossil fuels or to produce hydrogen as stored energy.

Key INZEM Message

Centuries of affordable carbon-free energy

Elimination of nuclear fuel waste

Massive avoidance of CO_2 emissions (over 900 billion tons by 2500)



The INZEM EnergySystem overview ⋯

The INZEM Aim: centuries of energy; no nuclear fuel waste; no carbon emissions

➢ INZEM Energy System Plan is ⋯

Feasible
- ✧ 30+ years FNR operating experience - small modular and large reactors worldwide
- ✧ Heavy lifting by nuclear power - energy when needed / climate proof
- ✧ Initial Canadian funding exists

Relevant
- ✧ Entire energy system free of CO_2 emissions
- ✧ Low cost surplus energy from idle generation (up to 2/3rds of total)
- ✧ Workable gradual transition to clean energy

Transformational
- ✧ Recycles/eliminates Canada's stockpile of spent nuclear fuel waste in decades
- ✧ CO_2-free heat & electricity for 500+ years for homes, transportation & industry

➢ INZEM Energy System Plan provides ⋯

- ✧ 420,000 new clean-energy jobs by 2070 --- equal to fossil industry employment
- ✧ Returns of 11% on equity ⋯ total investments increase at a manageable rate
- ✧ $1 billion/year in investments in 2020 peaking at $40 billion/year between 2040 & 2050
- ✧ Maintains Canada's status as energy superpower
- ✧ Leadership in clean energy, hydrogen and nuclear --- with export opportunities for goods/services
- ✧ Kudos to Canada for meeting its 2070 & 2100 international climate change commitments

Abbreviation: CO_2 – Carbon dioxide FNR – Fast-neutron reactor

The INZEM EnergySystem overview …

The INZEM Aim: centuries of energy; no nuclear fuel waste; no carbon emissions

ENABLERS	BARRIERS	MITIGATION
Nuclear fuel recycling facility	Federal policy to bury waste	Policy change to recycle used fuel
FNR deployment	Public fear of nuclear power	Use walk-away safe FNRs, outreach
Electrolyser deployment	Cost of electrolysers	Green funding support for hydrogen
District energy system deployment	Lack of regulations & standards	Develop regulations & standards
Electricity price reform (see box)	Provincial electricity price policies	Policy Change - energy at marginal price
Carbon price at $200/tonne CO_2	Public resistance	Education on benefits of no carbon
Energy infrastructure easements	Competition with other utilities	Allow all utilities to buy DESs
Support from fossil fuel sector	Stranded assets if change too rapid	Incentivize fossil sector to participate
Skilled workers and teams	Lack of appropriate skills	Education, skill-based immigration

Electricity Price Reform

- Historically the cost of generating electricity was dominated by the price of fuel (coal, gas) for each kWh. It was logical therefore to charge the customer primarily for each kWh used.
- Non-carbon electricity generation is dominated by the fixed cost of the generating plant. Fuel being virtually "free", the retail price structure has not changed to reflect this.
- Electricity price reform should make surplus non-carbon electricity available for fossil fuel displacement at its marginal cost of less than 2 cents/kWh instead of exporting it at low prices or discarding it.

Abbreviations: FNR – Fast-Neutron Reactor; DES – District Energy System; CO_2 – Carbon dioxide; kWh - kilowatt-hour

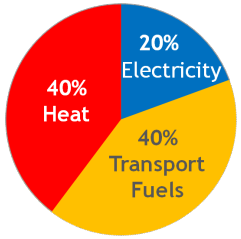
The INZEM EnergySystem in context …

The INZEM Aim: centuries of energy; no nuclear fuel waste; no carbon emissions

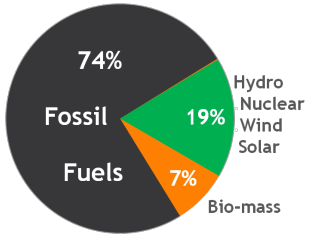
BACKGROUND: Canadian Economy-Wide Emissions and Commitments

