Integration of Wind and Hydro Power Systems

A discussion on the minimization of cost (or optimization of value?) of wind integration for grid operators

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Wind

Topical Expert Meeting #41

Portland, November 5-6 2003

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- Answers
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    - Comparing to other generation sources
- Ongoing research
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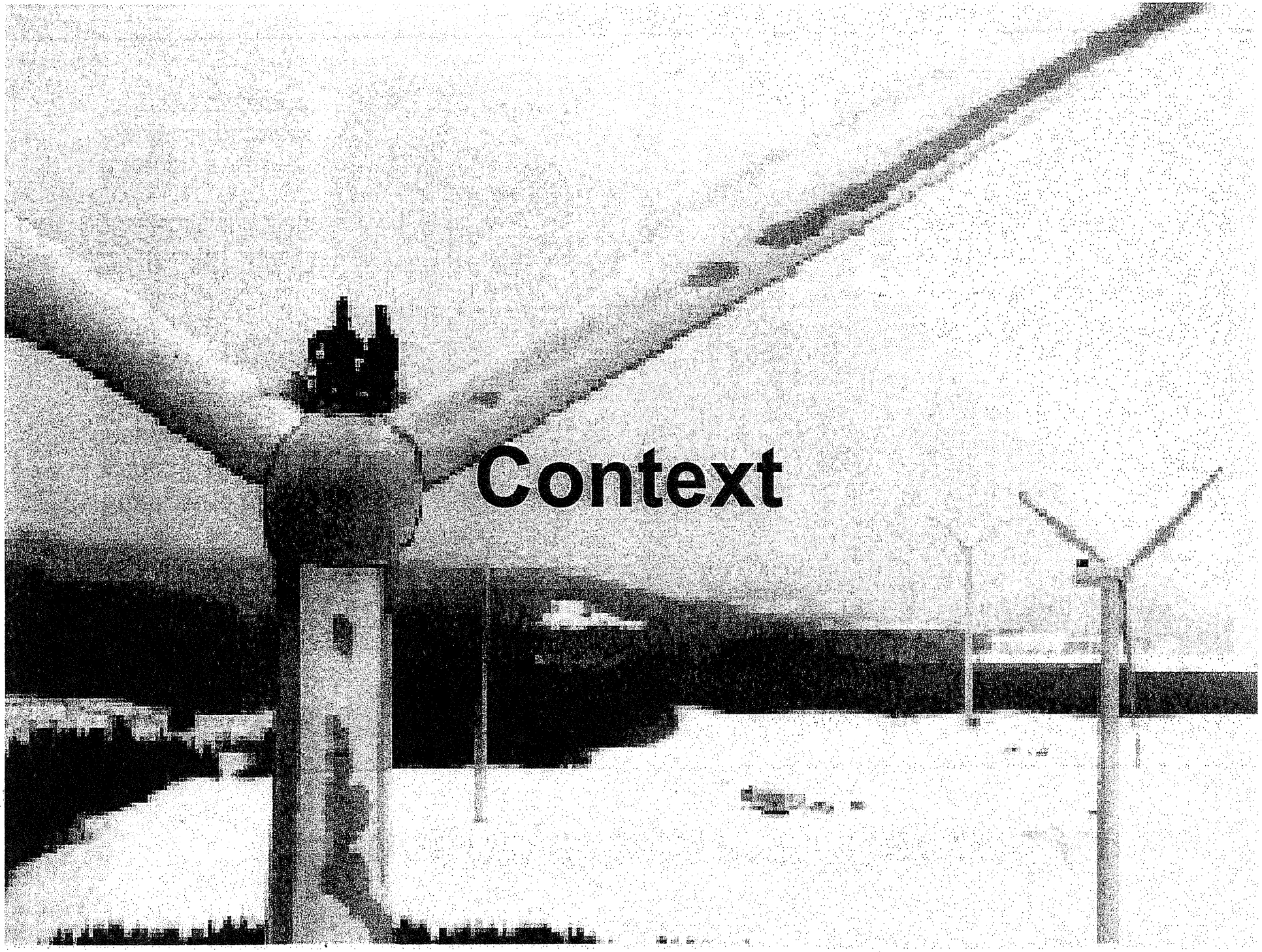
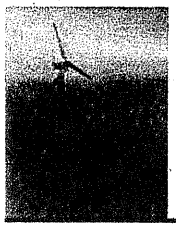
    - Electrical modelling
    - Wind "inflow" modelling


