NATIONAL ENERGY TECHNOLOGY LABORATORY

Role of Alternative Energy Sources: Hydropower Technology Assessment

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August 28, 2012

U.S. DEPARTMENT OF ENERGY

Agenda

- Technology Description
- Resource, Capacity, and Growth
- Environmental Analysis
- Cost Analysis
- Barriers to Implementation
- Risks of Implementation
- Expert Opinions

Grand Coulee Dam in Washington (BPA.gov)

Technology Description: Hydropower Types

Conventional Hydropower

- Includes installation of large scale dam or other impoundment, combined with controlled release mechanism and turbine/generator train
- Hydraulic head from reservoir drives turbines and generators, providing electricity
- Produced 253 terawatt-hours of electricity in 2009, equivalent to 72 percent of total renewable power generation or 6.9 percent of total power generation in the U.S.
- Installed capacity has remained flat since 2000 (near 77 GW)

Hydrokinetics

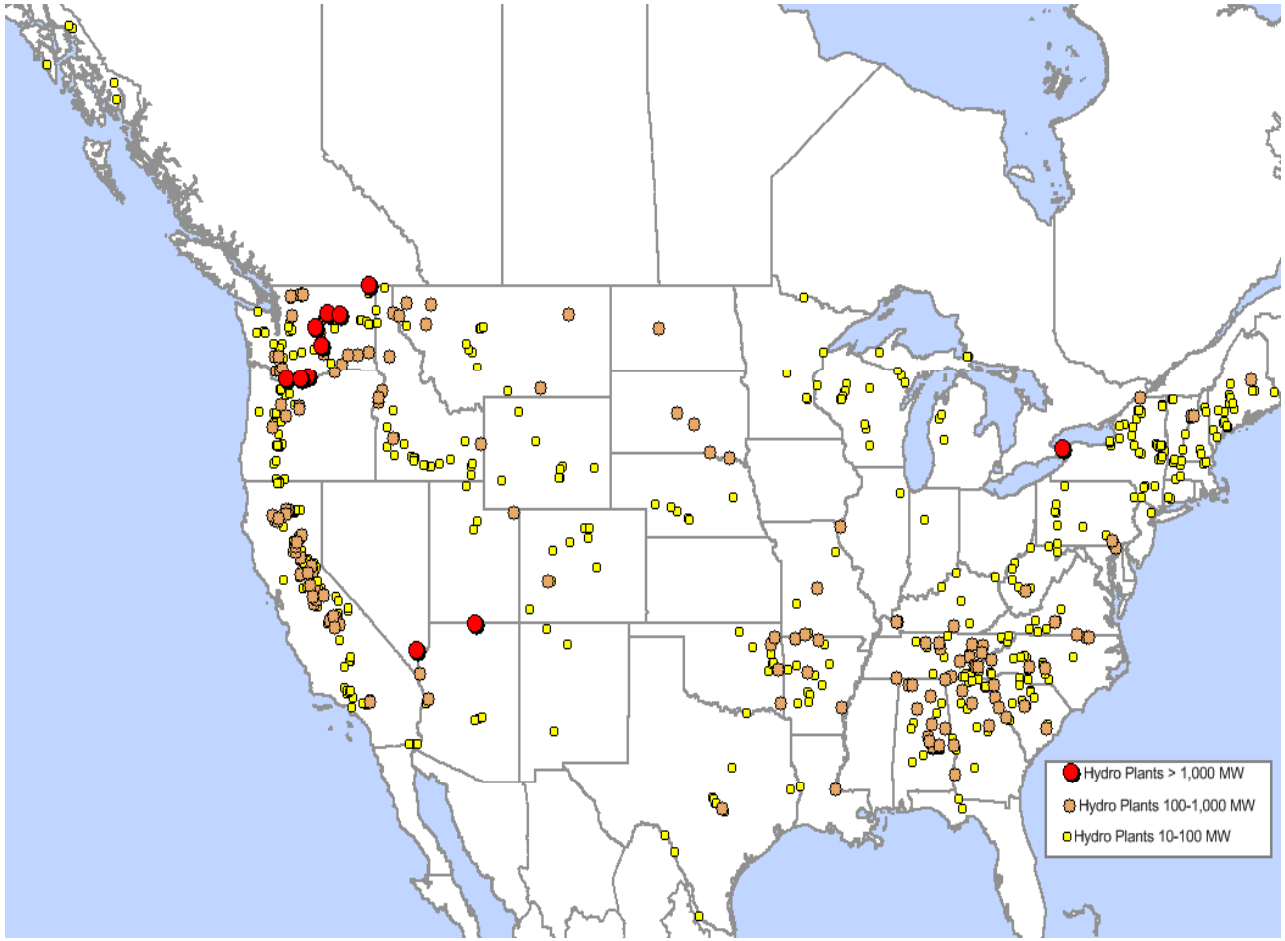
- Harnesses energy that is contained in water moving past a fixed point
- Employs in-stream turbines that typically resemble small scale horizontal axis wind turbines
- First commercial scale in-river installation was completed in January, 2009, near Hastings, Minnesota (0.07 MW)
- New hydrokinetic turbines are currently being installed along Mississippi River system
- Minimal data available, therefore not considered for environmental or cost analyses