➢ Present emissions	722 Million tons (2015)
➢ Environ. Canada's (bus. as usual) projection	742 Million tons (2030)
➢ Canada's national commitment	523 Million tons (2030)
➢ Canada's COP21 Paris commitment	122 Million tons (2050)
➢ Canada's G7 commitment	61 Million tons (2100) [no fossil energy]

Canadian Energy Use



Canadian Energy Sources



The INZEM Energy System can affordably reduce emissions 20% per decade

Electricity can be made non-emitting → with a marginal cost less than fossil fuels

Affordable path to zero emissions in energy → use non-emitting surplus electricity as well as waste heat from nuclear electricity production

The INZEM EnergySystem in context …

The INZEM Aim: centuries of energy; no nuclear fuel waste; no carbon emissions

BACKGROUND: Generation Technologies Available Today for Carbon-Free Energy

Technology	Energy Output	Challenges in Increased Use
Hydroelectric	24/7	Limited supply, local environmental concerns
Wind turbines	Intermittent	Carbon backup, carbon-free backup is expensive
Solar panels	Intermittent	Carbon backup, carbon-free backup is expensive
Bio-mass	24/7	Limited supply, local environmental concerns
Fusion reactors	not ready	More than 50 years into the future
Fission reactors	24/7	**See box below**

Small Modular Fast-Neutron Reactors (FNRs)

- Developed as comprehensively safe civilian plants
- Use fuel efficiently, up to 100% (extends fuel supply)
- FNR fuel recycling technology available since 1980s
- Economical access to used fuel for over 500 years
- Proven walk-away safe and operate at low pressures
- Can be located close to loads to utilize waste heat
- Lower up front investment, mass production in factories to eliminate cost/schedule risk

Existing Large Centralized Reactors

- Developed from military (naval) reactors
- Uses fuel inefficiently (less than 1% consumed)
- Produce large amounts of long lived wastes
- Economical fresh uranium fuel only sufficient till ~2050
- Not walk-away safe, pumped cooling must be maintained
- Approval challenges, sites are long distance from loads
- Large up front investment, cost/schedule risk

FNRs have demonstrated they do not melt down due to failure of cooling, power or control rods
FNRs are a key component of a low emission affordable energy system

The INZEM EnergySystem in context …

The INZEM Aim: centuries of energy; no nuclear fuel waste; no carbon emissions

FNR Safety

The type of FNR envisioned for deployment has been shown to be walk-away safe during extensive testing under severe failure challenges, each time shutting down to a safe temperature without power and without human or automated intervention.

Such FNRs would not have incurred accidents like Fukushima, Three-Mile-Island, or even Chernobyl.

Why Nuclear? Insights on Emissions and Electricity Costs: Ontario versus Germany

	Ontario	Germany
2005 Emissions	210 grams CO_2 per kWh	690 grams CO_2 per kWh
2015 Emissions	51 grams CO_2 per kWh	535 grams CO_2 per kWh
Change in Emissions	- 76 %	- 22 %
2015 Electricity Price	**14 CDN cents per kWh**	**47 CDN cents per kWh**

Reasons for Success – Ontario	Reasons for Inferior Results - Germany
Eliminated coal	Eliminated nuclear
Added wind + solar + nuclear	Added wind + solar
Added natural gas for renewable backup	Added coal + natural gas for renewable backup
Engineering guided energy policy decisions	Fear of nuclear guided energy policy decisions

Abbreviations: FNR – Fast-Neutron Reactor CO_2 – Carbon dioxide kWh – Kilo-watt-hour

The INZEM EnergySystem in more detail …

The INZEM Aim: centuries of energy; no nuclear fuel waste; no carbon emissions

Energy Integration Among Sectors Ensures Affordability

Zero-emission surplus electricity at marginal cost is cheaper than fossil fuels
Surpluses are exchanged between sectors or stored as carbon-free hydrogen for later use