Context



Canadian Electricity Context

Electricity Generation Mix

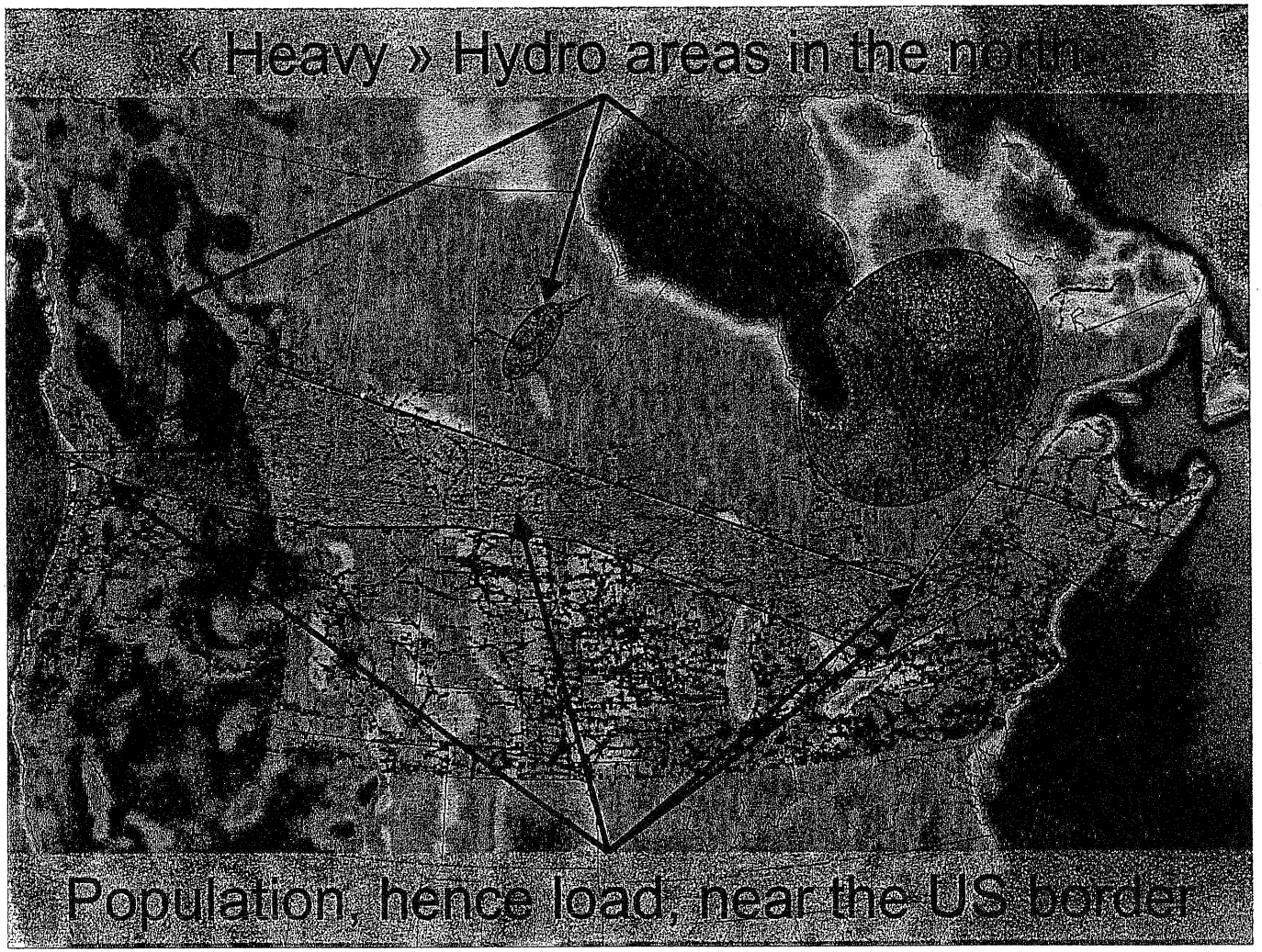
- 62% Hydro
- 26% Fossils
- 12% Nuclear

- Small wind base with 236MW installed (Sept. 2003)