Technology Description: Hydropower Performance Characteristics

Parameter	Units	Conventional Dam
Plant Lifetime	Years	80
Average Net Power Output of Plant	MW	2,080
Average Annual Capacity Factor	%	37
Reservoir Area	Acres	158,000
	m^2	640,000,000
CO_2 Emissions from Reservoir	kg/m^2-yr	2.42E-01
	kg/MWh_{net}	23.0
CH_4 Emissions from Reservoir	kg/m^2-yr	3.40E-03
	kg/MWh_{net}	0.323
Total Project Capital	2002$/kW	1,900-6,300

- Reservoir areas in U.S. are variable based on reservoir capacity and on topographic conditions
- Emissions of CO_2 and CH_4 from conventional reservoir surface were based on results of a study that published gas flux from surface of different reservoirs in North and South America
- Emissions are based on measurements from reservoirs in Colorado and Wisconsin (St. Louis, et al., 2000)

Resource, Capacity, and Growth



- Existing installed base is approximately 77 GW (NREL, 2010)
- Existing hydropower plants shown at right
- Red dots are facilities with over 1,000 MW installed capacity
- Not shown are many thousands of very small facilities under 10 MW
- Many of best sites for very large scale hydropower have already been developed
- Many smaller reservoir sites (under ~400 MW) are still available