INZEM Overall Energy Optimization --- minimizes waste / lowers costs

	Electricity		Heat	Hydrogen	Synthetic fuels
Time of Use	Continuous	Daytime Peak	Continuous (steam/hot water)	Anytime	Anytime
Optimum source	Nuclear RoR hydro	Solar Dam hydro	Nuclear	Wind Surplus electricity	Bio-mass + Hydrogen

Trade-offs location sensitive

- Urban areas: served mainly by electricity grid, DES and zero-emission gas distribution system
- Rural areas: served mainly by electricity grid, hydrogen and synthetic liquid fuels
- Off-grid areas : individual treatment depending on population density & road, rail or air access

INZEM Phased-In: Reduces stranded fossil fuel assets and social disruption

Phase 1: Surplus electricity Phase 2: FNR and DES deployment Phase 3: Synthetic liquid fuels

2070 to 2100 climate change targets can be achieved without economic or social disruption.

Abbreviations: FNR - Fast-Neutron Reactor DES - District Energy System RoR - Run of the river

The INZEM EnergySystem in more detail …

HIGH LEVEL OVERVIEW
ENABLERS, BARRIERS & MITIGATION
CONTEXT/BACKGROUND
- Emissions and Commitments
- Energy Use
- Technologies Today
- Reactor Safety
- Insights from Others

INZEM ENERGY SYSTEM
- Integrate
- Optimize
- Trade-offs
- Phasing in INZEM

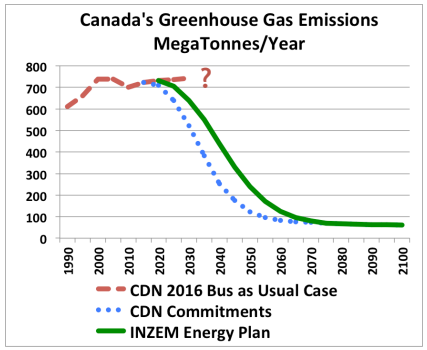
BENEFITS
- Emissions
- Energy Costs
- Nuclear Waste
- Carbon Price
- Investments
- Jobs

SUPPORTING DATA & BUSINESS CASE

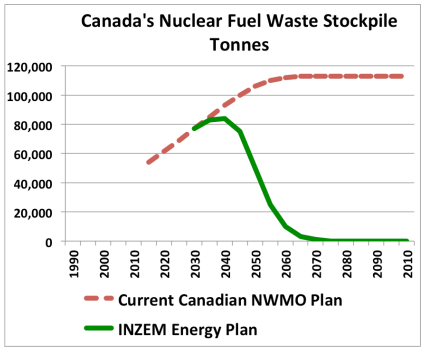
The INZEM Aim: centuries of energy; no nuclear fuel waste; no carbon emissions

INZEM BENEFITS compared to Current Federal/Provincial Energy Policy Approach

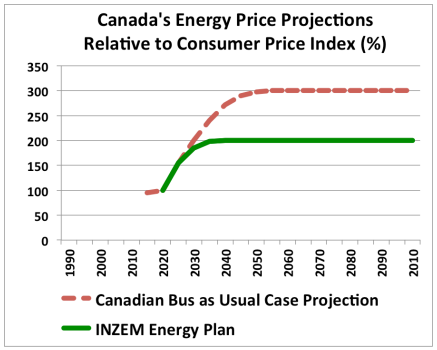
Very Low Emissions



No Nuclear Waste Legacy



Lower Overall Energy Costs



Carbon Price 75% Lower than Current Canadian/Provincial Energy Policy Approach

- Rising \$20/yr from 2019 to \$200/tonne CO_2 (instead of \$800/tonne CO_2, ref: Strapolec Study 2016)
- Regulations will be needed to complete fossil fuel phase-out in later years.