- 550 TWh in 1999

Hydro Located in Remote Areas

- Extensive electrical network
- Relative distance



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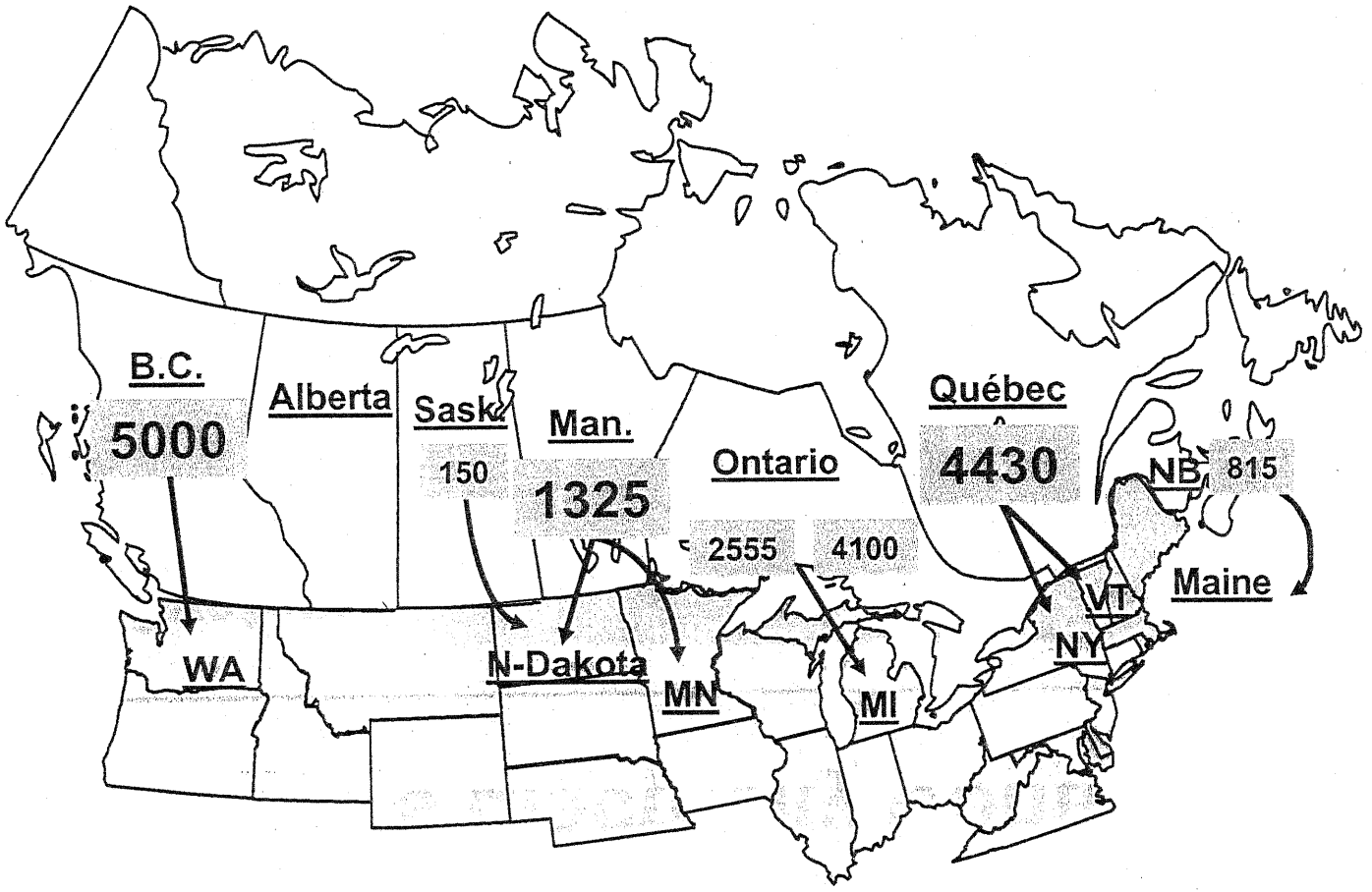
Canadian Electricity Context

Exports

- ~7.5% of Canadian power generation is exported to the USA
- Existing interconnections south of large hydro basins

Interconnections in MW (1995)



Hydro-Québec's Electricity Context

Québec/Labrador System

Generating Power Capacity: 40 000 MW
(36% of total Canadian system)