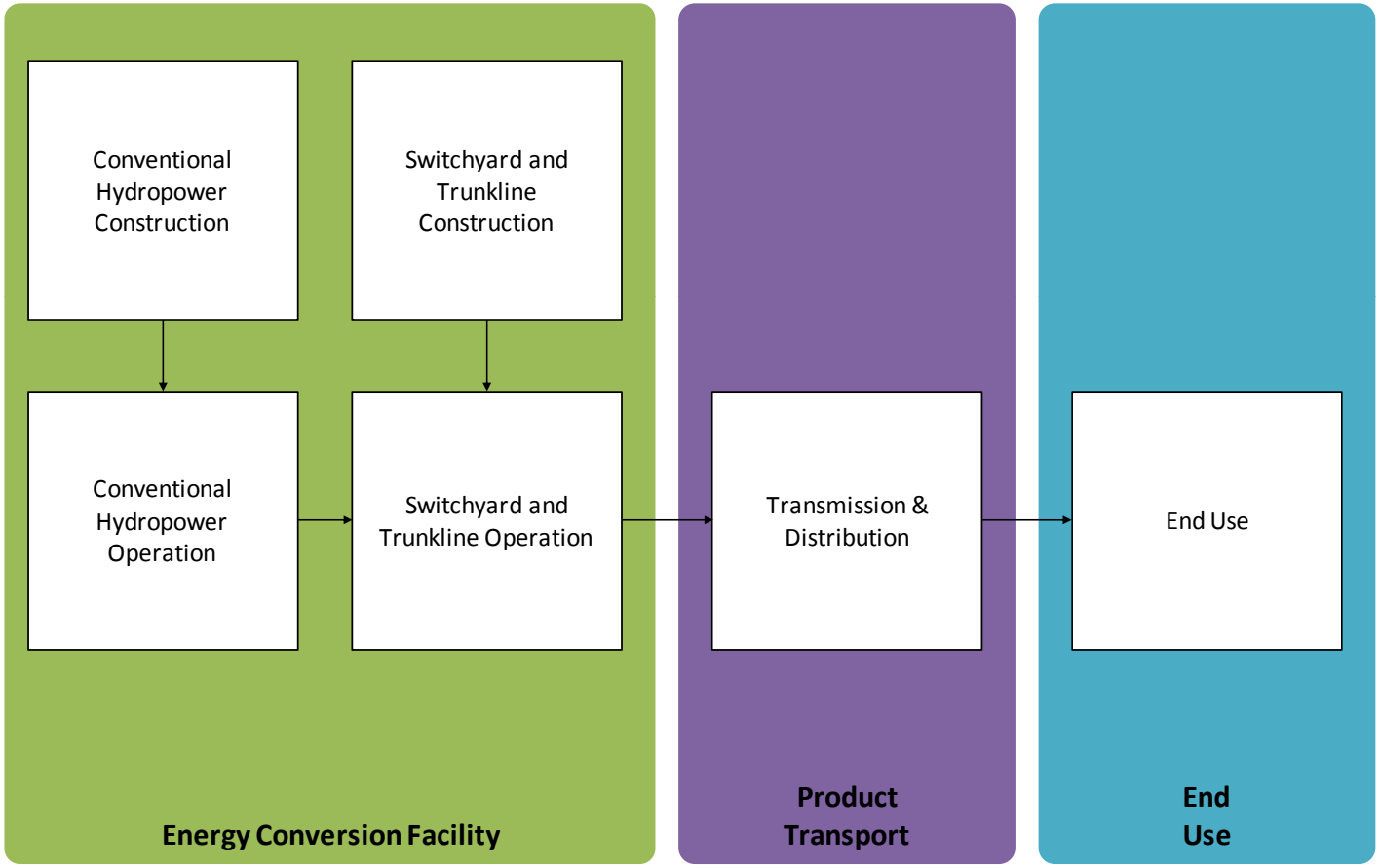
Resource, Capacity, and Growth

Technology	Potential Capacity (GW) (EPRI, 2007)	Issued Preliminary Permits (FERC, 2011b)		Pending Preliminary Permits (FERC, 2011b)	
		Capacity (GW)	No. of Projects	Capacity (GW)	No. of Projects
Conventional	62.3	3.1	259	1.6	122
Hydrokinetic	12.8	3.6	36	8.4	87
Ocean Energy	20.0	5.7	34	<0.1	4
Total	**95.1**	**12.5**	**329**	**10.0**	**213**

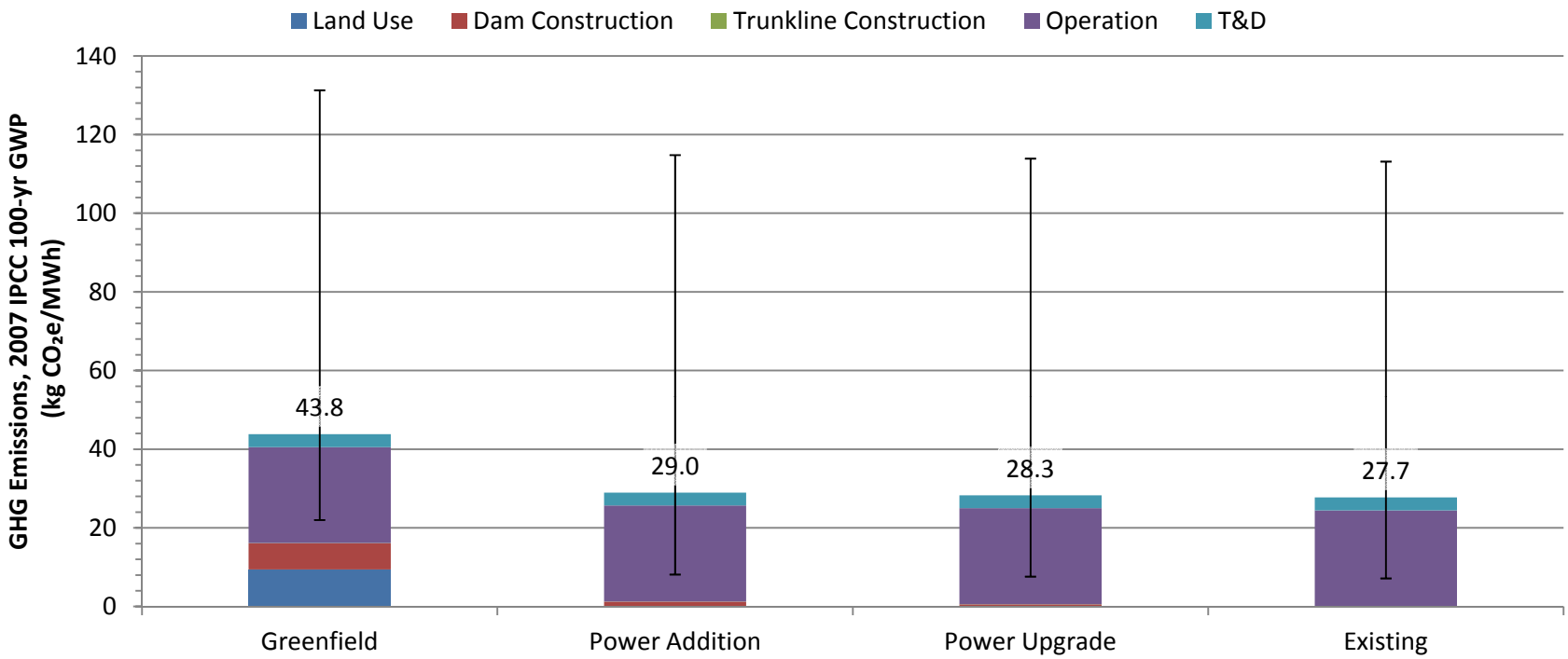
Source: FERC, 2011

- EIA Annual Energy Outlook (AEO) projects hydropower generation growth at 0.5 percent and capacity growth at 0.1 percent per year from 2008 and 2035
- EPRI (2007) estimated an additional 62 GW of conventional hydropower is available for development
- Over 250 preliminary permits issued by FERC as of 2011
- Issued and preliminary FERC permits for conventional hydropower totaled 22.5 GW as of 2011, on top of existing 77 GW installed base
- Issued and preliminary permits for hydrokinetic totaled 12 GW
- Hydrokinetic mostly along Mississippi River as shown