Significant Investments in Energy Infrastructure (Double Current Fossil Fuel Investments)

- \$1 billion/year in 2020 peaking at \$40 billion/year between 2040 & 2050

Significant New Jobs in Clean Energy Sector (Comparable to Fossil Fuel Sector Now)

- 420,000 direct and indirect support jobs by 2070

Abbreviations: CO_2 – Carbon dioxide NWMO – Nuclear Waste Management Organization

The INZEM EnergySystem in more detail …

The INZEM Aim: centuries of energy; no nuclear fuel waste; no carbon emissions

Financial (#1):	New Capital Investments to 2070 Billions $s	New Revenue in 2070 Billions $s	Net Income in 2070 Billions $s	Rate of Return On Equity (projected)
Electrical Grid (#2)	890	125	33	11%
Hydrogen Electrolysers	65	17	4	15%
DES (Thermal Energy)	(#3) 135	52	4	7%
TOTALS (in 2020 $s)	**1,090**	**194**	**40**	**11%**

#1 - Financials based on typical utility investment practices (eg: 65% debt/35% equity)
#2 - Includes FNRs, fuel recycling facility and electrical transmission and distribution investments
#3 - Portion of capital costs may form part of property development charges in some municipalities.

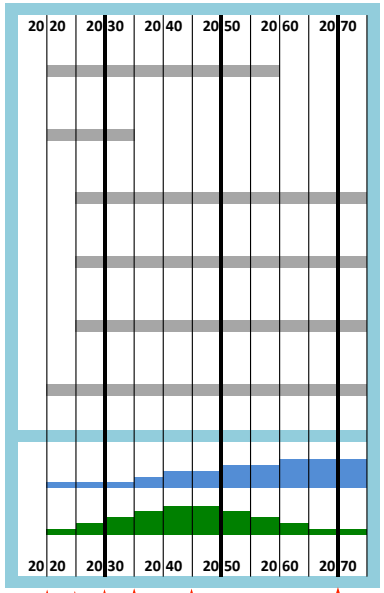
Funding Sources:

- Early stage commercialization (fuel recycling, FNRs, electrolysers)
  - Federal grants, subsidies and guarantees to lower risk for private investors
  - Carbon price income used to support development of higher cost zero-emission technologies
  - Repurposing nuclear fuel waste management trust fund for fuel recycling instead of burial
- Commercial Deployment:
  - 25% Developers, 75% other parties (infrastructure and commercial banks, etc.) to build projects
  - Sold to owners/operators at operational in-service date
  - Projected 11% per year ROE for FNR owners after in-service date
  - Debt and/or equity funding from pension/sovereign funds, insurance co., public markets
  - Municipal property development charges for district energy systems

Abbreviations: ROE – Rate of Return on Equity FNR – Fast-Neutron Reactor DES – District Energy System

The INZEM EnergySystem in more detail …

The INZEM Aim: centuries of energy; no nuclear fuel waste; no carbon emissions



Deployment Schedule, Labour/Financing Timelines

Electrolyser Deployment
[initial deployment using surplus clean electricity, later for syn. fuel production]

Spent Fuel Recycling Facilities Deployment
[install recycling capacity to convert spent nuclear fuel waste into SM-FNR fuel]

Small Modular Fast-Neutron Reactor Deployment
[by 2025 receive license to build the 1st standard size, then additional sizes]

District Energy Systems Deployment
[start with industrial, later with commercial and high density residential]

Transmission and Distribution Required by Reactors
[capacity and timing follows reactor deployment]

Methanol and Synthetic Liquid Fuels Deployment
[start methanol in 2020, start synthetic high energy dense liquid fuels 2035]

Cumulative new jobs created (420,000 direct & support jobs by 2070)

Investments (up to $40 billion per year)

Canada's international climate change commitments met by 2070
Peak investment rate of $40 billion per year between 2040-2050
Start of synthetic liquid fuels production facility design by 2035
First fast-neutron reactor & district energy system - operational by 2030
License for first small modular fast-neutron reactor before 2025
First electrolyser, recycling facility, methanol plant - design start by 2020