~95% Hydro

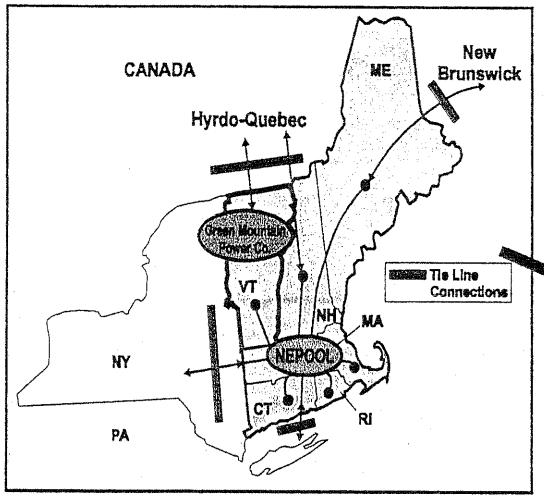
185 TWh of average annual water inflow

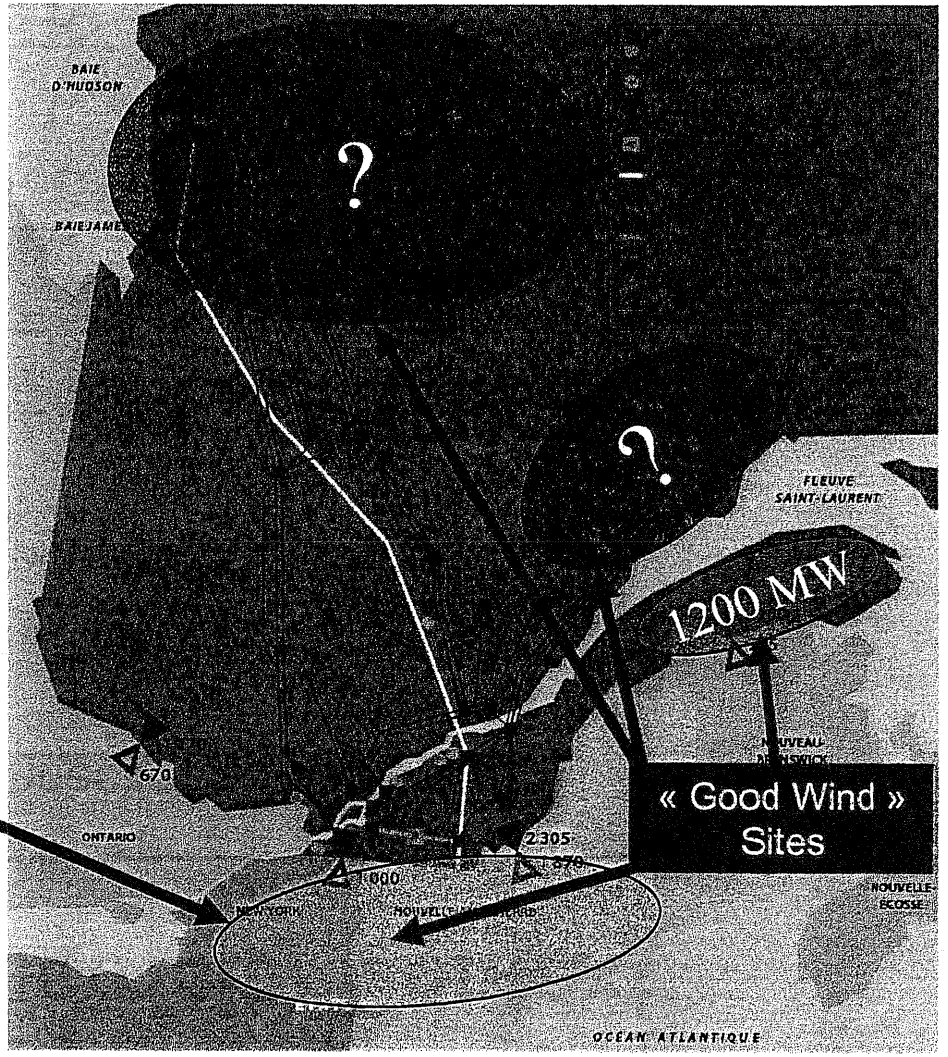
Interconnection Capacity : >6900 MW
4430 MW with the North Eastern USA