Environmental Analysis of Hydropower: LCA Modeling Structure



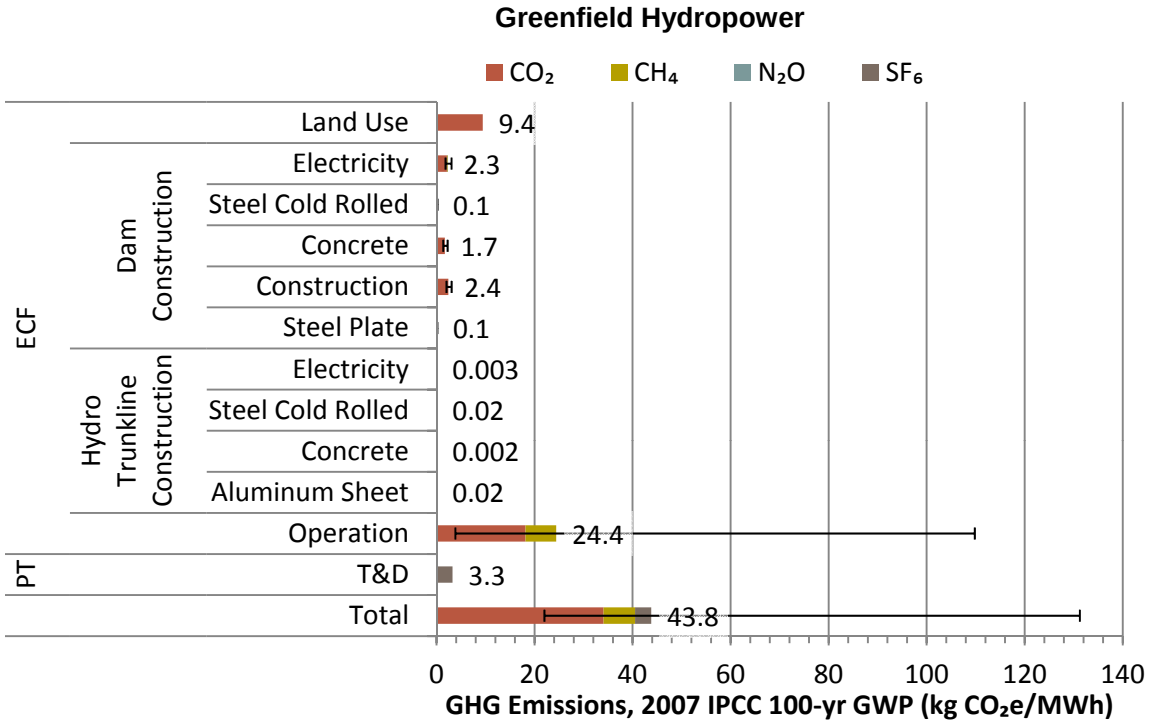
Environmental Analysis: GHG Results

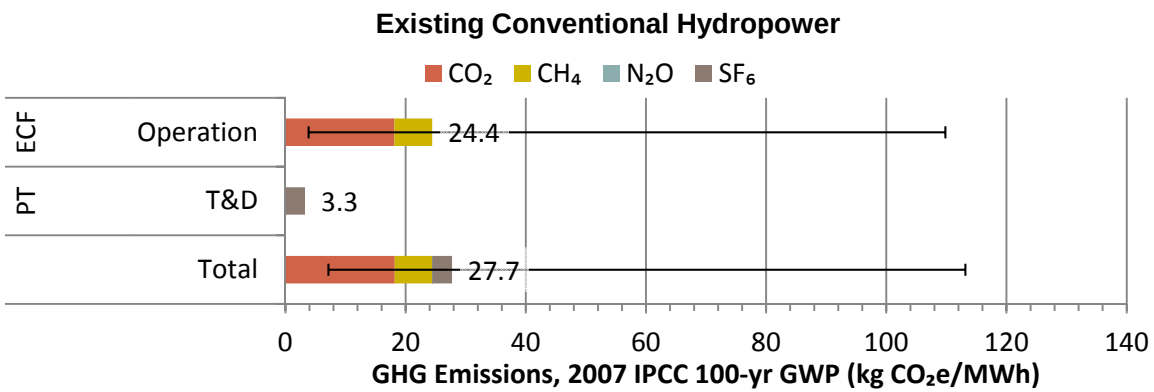


- Expected GHG emissions for all scenarios falls within range from 27.7 to 43.8 kg CO_2e/MWh
- CO_2 and CH_4 emissions from reservoir operation dominate life cycle GHG emissions and range from 56 to 88 percent of total GHG emissions

- The primary GHG emissions differences between Greenfield and other scenarios are land use and construction
- Land use only considered for Greenfield, representing 9.4 kg CO_2e/MWh
- Greenfield construction represents 6.4 kg CO_2e/MWh
- Existing only considers operation and T&D

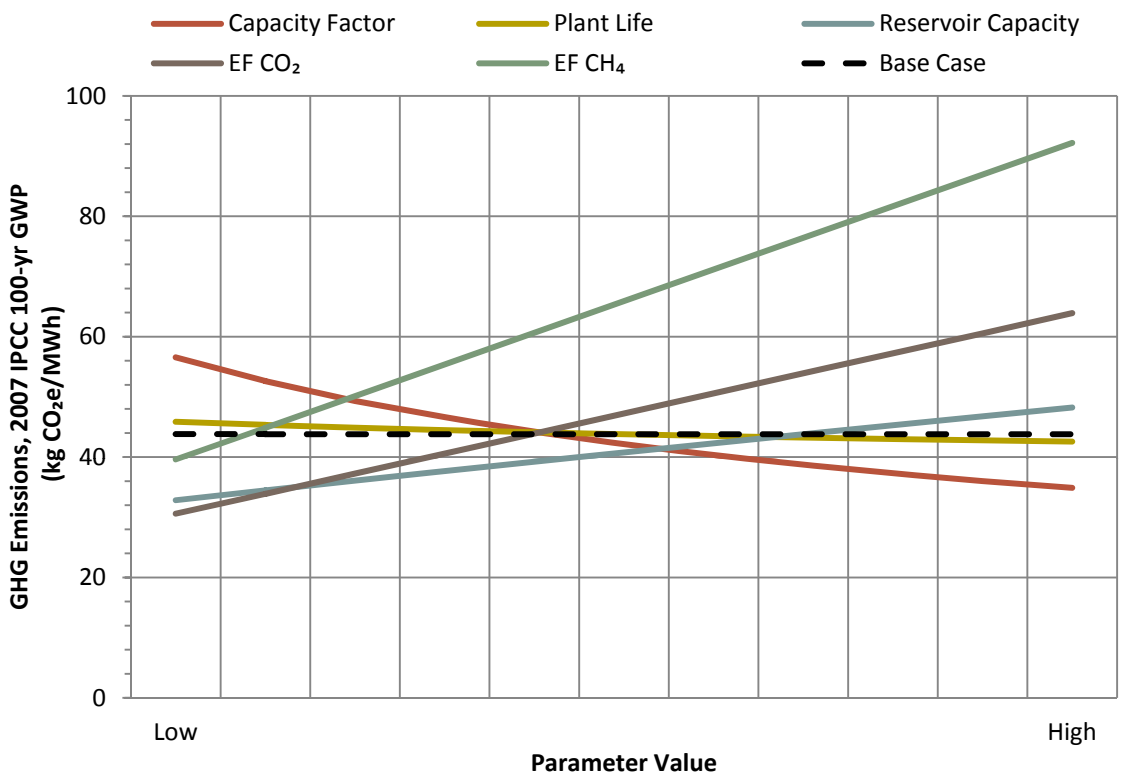
Environmental Analysis: GHG Results





- Stagewise GHG emissions shown for Greenfield Hydropower and Existing Conventional Hydropower
- For Greenfield Hydropower, operation accounts for 24.4 (56 percent) out of 43.8 kg CO_2e/MWh of GHG emissions
- Land use and dam construction also contribute to emissions from Greenfield Hydropower
- For Existing Conventional Hydropower, operation accounts for 24.4 (88 percent) out of 27.7 kg CO_2e/MWh of GHG emissions
- Land use and dam construction are not considered for Existing Conventional Hydropower