102 MW of Wind On-Line

RFP for 1GW more before 2012

Potential ?
... Unknown





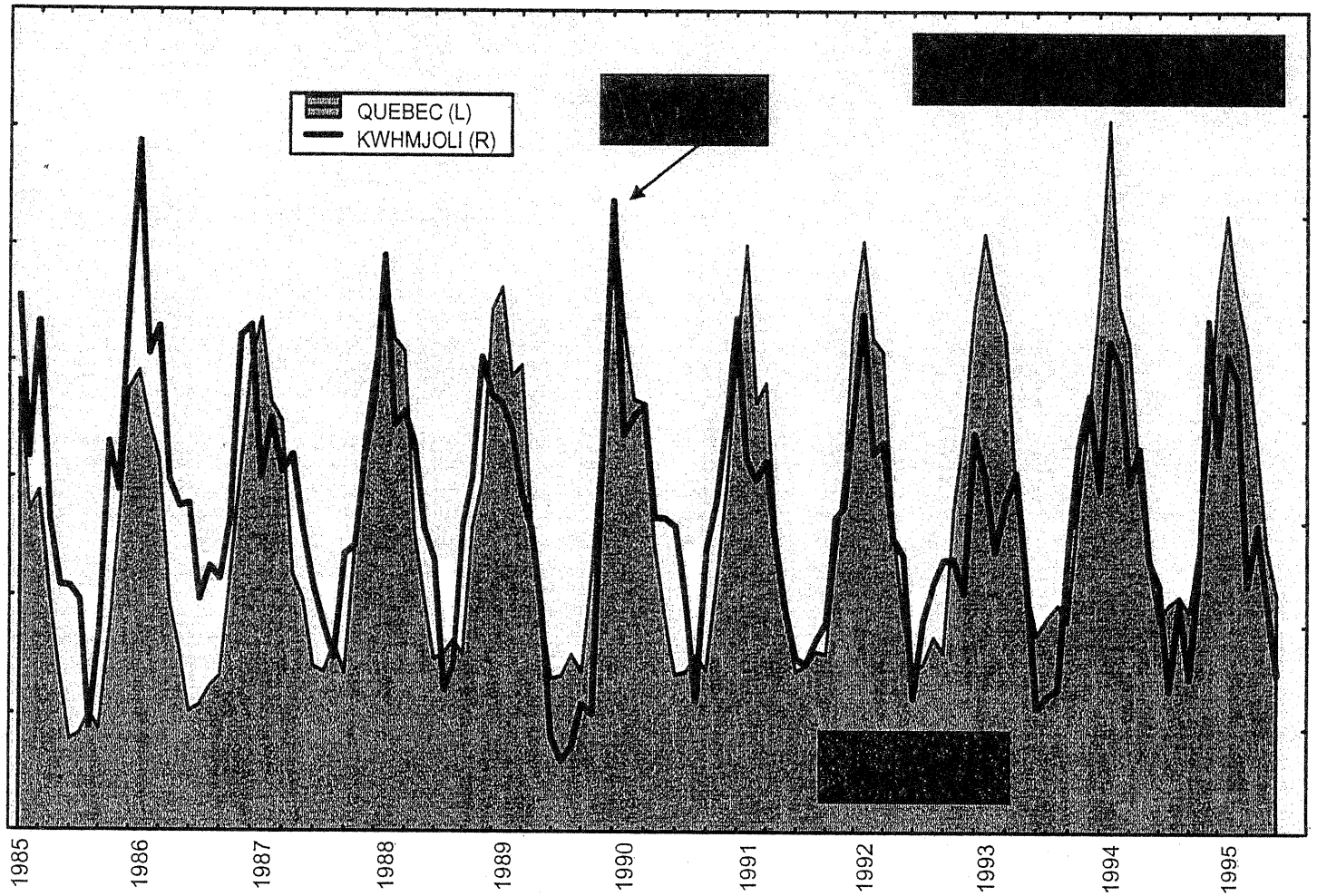
Hydro-Québec's Electricity Context

- Electricity is cheap: 3.4 $¢_{us}$/kWh (wholesale)
- Massive resistive heating in a cold climate
  - Load is highly cycled daily and seasonally
    - High diurnal peaks
    - High winter peaks
- Electrical load is correlated
  - positively with wind, daily and seasonally
  - negatively with water inflows seasonally

Wind – Load correlation

(monthly basis)

Wind power output compared to total load

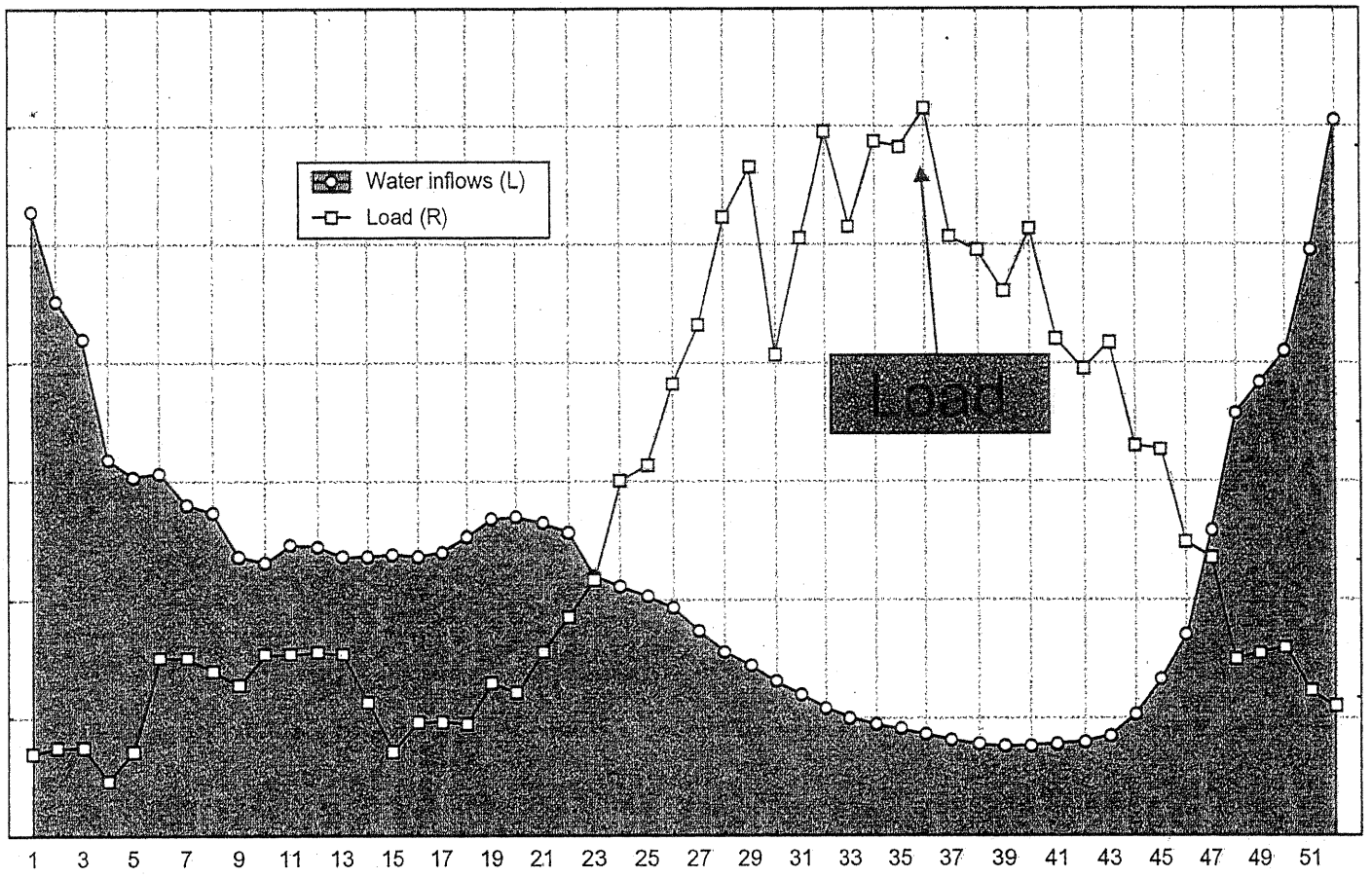


Water inflows - Load correlation

(weekly basis)

Water inflows and load Variation

(Québec)



Hydro-Québec's "Hydro" Context

- What does "Large Hydro" mean for Hydro-Québec ?
  - Coordination of a system of multi-annual, mid-term and short-term reservoirs, interlinked into basin large management systems
  - Example of the "La Grande" River basin
    - 16 GW of installed power in 8 multi-turbine plants
    - 7 reservoirs totaling 12000 km^2 (4650 mi^2)
      - An area as large as Connecticut... or 40% of Belgium
    - High voltage lines stretched over distances equal to New-York-Chicago
    - Impacts on ecosystems comparable in size to many European countries
    - Years to fill

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Hydro-Québec's "Hydro" Context

- Reservoir management
  - Within one basin, "chained" hydro plants are constrained by
    - Each other, depending on their configurations and the capacity of their own reservoirs
    - Inflow, the fluctuating volume of water drained by the basin
    - Other limiting factors like minimum/maximum water outflow
  - System wide, reservoir management is constrained by reliability issues
    - Capacity reserve and balancing of load level and other generation plants
    - Electrical limits on the transmission system
    - Other limiting factors like contractual clauses, interruptible/non-interruptible exports