Environmental Analysis: Sensitivity/Uncertainty

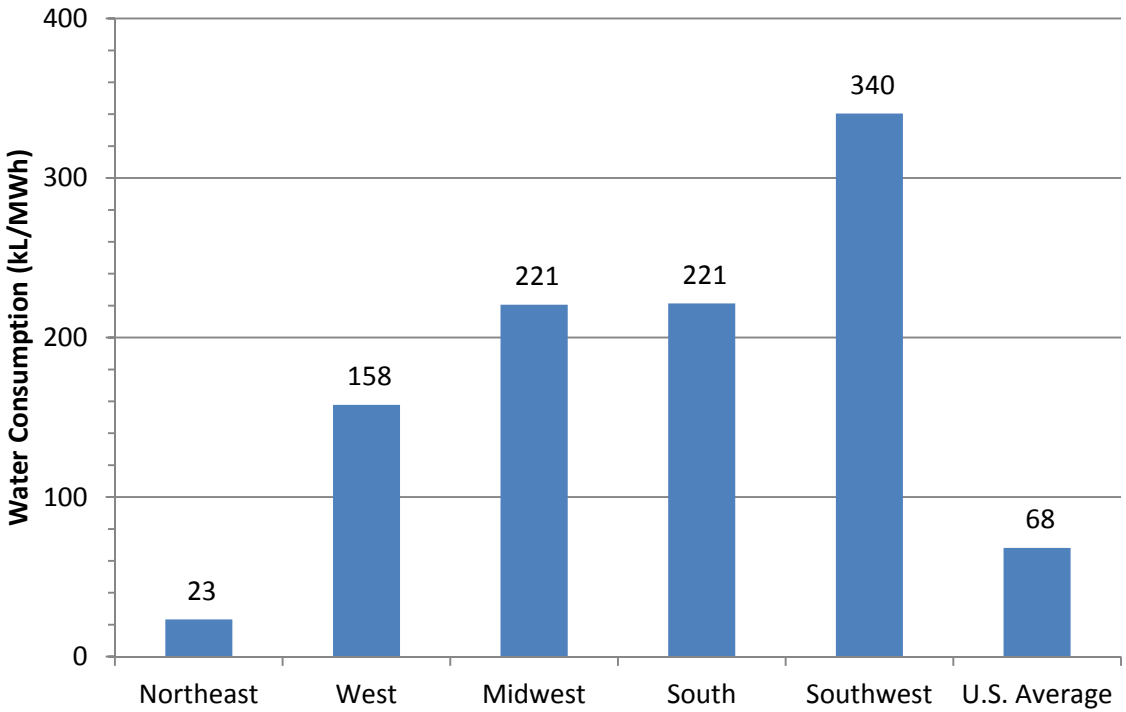


Parameter	Low Value	Expected Value	High Value	Units
Capacity Factor	26.3	37.1	52.0	%
Plant Lifetime	60	80	100	Years
Reservoir Capacity	0.35	0.70	0.85	Proportion
CO_2 Emission Factor	0.0657	0.2424	0.5110	kg/m^2-yr
CH_4 Emission Factor	0.0011	0.0034	0.0292	kg/m^2-yr

- Sensitivity and uncertainty shown for Greenfield hydro
- Expected Greenfield hydro base case result of 43.8 kg CO_2e/MWh is shown for reference
- Possible range of GHG results for Greenfield hydropower: 30.6 to 92.2 kg CO_2e/MWh depending on value of parameters
- Figure indicates where in range of parameter values the expected model input is located
- Slopes of parameter lines show that methane and carbon dioxide emission factors are not only the most sensitive, but also add the most uncertainty in overall GHG emissions
- Nonlinearity in results with respect to the capacity factor parameter (reservoir modeling)

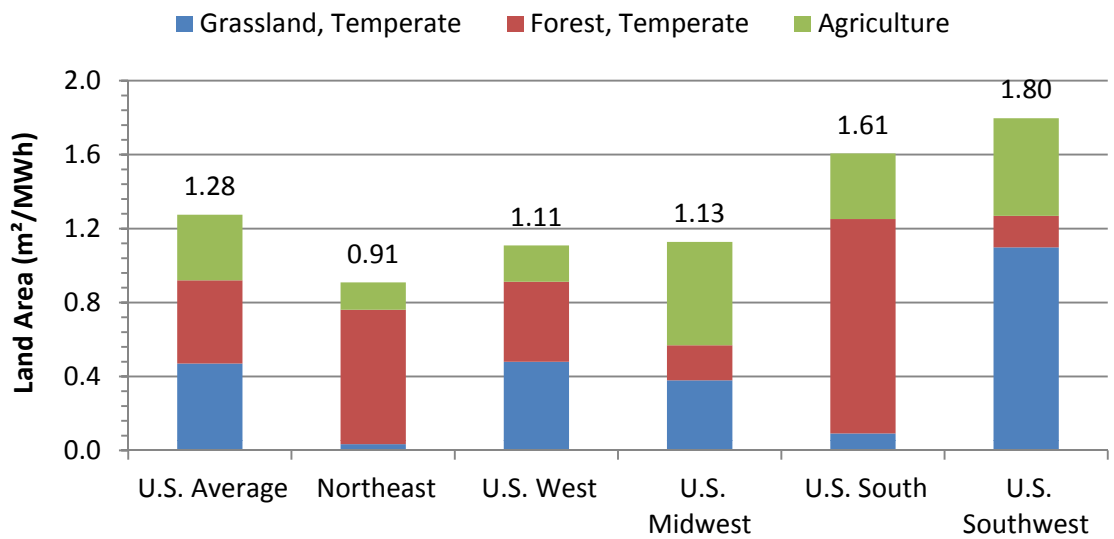
Environmental Analysis: Water Use

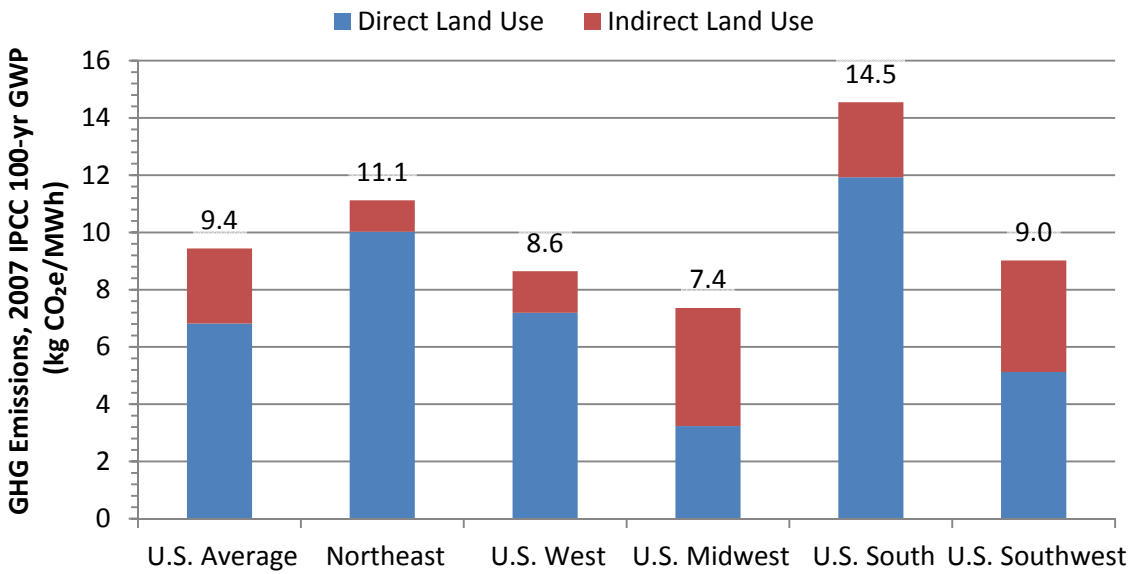
Hydropower Technology	Net Water Consumption, Construction (L/MWh)	Net Water Consumption, Operation (L/MWh)
Conventional Concrete Dam	9.54E+00	7.33E+04
Conventional Earthen Dam	3.82E-02	7.33E+04
80/20 Mix of Conventional Concrete and Earthen Dams	7.64E+00	7.33E+04



- LC water consumption for hydropower was quantified based on anticipated evaporation, per a regional evaluation of evaporation potential from reservoirs, completed by NREL
- Evaporation rates vary regionally based on climate
- U.S. average is weighted by power generation capacity
- Net water consumption during construction is negligible in comparison to water consumption during operation
- 80/20 mix of conventional concrete and earthen dams approximates existing U.S. installed base
- Concrete dam construction uses more water than earthen