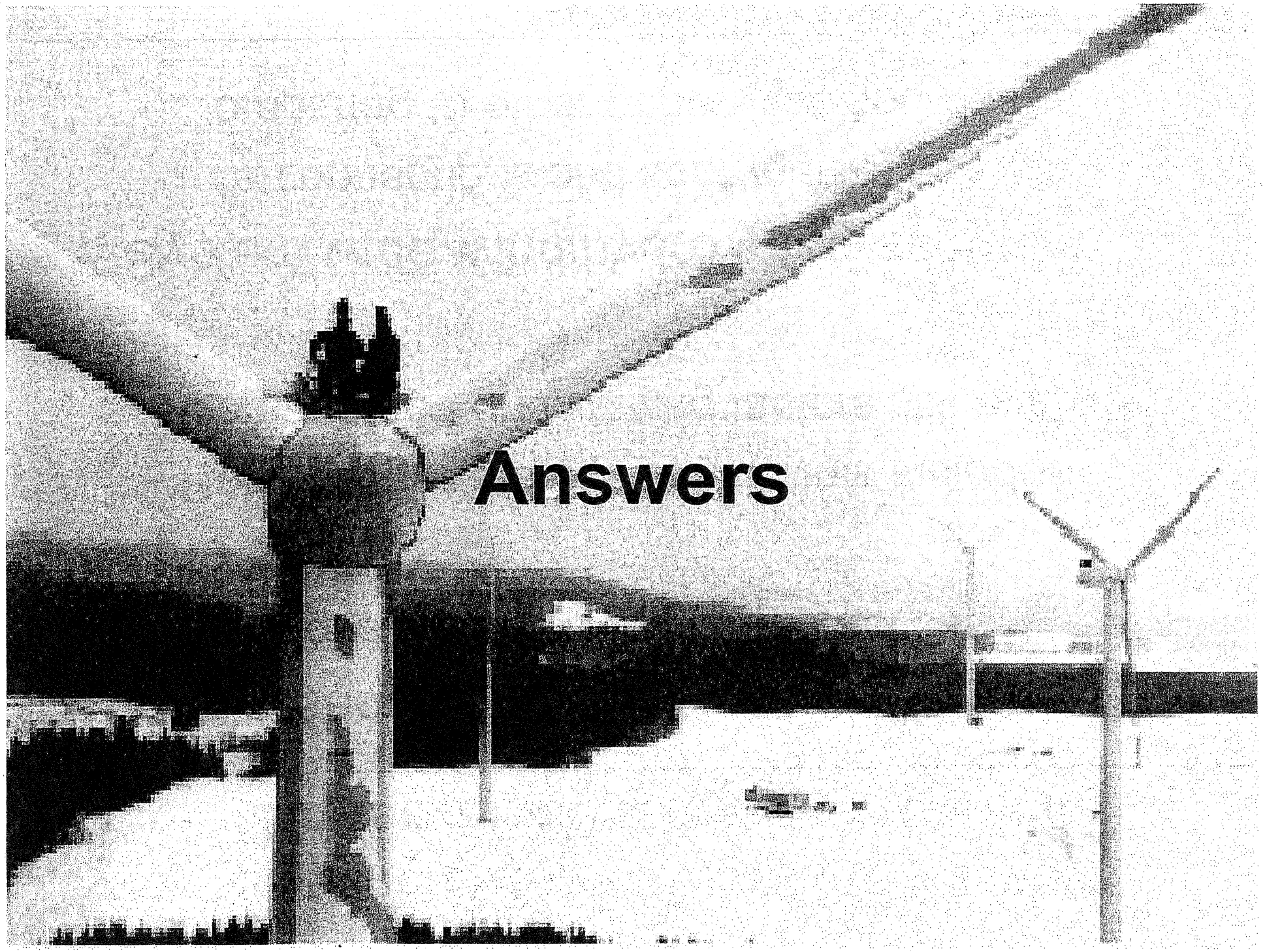
Hydro-Québec's Market Context

- Today's market context
  - Maximize revenues
    - Import/Export electricity with neighbouring networks
      - Seasonally, the NEPOOL price is negatively correlated to Québec's demand
    - "Load managing" the increasing demand
  - Guarantying the future
    - Maintain a sufficient annual water reserve
    - Invest in new generation capacity

Apart from its base COE,

Is *integrated* wind power competitiveness improved

in a large hydro system?


Answers

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Seeking Different Levels of Answers
Mid-term management modelling

- One reservoir
  - Not closely tied to operating practices
- One basin
  - Regional generator's constraints included
  - Demand and grid limiting factors still excluded

...