Environmental Analysis: Land Use

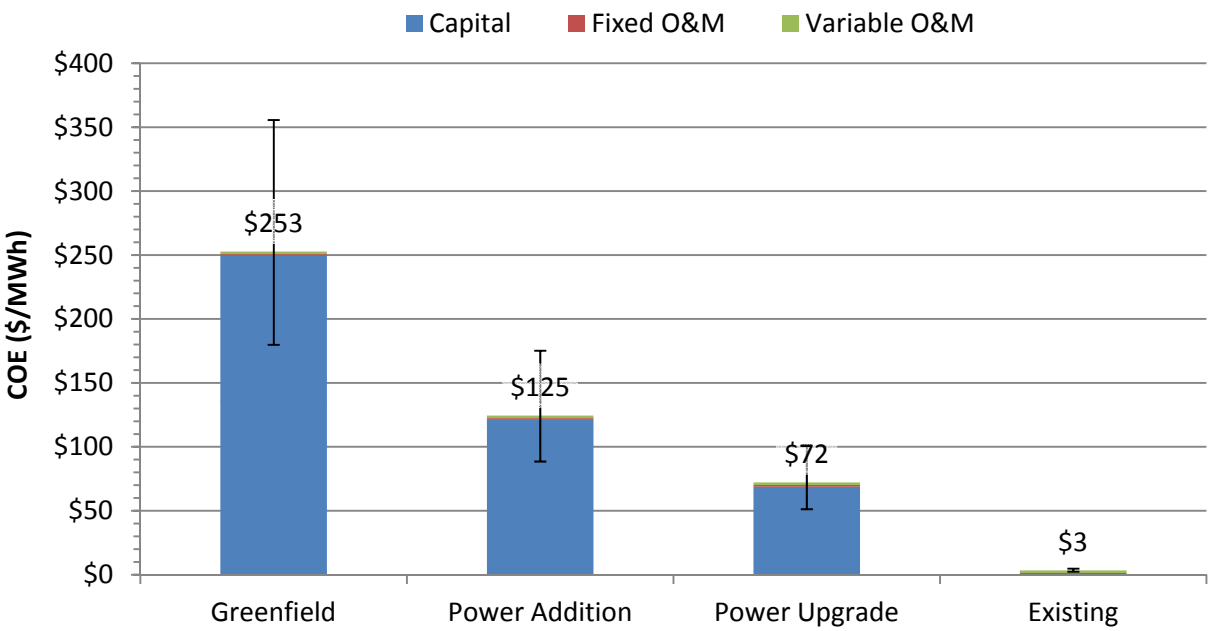




- Consistent reservoir area and nameplate generation were considered for each region
- Variation in total land use area results from regional differences in capacity factor
- Regional differences in existing land use type composition reflect regional variability in vegetative cover

- GHG emissions from reservoir that result from slow decay over time were considered outside of the land use analysis
- Emissions resulting from the removal and decay of existing biomass along the trunkline alignments were considered
- Indirect land use considers only the displacement of agriculture

Cost Analysis: LCC Results



Parameter	Greenfield	Power Addition	Power Upgrade	Existing
Operating Life (years)	80			N/A
Capital Costs of Energy Conversion Facility (Million 2007$)	$15,200	$7,720	$4,580	N/A
Capital Costs of Trunkline (Million 2007$)	$91.2		N/A	
Plant Output (MW)	2,080			
Capacity Factor (%)	37%			

- Wide overall range from $3 to $253/MWh (2007 $)
- Existing hydropower has no capital expenditures
- Greenfield hydropower has highest capital cost requirements
- 95 to 99 percent of the total COE for Greenfield is due to capital costs
- Hydropower does not require the purchase of fuel for operation, thus O&M costs are small
- Greenfield scenario bears the full capital costs of site preparation and dam construction
- Conventional dams also provide irrigation and flood control, which are not considered here

Barriers to Implementation

- **Dependence on Natural Flows**
  - Capacity factor depends strongly on water availability
  - Drought means less power production
  - Water availability is especially an issue in the West
  - Climate change may alter flow regimes/water availability in comparison to existing conditions
- **Lack of Extensive Hydrokinetic Field Testing**
  - Only limited field testing has been completed for hydrokinetic, although new installations are under construction
- **Environmental Damage**
  - Dams block stream flow and restrict fish movement/migration/spawning (U.S. Bureau of Reclamation, 2011)
  - Dams also strongly affect downstream hydrologic properties
  - Hydrokinetic may also directly interfere with fish

Risks of Implementation

- **Environmental Review and Permitting:**
  - Environmental review and permitting of large conventional hydropower in the United States can take 5 to 10 years or more (Contra Costa Water District, 2011)
  - However repowering of an existing facility is less arduous
  - Permitting for hydrokinetic installations has also proven to be less arduous (FERC, 2010)
- **Conflicting Uses**
  - Many dams provide other functions such as flood control, water storage for municipal supplies or irrigation, and recreation
  - Operations management often optimized for flood control or water supply, with electricity generation only occurring in conjunction with these uses
- **Public Opinion**
  - Conventional dams flood large tracts of land
  - This is largely unpopular with the public

Expert Opinions

- **National Hydropower Association**
  - Projections from trade organizations may be optimistic with respect to operating environment
  - Modernizing existing conventional hydropower could yield an additional 9 GW of capacity (NHA, 2011)
  - Converting the most promising non-powered dams could yield 10 GW of additional capacity
  - 15 GW of capacity could be added by implementing river, tidal, and wave hydrokinetic assets
  - NHA is lobbying to extend same level of tax credits to hydropower as are currently available to other renewables (hydro currently qualifies for 50 percent)
- **Existing Facilities are Aging**
  - US Army Corps of Engineers (USACE, 2011) dam median age is 47 years
  - Drives unplanned outages for maintenance
  - Difficult to meet the industry goal of 95 percent unit availability
  - Federal funding for upgrades is difficult to obtain due to competing priorities
- **Electric Power Research Institute**
  - Compares the potential expansion of hydropower, particularly hydrokinetics, to the expansion of wind energy that has taken place over the last 10 years and predicts capacity additions of 23 GW by 2025 (EPRI, 2007)

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