- System wide wind/hydro integration
  - Interconnections and spot market effects
  - Comparing to other generation sources

System wide wind/hydro integration
Using the SAGE Model

- Deterministic mid-term generation planning model called SAGE (presently used at *Hydro-Québec Production*):
  - Parameters
    - Time step : day/week - Horizon time : 1 year
    - Demand classes : one to three per day
    - Wind generation is predetermined
    - Area of interest is divided in regions based on the configuration of main transmission lines
    - Each region has a load to satisfy and production plants
    - Interconnections with neighbors are modeled
    - The generation of a hydro-plant is modeled in taking account the water head
  - Constraints:
    - Electric constraints (capacity on transmission lines).
    - Hydraulic constrained (reservoir volume, river section flow, water flow conservation, etc...)
  - Objective : Satisfy load at minimum costs

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Interconnections and spot market effects
Vermont Study – Case I

- Base case: Vermont with the NEPOOL
  - No possibility, inside Vermont, to manage wind with large hydro plants
    - Typical thermal system
    - Limited, highly constrained, short term energy storage
  - Vermont depends essentially on imports
  - No correlation between Vermont wind and spot price
  - No clear correlation between Vermont wind and load
    - Thermal heating during the winter

Interconnections and spot market effects
Vermont Study – Case I

- Results
  - Technically, high penetration of wind is possible in Vermont today, but…
  - Economically, wind value depends strongly on NEPOOL spot price
    - Required price support of 1.32 cents/kWh today
    - Depending on assumptions for pool price and wind COE changes by 2010, range of needed support is either negative or positive

Change in COE Needed For Wind To Break Even In 2010 (cents/kWh, year 2000 dollars)			
Average Annual NEPOOL Wholesale Price - cents/kWh (% change from 2000 value)	Percent Change From 2000 Average Wind COE of 5.4 cents/kWh		
	-32%	-24%	0
3.9 (-10%)	0	0.4	1.7
4.3 (0.0%)	-0.4	0	1.3
5.7 (32%)	-1.7	-1.3	0

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Interconnections and spot market effects
Vermont Study – Case II

- Base case + interconnections with Hydro-Québec and coordinated management
  - Best case scenario
    - Perfect correlation of HQ Price and Quebec's load was assumed
    - Selling stored energy when negatively correlated spot price/Québec's load were favorable
  - Results
    - Hydro-Québec's reservoirs were able to better optimize Vermont's wind energy value, thereby adding value above NEPOOL spot prices
      - Value of wind was 22% higher than if it were sold only at NEPOOL spot prices
      - Actual savings would be below this figure

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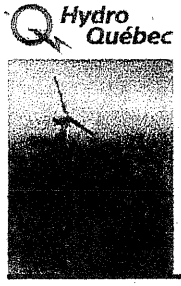
Comparing to other generation sources
Hydro-Québec study

- Integrating increasing amounts of energy from "other" generation sources with the hydro system
  - A large wind energy volume (more than 10 TWh) can be managed optimally by the hydraulic assets
  - Up to certain proportions (~10-20%), the annual generation profile (P=f(*t*)) of an energy source does not bring any particular value or cost when managed through large hydro storage
    - In the worst case, wind competes with other sources on the base of its COE
  - In a "power deficit" situation, wind integration value depends on:
    - Interconnections with neighboring systems
    - Correlation between wind and market spot price
  - Verification including stochastic nature of wind to be done


Ongoing research



Seeking Different Levels of Answers
Short-term management modeling

Again

- System wide management is constrained by short-term efficiency and reliability issues

  – Part of the answer comes through electrical modeling of short term effects
    - Electrical limits on the transmission system

  – Part of the answer comes through short term modeling of wind power and energy "inflow" management

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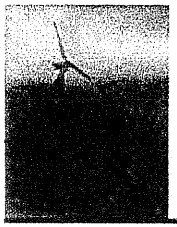

Short Term Electrical Modeling

- SimPower System (Matlab), PSS/E, EMTP, HyperSim
  - Models of turbines
  - Small installations
  - Large wind plants
  - Regional and system effects
    - Frequency
    - Voltage
    - Harmonics
    - Etc.

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Short Term Wind "Inflow" Modelling

- Development of models
  - Capacity reserve and hydraulic balancing of wind output
  - Unit scheduling and commitment
  - …
  - Optimization possibilities
  - Wind forecasting
  - …

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A Continuum of Systems

- System specificity
  - Rarely possible to directly extend a conclusion from one location to another
- But still a continuum of configurations
  - From a large scale wind-hydro system at one end to a small remote high penetration/no storage wind-diesel system at the other:

Conceptually similar, but improving wind value in the large system requires fine tuning to achieve economic leverage

What is the residual added-value of wind in a large scale hydro system ?

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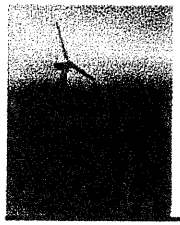

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